BEFORE THE NATIONAL GREEN TRIBUNAL (SOUTH ZONE) AT CHENNAI

APPEAL NO. 08/2020

Environment Support Group & Another ...Appellants

Vs.

Karnataka Road Development
Corporation Limited & Others ...Respondents

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BEFORE THE NATIONAL GREEN TRIBUNAL SOUTH ZONE AT CHENNAI

APPEAL NO. 08/2020

Environment Support Group
And Another ...Appellants

Vs.

Karnataka Road Development Corporation Limited
Represented by its Managing Director
And Others ...Respondents

REJOINDER FILED ON BEHALF OF THE APPELLANTS

It is submitted on behalf of the Appellants as follows:

1. It is submitted that the contents of the counter affidavits filed by the 1st Respondent and 6th Respondent are false except to the extent as admitted hereunder.
2. With respect to the averments in para 5 of the counter statement of the 1st Respondent, it is submitted that the 1st Appellant Trust was registered vide the trust deed dated 16.04.1998, already filed as Annexure A36 to the appeal. This trust deed also reveals that Dr. Tekur and the 2nd Appellant were trustees of the 1st Appellant Trust. It is submitted that Dr. Tekur, a physician and community health practitioner par excellence who had also served in the Army Medical Corps, passed away due to Covid-19 in May 2021 after treating and curing hundreds of persons affected by the pandemic. Vide the resolution dated 01.07.2021, the 1st Appellant Trust has designated the 2nd

Appellant and another trustee, Ms. Bhargavi S. Rao to attend to its operations including attending to legal matters. The Appellants have filed an application to seek this Hon'ble Tribunal's leave to bring on record Bhargavi S. Rao as its authorised representative. The resolution dated 01.07.2021 as well as Dr. Tekur's death certificate is filed at **Annexure A37 colly**.

Locus standi

3. The averments in para 6 of the 1st Respondent's counter statement are denied as false. It is submitted that the 1st Appellant Trust is a not for profit public interest research, advocacy, education and campaign initiative that has been at the forefront of advancing several environmental and social justice causes through Public Interest Litigations in Bengaluru and Karnataka before the Hon'ble High Court of Karnataka and this Hon'ble Tribunal. The 2nd Appellant is the Coordinator of the Trust and one of its trustees. Before this Hon'ble Tribunal, the 1st and 2nd Appellants have raised a range of issues concerning environmental protection in the public interest. A prominent instance is O.A. Nos. 6 & 12 of 2013 (South Zone) (***Leo Saldanha & Anr. v. Union of India & Ors.***) filed to challenge the diversion of over 10,000 acres of "Amrit Mahal Kaval" grasslands in Chitradurga, Karnataka for the construction of a Science City. These applications were disposed of on merits vide judgment and order dated 27.08.2014. Another instance is O.A. No. 38 of 2018 (Principal Bench) (***Environment Support Group v. Union of India & Ors.***), filed to challenge a tender issued by the Karnataka Excise Department for the production of 1152 crore plastic labels for use on excise control bottles and other containers, apprehending the environmental harm to be caused by subsequent plastic pollution. This application was admitted by this Hon'ble Tribunal vide its order dated 30.01.2018.

4. Further, this Hon'ble Tribunal has on a number of occasions affirmed that the term "person aggrieved" has to be interpreted widely in environmental issues, including in ***Vimal Bhai v. Ministry of Environment and Forests*** (NGT (Principal Bench), vide order dated 14.12.2011. The Appellants have filed the instant appeal to challenge the grant of prior Environmental Clearance ("**EC**") by the 6th Respondent, the Karnataka State Environment Impact Assessment Authority ("**SEIAA**") to a 102.4 km elevated highway across Bengaluru city ("**Elevated Corridor**"), citing non-adherence with mandatory provisions of statutory review and public consultation, and inadequate consideration of the environmental and social impacts of the project. It is submitted that if the project is permitted to proceed in its current state, it will severely undermine the public interest. In such circumstances, it is submitted that it is not for the 1st Respondent to claim that the Appellants are not persons "aggrieved" under the National Green Tribunal Act, 2010.

The Prior EC is Premature, not the Appeal/Re: Approval for Change in Land Use

5. The averments in para 7 and 81 to 83 of the 1st Respondent's counter statement are denied as false. The Appellants have nowhere submitted that the prior EC granted to the 1st Respondent is tantamount to other necessary consents and approvals. Indeed, the entire argument is that several mandatory legal requirements that should have been completed before applying for prior EC have been given a go-by. Once an EC is issued, the manner in which it is to be assailed is provided in law and the appeal cannot be termed premature.
6. Further, contrary to the 1st Respondent's submission that the appeal is premature, we submit that it is the 1st Respondent who has obtained the prior EC at a premature stage, as it had not even

finalised the alignment of the Elevated Corridor project at the time of application for EC. In ***BDA v. Sudhakar Hegde*, (2020) 15 SCC 63**, the Hon'ble Supreme Court dealt with when the obligation to commence the EIA process is incurred by a project proponent. The Hon'ble Court was called upon to interpret the terms of para 2 of the Environmental Impact Assessment Notification, 2006 ("**2006 Notification**"), as per which an application for prior EC has to be made after the "*identification of prospective site(s) for the project and/or activities to which the application relates*". The case pertained to the Peripheral Ring Road ("**PRR**") project in Bengaluru, promoted by the Bengaluru Development Authority ("**BDA**"). The question before the Hon'ble Court was whether it was the issuance of the preliminary notification under Section 17 of the Bengaluru Development Authority Act, 1976 ("**BDA Act**") or a final notification under Section 19 of the BDA Act that constituted the identification of the proposed site for the project and marked its commencement for the purposes of the 2006 Notification. In this regard, the Hon'ble Court held that the answer could only be the latter, observing as follows:

> "20. … It may be possible that following the formulation of a scheme under Section 15 and the issuance of a preliminary notification under Section 17, government sanction is denied or the appellant drops the proposed scheme prior to the grant of sanction or the issuance of the final notification. **In such situations, if it were held that it is the issuance of the preliminary notification identifying the proposed site for the project that marked the commencement of the project for the purposes of the 2006 Notification, the appellant would be under an obligation to carry out the EIA process for a proposed scheme which may not eventually materialise.**
>
> 21. The EIA process under the 2006 Notification serves as a balance between development and protection of the

environment: there is no trade-off between the two. In laying down a detailed procedure for the grant of an EC, the 2006 Notification attempts to bridge the perceived gap between the protection of the environment and development. The basic postulate of the 2006 Notification is that the path which is prescribed for disclosures, studies, gathering data, consultation and appraisal is designed in a manner that would secure decision-making which is transparent, responsive and inclusive. While the BDA Act was enacted with the purpose of establishing a development authority for the development of the city of Bangalore and adjacent areas, the 2006 Notification embodies the notion that the development agenda of the nation must be carried out in compliance with norms stipulated for the protection of the environment and its complexities. The BDA Act and the 2006 Notification operate in different fields. **It cannot be said that a site is deemed identified for the purpose of triggering the obligations under the 2006 Notification upon the issuance of a preliminary notification under Section 17 of the BDA Act. Adopting a contrary interpretation would lead to the absurd result where a project proponent is obligated to carry out the EIA process for a scheme even prior to the grant of government sanction and a final notification carrying into effect the proposed scheme.** In this view of the matter, the prospective site is deemed to be identified only upon the issuance of the final notification under Section 19 after the proposed scheme has received government sanction under Section 18(3)." (emphasis supplied)

7. Subsequently, the Hon'ble Supreme Court in its decision in ***Project Director, Project Implementation Unit v. P.V. Krishnamoorthy***, (2021) 3 SCC 572 similarly affirmed that prior EC in terms of the 2006 Notification is required to be taken "*before commencing the actual work or executing the proposed work/project*", which in that case was a national highway project being executed by the National Highway Authority of India. The Hon'ble Court further observed that this would happen only after

the acquisition proceedings were taken to their logical end, and the land finally vested in the NHAI or was entrusted to it by the Central Government for building/management of the national highway.

8. It is submitted that as far as the Elevated Corridor project is concerned, the 1st Respondent had not even obtained permissions for land use change from statutory authorities (as is mandated under Form IA under the 2006 Notification) at the time that EC was applied for and granted, far from having issued any notification for the acquisition of land, giving short shrift to the mandatory statutory process under the Karnataka Town and Country Planning Act, 1964 ("**KTCP Act**") described at para 33-34 of the appeal. It is respectfully argued that the above exposition by the Hon'ble Apex Court leaves no room for doubt that the application for prior EC was premature in the instant case, and the impugned clearance deserves to be quashed on this preliminary ground itself.

7. Furthermore, it is not open to the 1st Respondent to argue that it does not need permission to change land use since the alignments follow existing road alignments, as it has done in para 81 to 83 of its counter statement. This is because the 1st Respondent has already conceded that widespread land use change will be necessary for the project, as is evident from Chapters 2 and 7 of the Final Feasibility Report ("**FFR**") Volume I Main Report (or Detailed Feasibility Report ("**DFR**").

No Consideration to Induced Demand for Vehicles Due to Road Capacity Augmentation

9. Para 8 to para 25 of the counter statement of the 1st Respondent contain general averments on the need for the Elevated Corridor project, based on the premise that augmentation of road capacity, particularly through the Elevated Corridor, will be able to reduce traffic congestion in a sustainable way. The Appellants vehemently

deny the suggestion made through these averments that an elevated highway of the proposed nature is a necessary response to the growth of traffic in Bengaluru city. It is submitted that improving mass transit systems like the public bus and integrating them seamlessly with bicycling and walking paths will lead to reducing the number of cars and vehicles on the road – but this aspect has not been considered by the respondents.

10. The 1st Respondent admits at para 16 of its counter statement that as per the Indian Road Congress, the ratio of Volume to Capacity of roads ("**V/C ratio**") should be 0.6 for city roads, and is currently as high as 4 for most roads. Yet, the 1st Respondent proposes to undertake a project that will induce more traffic by increasing road capacity, due to the phenomenon of '**induced demand**' that has been well documented in several cities across the world, as submitted in the appeal. This phenomenon results in long term modal shifts that increase the use of vehicles and therefore increase congestion, thus rendering the whole project (of increasing road capacity) ineffective. The Appellants are submitting three research studies from across the globe documenting this phenomenon, at **Annexure A38 colly**.

11. In fact, an analysis of the project's technical details as outlined in the Detailed Feasibility Report by researchers at the Indian Institute of Science, Bengaluru ("**IISc**") also shows that due to induced demand the Elevated Corridor will yield no improvement in the city's traffic condition. The study, entitled "*Sustainability Analysis of the Proposed Elevated Road Corridors in Bengaluru City – A Comparative Scenario Analysis With Metro Rail System*" by Prof. Dr. Ashish Verma and others, is filed at **Annexure A39**. The study predicted that the V/C ratio at KR Puram Junction road by 2030 would be as high as 3.18 for the Elevated Corridor and 0.81 for the adjacent road (both above the ideal 0.6). On the other hand, it

would be 0.09 for a Metro line along the same alignment, and 0.58 for the adjacent road, below the ideal of 0.6.

12. This study also predicted that from 2017 to 2020, the benefit of reduction in travel time generated would have been 8% for the Elevated Corridor and 40% for the metro along the same alignment. However, by 2030, this benefit generated by the Elevated Corridor would slip to 5.3%. On the other hand, the metro corridor on the same route would reduce total travel time by at least 53.4%. This suggests that over time, the benefit of reduction in travel time will only decrease for the Elevated Corridor, possibly even turning into an increase in travel time eventually. In contrast, the benefit of reduction in travel time would increase for the metro corridor over time.
13. It is submitted that this gives the lie to the 1st Respondent's claims that road capacity augmentation is the only alternative available to ease road congestion, and in fact indicates a blatant lack of careful consideration of various available alternatives. Indeed, the 1st Respondent has nowhere produced any study that factors in induced demand to show how many vehicles the Elevated Corridor can accommodate in relation to the number of vehicles that are expected to ply by 2030, and is put to strict proof of the same.
14. The averments in para 26 to para 30 of the 1st Respondent's counter statement suggest that the Elevated Corridor will lead to higher vehicle speeds and less idling, and concomitantly reduce air pollution, greenhouse gas emission, and vehicle operating costs. This suggestion is denied, in as much as any gain made will soon be negated due to the phenomenon of induced demand explained above. Indeed, from the IISc study filed at Annexure A39 above, it is concluded that the Elevated Corridor would only yield a short-term reduction in CO2 emissions, and by 2030, emissions would again have increased by 8% compared to 2017. In contrast, by 2030, metro construction along the same alignment would yield

a 26% reduction in CO2 emissions. Further, the study finds that particulate matter (PM) pollution would see a short-term increase of 7% (from 2017 to 2020) and a long-term increase of 11% (by 2030) due to the construction of the Elevated Corridor. In contrast, metro construction along the same alignment would reduce PM emissions by 20% by 2020 and 23% by 2030.

15. At the same time, a perusal of Section 4.7.1 of the DFR Volume I Main Report reveals the astonishing fact that the 1st Respondent was clearly informed of the predicted choking of the Elevated Corridor project. This is evident from the following extracts from the said section:

> "With growing urbanization trends of Bangalore in terms of growth in population and traffic numbers in the city, the **enhanced capacity of these proposed elevated corridors will soon be utilized fully within the horizon year 2023, when capacity of most of the elevated sections (around 70%) will be exhausted**. Traffic assignments on the proposed corridors in all three suggested scenarios for the horizon years clearly indicate the same. Some of the proposed elevated sections are found to be exhausted in the base year situation only if the corridors are assumed to function from the base year only.
>
> **In Phases I, II and III section loads along the proposed elevated corridors show a steady increase in traffic volume from 2016 to 2023 where most part of the corridors have exceeded their maximum design capacity and shall be bound to congestion, decreased journey speeds and longer travel times.**
>
> The situation needs to be addressed with a holistic approach. The growing trends of urbanization are bound to have drastic impact on the traffic numbers on roads. The main goal is to reduce the number of private vehicles like two wheelers and cars on the road and provide the urban population better means to commute via public transit. **With growing population trends and travel demand in the city of Bangalore, it is definitely advisable to bring forth a comprehensive mass transit system planning to shift**

more people to public transport than using private vehicles." (emphasis added)

It is clear that in spite of being aware of the futility of the Elevated Corridor project, the 1st Respondent is inexplicably promoting it as a panacea for the traffic problems of Bengaluru.

16. The contents of para 31-35 of the counter statement of the 1st Respondent deal with the details of the Elevated Corridor proposal and do not require a response from the Appellants. However, the suggestion in para 33 that the elevated highway will enable seamless and stop-free travel in the city is denied on the grounds laid out in the preceding paragraphs.

17. The contents of para 36 to 39 of the counter statement of the 1st Respondent are denied as false, in as much as they suggest that the 1st Respondent has complied with all statutory requirements while submitting Forms I and IA to the 6th Respondent and that there is no illegality in the grant of prior EC.

Re: Environmental clearance and processes

18. The contents of para 40 to para 52, 63 to 68, 115 and 118 to 120 of the counter statement of the 1st Respondent and para 3, 4, 5 and 8 of the counter statement of the 6th Respondent are denied as false. It is submitted that the 1st Respondent is trying to mislead this Hon'ble Tribunal by claiming that only prospective identifications of the details of a project are required at the time of applying for prior EC for constructing a highway in the nature of the Elevated Corridor. As has been submitted above, the 1st Respondent was required to have at least finalised the alignment and issued the final notification for land acquisition before applying for prior EC, as is evident from the decisions of the Hon'ble Supreme Court in ***Project Director, Project Implementation Unit v. P.V.***

Krishnamoorthy (supra) and ***BDA v. Sudhakar Hegde*** (supra). Further, it is submitted that the 1st Respondent has deliberately and wrongfully obtained clearance under Clause 8(b) of the Schedule to the 2006 Notification ("**the Schedule**") instead of Clause 7(f). This subterfuge cannot be used to argue that only a conceptual plan was required to be submitted at the time of applying for prior EC.

19. It is further submitted that the Hon'ble Apex Court in ***BDA v. Sudhakar Hegde*** (supra) held that the PRR project in Bengaluru city is covered under Clause 7(f) of the Schedule by virtue of being an 'expressway', even though it is not a National or State Highway. Clause 7(f), which applies to 'highways', clarifies that it includes 'expressways' within its ambit. The Hon'ble Apex Court relied upon the definition of the latter term under the Indian Road Congress Manual of Specifications and Standards, which is as follows:

> "… For this purpose, the expressway is defined as an arterial highway for motorised traffic, with divided carriageways for high speed travel, with full control of access and provided with grade separators at location of intersections. Generally, only fast-moving vehicles are allowed access on expressways…."

19.1 The Apex Court was of the considered opinion that the PRR fulfilled all the above criteria, and therefore attracted clause 7(f) of the Schedule under the 2006 Notification. It is submitted that the design elements of the Elevated Corridor, as described by the 1st Respondent in para 33-34 of the counter statement, fit the above definition perfectly:

> "*It is submitted that the Elevated Corridor Project is a* ***'grade-separated'*** *road where a corridor is built to enable vehicles to keep moving in their desired direction, without having to cross oncoming traffic. The elevated corridors connecting the suburbs to the city centre and to each other, are meant to enable* ***seamless, stop-free travel*** *between any of the corridors'* ***entry and exit points***". (emphasis added)

19.2 Similarly, at para 65 of the counter statement, the 1st Respondent explains:

> "*The proposed six elevated corridors having a length of 102.04 km is to decongest the internal city roads and to give* ***access controlled*** *connectivity to the arterial roads which are connecting important neighbouring towns and cities*…" (emphasis added)

19.3 Thus, the 1st Respondent's argument that the Elevated Corridor cannot be classified as national or state highways looking to their "functional and locational role" is misleading. Indeed, looking at the functional and locational role of the project it becomes exceedingly clear that it is an expressway, and thus a highway, within the meaning of Clause 7(f). What is more, the 1st Respondent has admitted in para 65 of its counter statement that several stretches of the Elevated Corridor form part of National Highway 4 and 7, and State Highways. In such a scenario, it is submitted that the 1st Respondent cannot be allowed to escape the scrutiny invited under Clause 7(f). It is submitted that the nomenclature employed and the implementing agency do not determine if a proposed highway/expressway exerts an impact on the environment. The impact of the proposed expressway is the same irrespective of whether or not it is implemented by the highways department and called a highway/ expressway. The project is for the construction of an expressway and its impact needs to be studied under Clause 7(f) of the Schedule.

19.4 It is also submitted that the averment in para 66-68 of the counter statement of the 1st Respondent that the project did not even need prior EC under Clause 8(b), being six distinct corridors, is misleading since it obscures the fact that even the individual corridors distinctly considered have built up area exceeding that prescribed under Clause 8(b).

19.5 Further, at para 68 of its counter statement, the 1st Respondent has relied on the decision dated 13.03.2017 of this Hon'ble Tribunal in

Neeliah v. Union of India & Ors. (Application Nos. 243 and 245 of 2016 (SZ)) ("***Steel Flyover***") to argue that the Elevated Corridor project at best qualifies under Clause 8(b) of the Schedule. This submission has also been made by the 6th Respondent at para 3 of its counter statement. It is submitted that the facts of the ***Steel Flyover*** case are different from the present case. The proposed steel flyover was a single 7 km-long six-lane elevated road from Basaveshwara Circle to Hebbal flyover in Bengaluru, i.e. connecting two points, and is different from the present project in terms of purpose, magnitude and impact on the environment as well as on mobility patterns of the city. In the ***Steel Flyover*** case, this Hon'ble Tribunal held that the project would require prior EC under Clause 8(b) of the Schedule. However, the question of whether the proposed project would qualify as an 'expressway' under Clause 7(f) was not raised before the Hon'ble Tribunal, and consequently not dealt with. Furthermore, the Supreme Court's decision in ***Sudhakar Hegde*** was delivered subsequent to the ***Steel Flyover*** judgment. Hence, it is submitted that the 1st Respondent cannot rely on the ***Steel Flyover*** judgment to claim that Clause 8(b) was the correct category to obtain prior EC for the Elevated Corridor.

19.6 The contents of para 53 to para 55 of the counter statement of the 1st Respondent are denied as false. The Appellants have given detailed reasons in the appeal showing how the grant of prior EC was rushed through and is vitiated under law. Apart from making bald claims, the 1st Respondent has not shown why the arguments in the appeal are unfounded. The submissions made in the appeal are reiterated, and are further elaborated below.

20. The contents of para 57 of the counter statement of the 1st Respondent are denied as false. It is submitted that the EIA Report submitted by the 1st Respondent is not exhaustive. As is pointed out in the appeal, it lacks material particulars such as data produced by

computer modelling on water, noise and other pollution to be caused by the construction and operation of the Elevated Corridor, provides arbitrary data on air pollution modelling, fails to even evaluate even a single alternative to the project, and does not comply with the specified Terms of Reference on several counts.

Re: Project Alignment Yet to be Finalised

21. It is submitted that the admission of the 1st Respondent in para 58 and 69 of its counter statement that the DFR does not contain the final alignment of the project, and that the same will be finalised only at the stage of implementation of the project, supports the Appellants' contention that the prior EC granted is premature. The decisions of the Hon'ble Court in ***P.V. Krishnamoorthy*** (supra) and ***Sudhakar Hegde*** (supra) indicate that the final notification for land acquisition needs to be published before EC is applied for. By no stretch of the imagination can this be done without the alignment of the highway being finalised. Without knowing the alignment, no meaningful impact assessment studies can be conducted, vitiating the entire process of grant of EC.

22. The averment in para 59 of the counter statement of the 1st Respondent is denied as false. The 1st Respondent wishes to justify the variance in the sanctioned project amount in the financial sanction vide GO No. AE 149 AKO-1 2019 dated 21.02.2019 (Rs. 26,690 crores) and the impugned order (Rs. 26,959 crores) by stating that the "*initial amount sanctioned through the Government Approval is only an advance released towards the initiation of steps for the implementation of the project*". It is submitted that, firstly, the variance pointed out by the Appellants is not between the initial Government Approval and the financial sanction, but between the impugned clearance and the financial sanction. The project cost mentioned in the impugned order exceeds the financial sanction by a whopping Rs. 269 crores. At the same time, this amount is only 1% of the estimated project cost, and the 1st Respondent has not explained how the

amount mentioned in the financial sanction, which is 99% of the estimated cost mentioned in the impugned clearance, can be called a mere "advance".

23. The averment in para 60 of the counter statement of the 1st Respondent is denied as false and misleading. The Appellants have brought ample evidence on record to show that the impugned clearance was granted in haste. It is submitted that para 10 of the appeal reveals very clearly that the entire process starting from the filing of the application for prior EC to the issuance of the EC and the tender for Engineering, Procurement and Construction of the Elevated Corridor project was rushed through in a matter of six months. In this rushed process, it has been argued in the appeal, several key requirements have either been skipped or given short shrift, ranging from generic and inchoate Terms of Reference, an inexhaustive EIA Report, non-completion of mandatory prior formalities such as approval from the Metropolitan Planning Committee, land use change, and land acquisition, failure of the SEAC and SEIAA to apply their minds to the application and EIA Report, and the impugned clearance being a non-speaking order.

Re: Form I and IA rife with false information

24. The averments in para 61-62 of the counter statement of the 1st Respondent are denied. The appellants have argued in the appeal that several responses in the said forms are either false or misleading, or suppress relevant information, taking great care to highlight relevant examples from the submissions of the 1st Respondent in Forms I and IA. As such, the question of cherry-picking entries does not arise. The respondent is under a sacrosanct statutory duty to provide true, correct and accurate information for each entry in Form I. The failure to provide information in Form I vitiates the entire process and renders the EC liable to be quashed, as held by this Hon'ble Tribunal in several cases.

24.1 Further, it is not open to the 1st Respondent at this stage to provide clarifications and embellishments to its responses in Form I and IA which

were not provided in the forms themselves. It is submitted that this attempt is completely alien and unknown to the environment impact assessment process, and any such explanation furnished by the 1st Respondent is liable to be disregarded by this Hon'ble Tribunal. The whole idea of seeking detailed information at the stage of application for prior EC is so that the impact assessment authority can adequately gauge the impacts of the project, decide whether clearance should be granted or denied, and if granted, what conditions should be imposed to mitigate impact. It is submitted that the failure to furnish the required information raises the presumption that the decision to grant clearance was based on inadequate information and also that the conditions imposed for mitigating adverse impacts are insufficient.

24.2 It is also submitted that the responses furnished in the counter statement reveal that the 1st Respondent has, according to its own convenience, at some points claimed that details of environmental management (such as details of water sources) will be finalised at a later stage at the time of implementation of the project, and at other places adduced details (such as the list of affected trees) based on the interim alignments proposed, glossing over the possibility that the project impacts might change when the alignment is finalised. This absurd situation, it is humbly submitted, is a direct result of the fact that the prior EC was applied at a premature stage, and would not have arisen if the EC had been applied for after finalisation of the alignment.

24.3 In any event, the Appellants crave leave of this Hon'ble Tribunal to address the responses of the 1st Respondent in its counter statement to the arguments made in the appeal regarding the misinformation in Form I and IA:

Sl No.	Sl No. in the Form	Description	Comments	Response in Counter Statement	Appellants' Response
		Form I			
1	2, 9	Project Sector - New construction projects and Industrial Estates	The 102 Km long elevated highway is covered under entry 7 (f) under highways category and not just under 8 (b)	As has been explained above in paragraphs 22 to 26, it is submitted that by virtue of the operation of the direction of this Hon'ble Tribunal, the Project can be categorized under 8 (b) of the EIA notification and not under 7 (f)	The test for 'expressway' as laid down by the Supreme Court in ***Sudhakar Hegde*** (supra) is the relevant standard, based on which the project clearly falls within Entry 7(f). Refer to para 19 of this rejoinder.
2	8.3	Could the project be affected by natural disasters? (Floods, earthquake	Unless it is acknowledged that natural disasters, like earthquakes, are significant risk factors, and such risks have been comprehended,	The Appellants have deliberately misrepresented before this Hon'ble Tribunal. The EIA prepared by the Respondent No.1	The response provided by Respondent No. 1 does not actually address the question of risk of natural disasters. Section 4.15 (page 4-120) of the EIA Report deals with seismicity of Bengaluru city. It does not

		etc.) Answer provided - "NO".	worst case scenarios cannot be modelled and studied, and thus the presumption of no risk is clearly a figment of imagination.	specifically takes into account the design considerations of natural disaster like Earthquake. The Respondent No.1 has considered and assessed the risk factors associated with seismic activities in the city of Bangalore. The Respondent No.1 has considered the following aspects and loading as per relevant codal provisions while formulating the design of structures • The Bridge design life is expected to be 100 years; • The structures that are proposed to be built for the Project will	account for the risks to the Elevated Corridor project due to earthquakes. No other natural disasters are accounted for. Section 8.1.3 of the EIA Report pertaining to the Emergency Response Plan also only mentions in passing the possibility of floods during monsoon.

				be designed for normal exposure conditions with adequate concrete cover to exposed surfaces. It is submitted that while preparing the EIA report, the Respondent No.1 has considered the following loads for Structural Analysis and Design 1)Dead Load (DL) 2)Super Imposed Dead Load (SIDL): 3)Design Vehicular Loading (IRC Class Loading) 4)Longitudinal force of Live load due to braking (BR): Load due to Braking (BR): 5) Centrifugal forces (CF) 6) Vehicular Collision Load:	

				7) Accidental load on Crash Barriers 338) Wind loads 9) Seismic Loading-Zone-II 10)Bearing Replacement 11)Settlement (SE) 12) Earth Pressure 13)Creep and shrinkage effects (CR&S I-I) 14)Thermal Effect (CI.215 of IRC:6-2014) 15)Uniform temperature (TU) 16)Temperature Gradient (TG) It is submitted that the Respondent No. 1 has acknowledged and assessed the risk factors in the EIA report and for reasons best known to them, the Appellants have chosen to turn a	

				blind eye to the details provided in the EIA report.	
3	9	Consequential Development and cumulative impacts - Answer provided - "NO"	The project will have consequential development and during construction phase itself will have cumulative impact with other major projects like metro etc.	Since the Project is proposed to be constructed over the existing road alignment, there is no significant consequential development and cumulative impact. Moreover, it is submitted that all the concerned stake holders of the state machinery have been appraised of the integration of the Project and the implementation of the integration would be done while executing the Project.	The sundry adverse impacts of the project on air pollution, water bodies, biodiversity, etc. will occur irrespective of the construction of the project over the existing road alignment, and result in cumulative impacts when combined with the impacts of other activities and projects like the metro.
4	III (2)	Ecological sensitive areas like waterbodies	Deliberate suppression of the widespread impact on lakes,	It is submitted that the Appellants have made a generic statement that the	The Appellants have substantiated their arguments with references to the 1st Respondent's averments in Forms I and IA as well as the

		etc - Answer provided NO	parks, trees and green cover of the city.	project would have widespread impact on lakes, parks, trees and green cover. The Respondent No. 1 has dealt with each of these contentions separately in the following paragraphs individually. It is however submitted that since the proposed alignment follows existing road alignment, the question of impact on the water bodies due to the implementation of the Project does not arise.	DFR and EIA Report, and have not made any generic statements. The contentions have been elaborated upon in the following paragraphs individually. Refer to paras 35-39.
5	III (11)	Areas already objected to pollution or environmental damage (those where existing legal	Along the corridor, even according to KSPCB, air quality parameters exceed limits fixed by NAAQ 2009	The Appellants have made a generic statement that along the proposed corridor, air quality parameters exceed fixed limits. The	The argument of Respondent No. 1 is flawed since it does not account for the phenomenon of induced demand, and is in blatant contradiction to the analysis in Section 4.7.1 of the DFR Volume I Main Report (page 4-28). These

		environmental standards are exceeded) - Answer provided - "NO"		Appellants have failed to establish that the construction of the project would invariably lead to further deterioration of air quality parameters. It is submitted that one of the primal reasons for proposal of the Project is reduction of CO2 emission in the city of Bangalore. The implementation of the Project is estimated to reduce CO2 emission due to vehicular traffic by about 4.74 lakh tonnes. The implementation of the Elevated Corridor Project would substantially cut down the travel time and in turn	have been referred to at para 9-15 above. Thus, the promised reductions in travel time, CO_2 emissions, air pollution etc will not materialise.

				would reduce the man hour spent in traffic. The estimated cost savings in terms of fuel and travel time cost is about Rs. 9,000 Crores. It is submitted that the construction of the Project would thus improve the air quality parameters and would reduce the CO2 emission due to vehicular traffic. The claim of the Appellant that the project would further deteriorate the air quality is therefore baseless.	

Sl No.	SL No. in the Form	Description	Comments	Response in Counter Statement	Appellants' Response
		Form IA			
7	1.3	What are the likely impacts of the proposed activity on the existing facilities adjacent to the proposed site? (Such as open spaces, community facilities, details of the existing land use, disturbance to the local ecology).	Relevant information not provided. Land use, impact on open spaces or ecology not stated.	It is submitted that to the maximum extent, the proposed project corridor follows the existing road alignments. Since the Project is proposed to be built over the existing alignments, the impact on adjacent structures along the corridor are minimized by a large extent. Furthermore, the impact on the open spaces and ecology has been provided by the Respondent No. 1 in the EIA report submitted and the Appellants are attempting to misconstrue the Form I	Even going by Respondent No. 1's environmental and social impact assessments (Volume-IV of DFR and Chapter 7 of DFR Volume-I Main Report), there is widespread impact on existing facilities adjacent to the proposed Elevated Corridor, details of which were required to be disclosed in Form IA.

				and Form IA by reading them in isolation with the DFR and EIA report that were submitted by the Respondent No. 1.	

8	1.5	Will the proposal involve alteration of natural drainage systems? (Give details on a contour map showing the natural drainage near the proposed project site)	The interim alignments that have been released as part of the Detailed Feasibility Report reveal that the project will impact several lakes in Bangalore. It is admitted in fact at item 1.21 of Form 1 that "the alignment of East - West Corridor - 1 passes adjacent to KR Puram lake, Benniganahalli lake and Ulsoor lake; East - West Corridor - 2 passes adjacent to Varthur Lake, Thuberahalli lake and Vrishabhavathi	It is submitted that the proposed structure under the Project is an elevated structure (as the name itself suggests) and it does not affect the natural drainage system as runoff on elevated corridor is recharged through water recharge pit and at-grade level the existing drainage system/Pattern remains same. The EIA report of the Respondent No. 1 in fact clarifies this aspect at Section 6 of the Report.	Respondent No. 1's response in the counter statement does not address the impact on drainage in and around lakes due to construction of piers and other structures (which are admitted at pages 10-202 to 10-209 of the EIA Report). Further, impact on drainage is specifically admitted at Table 8-1 of the Environment Management Plan at page 8-170 of the EIA Report: "The flow of runoff water will be affected largely, and this be add [sic] to the problem of flooding if the runoff flow is not managed especially at certain locations where the drainage problem already exists". It is also outlined in Section 6.1 of the EIA Report: "In absence of effective management of surface runoff water, elevated corridor may create havoc in the form of flash floods, if the lead drains are not

			Stream; North South Corridor passes adjacent to Sampangi lake; Connecting Corridor - 1 passes adjacent to Agara lake; Connecting Corridor -2 passes adjacent to Ulsoor lake and Connecting Corridor - 3 passes adjacent to Chalkere lake". It is evident that the proposed project has a direct and irreversible impact on the drainage patterns of surface runoff around the impacted lakes.		maintained properly during monsoon." The entry in Form IA required Respondent No. 1 to first detail the impact on natural drainage, which it did not do in spite of being aware of such impacts (which is why it went on to propose extensive measures for mitigating the impact on drainage).

9	2.1	Give the total quantity of water requirement for the proposed project with the breakup of requirements for various uses. How will the water requirement be met? State the sources & quantities and furnish a water balance statement. - Project proponent has stated that 243 Million litres of water is required and that it will be drawn from borewells.	No information on water source, quantity proposed to be extracted from each source and absolutely no water balance has been provided. Surprisingly, bore wells have been stated as water source when the entire Bengaluru region has been classified as over exploited, there is serious threat of drinking water security and drawal of groundwater for megaproject construction cannot be permitted.	It is submitted that at the initial stage of submitting the application, it was proposed to draw water from Borewell. Later during according EC, the Committee has advised to explore drawing of water from other sources also. It is pertinent to note that the required quantity of water will be spread over four years of construction and implementation. However, the Respondent No.1 has ensured that the bore well water alone is not prescribed as the source inasmuch as the in the bidding document (which has since stand scraped) the Respondent No.1 had mandated that the contractor shall also	Breakup of requirements and water balance have still not been provided. In any case, the claim of diversification of water sources is a post-facto embellishment and only further reveals the blatant lack of planning and application of mind at the time of applying for prior EC.

				source the treated water from local STPs and from other sources.	
10	2.2	What is the capacity (dependable flow or yield) of the proposed source of water?	No information provided	It is submitted that the water source will be from various borewells along the existing alignment, STPs, surface water, etc,. which will be sources after obtaining necessary approvals from competent authorities. However, since the Project yet to be implemented such sources shall be identified by the contractor with the consent of the authority, during execution phase.	It is clear that Respondent No. 1 has, even now, not provided details of the dependable flow or yield from the proposed borewells, capacity of proposed STPs, etc.

11	2.3	What is the quality of water required, in case, the supply is not from a municipal source? (Provide physical, chemical, biological characteristics with class of water quality)	No information provided	Since the Project proposes construction of elevated corridor, which is a corridor of elevated road over the existing alignment of the existing roads, the Ministry of Road Transport and Highways (MoRTH) guidelines on the quality of water, (*which prescribes the physical, chemical and biological characteristics of water*) will be followed.	Respondent No. 1 was required to show in this entry how its proposed water sources satisfied any applicable guidelines on water quality. A generic statement that Respondent No. 1 will follow guidelines is hardly sufficient.
12	2.4	How much of the water requirement can be met from the recycling of treated wastewater? (Give the details of quantities, sources and usage)	Irrelevant information provided. Quantity, source, etc. not specified.	It is submitted that the water source will be from various borewells along the existing alignment, STPs, surface water, etc,. which will be sources after obtaining necessary approvals from competent authorities.	As submitted previously, a generic claim such as Respondent No. 1 has made here, without answering the question asked, completely defeats the purpose of environment impact assessment. Failure to furnish the required information raises the presumption that the decision to grant clearance was based on inadequate information and also that the conditions imposed for

				However, since the Project is yet to be implemented, the quantity and source shall be identified by the contractor with the consent of the authority, during execution phase.	mitigating adverse impacts are insufficient.
13	2.9	What are the impacts of the proposal on the ground water? (Will there be tapping of ground water; give the details of ground water table, recharging capacity, and approvals obtained from competent authority, if any)	List of sources and plan for sourcing water has not been provided. The fact that approval has not been obtained has not been noticed.	Since the project draws water from several sources like number of borewells, surface water, treated water, etc. and quantity to be harnessed from each source cannot be realistically assessed at this stage. The ground water table/recharge capacity of each borewell source to be harnessed could be assessed only during implementation.	See response for Item 2.4 above.

14	3.1	Is there any threat of the project to the biodiversity? (Give a description of the local ecosystem with its unique features, if any - Answer provided "No. The project corridor follows the existing major roads surrounded by resident and commercial built up section. The local ecosystem and biodiversity will not be hampered because of this project."	Suppression of fact that the felling of more than 3000 fully grown majestic heritage trees will affect biodiversity and local environment. During operation and construction, the increased pollution will affect photosynthesis and health of remaining avenue trees and trees in parks in a much wider area than the impact zone, including precious biological heritage in Lalbagh, Cubbon	It is submitted that though the implementation of the Project would require felling of trees, the issue has been considered and dealt by the Respondent adequately and as such there is no threat to the Biodiversity. The impact of felling of trees will be mitigated by compensatory afforestation at the rate 10 trees for each tree being cut. This factum has been elaborated by the Respondent No.1 in the EIA report filed.	The impact of tree felling and transplantation will result in major impacts on air quality, biodiversity and the local ecosystem in the affected area, which cannot be negated by compensatory afforestation elsewhere.

			Park and Palace Grounds.		
15	3.2	Will the construction involve extensive clearing or modification of vegetation? (Provide a detailed account of the trees & vegetation affected by the project). Answer provided- "The project requires to cut approximately 3,821 trees which are located adjacent to the road and 2,084 trees to be pruned."	Except to state that 3821 trees will be cut and 2084 trees need to be pruned, the project proponent has not provided "detailed account of trees and vegetation affected by the project." This, in any case, cannot be identified as the project alignment is yet to be finalized, though the project has been approved through an EPC tender.	It is submitted that the detailed account of trees (including the type of tree and other relevant details) affected by the Project has been provided at Annexure-5 of EIA report. As has been stated above, the Project is proposed over the existing road alignments and the allegation of the Appellants is therefore baseless.	The reference to Annexure-5 of the EIA Report should have been made in the response in the entry. Also, as submitted in the appeal, this list cannot be treated as the final list as it is based on the interim alignment.

16	4.1	Is there likely to be any displacement of fauna- both terrestrial and aquatic or creation of barriers for their movement? Provide the details. - Answer - "No. Project do not involve displacement of either terrestrial and aquatic fauna and do not cause barrier for their movement. There is no endangered species found except the local species."	Felling and pruning of around 6000 trees and more will directly impact the population of critically endangered Slender Loris that uses the city's close canopies to migrate, and this also affects adversely the migration of wide range of birds and other fauna.	It is submitted that there is no displacement of fauna both terrestrial and aquatic and there is no creation of barriers for their movement. The Appellants have alleged that the felling of 6000 trees (though the number of trees proposed to be cut by the Respondent No.1 is 3821) will directly impact the population of critically endangered Slender Loris, the Appellants have failed to provide any document or study to support their contention. On the basis of only the pleadings and in the absence of any document to support their contention of creation of a barrier to the migration of the	The Appellants have stated that 6000 trees will be felled or pruned, not just felled. Further, the Appellants are providing literature on the due to habitat destruction and fragmentation suffered due to concretisation and tree felling in Bengaluru by the Slender Loris, classified as Near Threatened as per the IUCN Red List of Threatened Species, at **Annexure A40 colly**. It is submitted that the impact on this species is illustrative of the impact on several other species.

				birds and other fauna, the Appellants contentions are therefore liable to be disregarded.	
17	4.2	Any direct or indirect impacts on the avifauna of the area? Provide details. - Answer - There will be no impact on avifauna (birds) of the area. The compensatory trees planted at the rate of 10 trees per each tree cut may attract birds creating a positive impact on the avifauna.	The felling of trees has a critical and direct impact on avifauna, and is not stated in the Form.	The Respondent No. 1 reiterates that there are no direct or indirect impacts on the avifauna. The Appellants have failed to produce any document or proof whatsoever to establish that the Project implementation would impact the avifauna.	It is self-evident that large-scale tree felling, pruning and transplantation will affect local bird habitats. Further, noise pollution from highways has been documented to impact birds adversely. Indeed, roads have been found to be a prominent cause of endangerment of bird species across the world. The Appellants are producing literature on this aspect at **Annexure A41 colly** (specific to Bengaluru city) and **Annexure A42 colly** (collating worldwide studies).

18	5.1	Will the project increase atmospheric concentration of gases & result in heat islands? (Give details of background air quality levels with predicted values based on dispersion models taking into account the increased traffic generation as a result of the proposed constructions) - Answer - "No. The proposed elevated corridors are signal free and planned to give access to all important peripheral roads leading	The construction of elevated corridor will lead to increased traffic and emissions from vehicles at an elevation and introduce areas along the alignment to increased exposure to pollutants. Such corridors will result in effects of heat island.	It is submitted that the Project will not increase atmospheric concentration of the gases and instead, after the construction of the project it will ease out the traffic congestion resulting in smooth flow of the traffic along the corridor. The implementation of the Project is estimated to reduce CO2 emission due to vehicular traffic by about 4.74 lakh tonnes. The implementation of the Elevated Corridor Project would substantially cut down the travel time and in turn would reduce the man hour spent in traffic. The estimated cost savings in terms of fuel and travel time cost is about Rs. 9,000 Crores.	See response in Item III(11) in the table on Form I. The 1st Respondent's argument does not account for the phenomenon of induced demand. With respect to augmentation of heat island effect, it is further pointed out that at page 5-137 of the EIA Report, it is mentioned that trees contribute substantially to mitigation of urban heat island effect. Yet the 1st Respondent has nowhere evaluated the impact of large-scale felling of trees and construction of megastructures of concrete on increasing this heat island effect. This is crucial since the material specifications detailed in Section 5.3.17.3 of the DFR Volume-I Main Report (at page 5-26) mention that a wearing coat of asphaltic concrete will be provided for the Elevated Corridor. This will significantly enhance the heat island effect of the highway. The Appellants are producing literature on the impact on urban heat due to large-scale

		suburban areas. Implementation of project will reduce the traffic congestion on the at-grade roads. This eases the traffic on the roads and reduces traffic jams leading to reduction of gaseous emissions and improves the air quality and will help in reduction of fuel consumption in the city."			highway/infrastructure projects at **Annexure A43**. The Appellants are also producing literature at **Annexure A44** showing that asphaltic concrete significantly contributes to urban heat, as it has a high albedo (reflective value) of 0.05-0.1 when newly laid, indicating that it is a high absorber of heat. (The albedo of black bodies is 0 and that of pure white objects is 1.)
19	5.2	What are the impacts on generation of dust, smoke, odorous fumes or other hazardous gases? Give details in	Impact during construction phase grossly misrepresented. Impact during operation phase not even stated.	The generation of dust during construction phase is mitigated by regular water sprinkling; however, this aspect has been addressed by recommending appropriate mitigation	The 1st Respondent has still not addressed impacts during the operation phase. The measures stated in Chapter 5.2.5 are not substantially different from the answer provided in Form IA and pertain only to the construction phase. Apart from a passing mention in Section 6.6 (page

		relation to all the meteorological parameters. Answer provided: "Dust generation is expected during construction of proposed elevated corridor. Primary sources of dust from activities like site preparatory earthworks; foundation excavation works; erection and use of heavy equipment and machinery; loading, transporting and unloading soil and construction materials and material handling; traffic		measures under Chapter 5.2.5 of EIA.	6-6), the impact of carcinogens like lead, benzene and Volatile Organic Compounds (VOC) has not been addressed.

		diversion; etc. Gaseous emissions like Carbon Monoxide, oxides of Nitrogen, Sulphur dioxide from the batching plants, hot mix plants and diesel generators are also expected during construction. Mitigation measures: Construction sites, material haulage roads and the traffic diversion routes shall be sprayed with water to prevent dust. The materials transported shall			

		be properly covered with tarpaulin; Construction vehicles used for the construction shall be serviced regularly and obtain the Pollution Under Control Certificate to ensure emissions norms prescribed by CPCB Construction establishments such as hot mix plants, batching plant, crusher plant, construction camps shall be sited sufficiently away from air sensitive receptors and shall ensure compliance and			

		strictly adhered conditions stipulated in the consent, A regular ambient air quality monitoring shall be done to ensure the emissions from construction activities within the National Ambient Air Quality Standards.			
20	6.3	Whether there are any local considerations of urban form & urban design influencing the design criteria? They may be explicitly spelt out. - Project proponent has	Patently false. Fails to mention that the revised master plan 2015 does not factor the present elevated highway	It is submitted that the Master Plan is nothing but a static long-term planning document that provides a conceptual layout to guide future growth and development. Master planning is about making the connection between buildings,	The 1st Respondent had admitted in Chapter 7 (Social Impact and RAP) of Volume I of the DFR Main Report that land use change and land acquisition is required for the Elevated Corridor Project. Chapter 6.6 (Potential Environmental Impacts) and Chapter 7 also outline the impact on various buildings, heritage structures and open spaces. The EIA Report has

		responded saying that Master Plan 2015 has been considered.		social settings, and their surrounding environments. A master plan takes into account zoning regulations and includes analysis, recommendations, and proposals for housing, transportation, community facilities, and land use. It is based on public input, surveys, planning initiatives, existing development, physical characteristics, and social and economic conditions. It is important to consider the Master Plan as a dynamic document that can be altered based on changing project conditions over time. It is submitted that the area along which the Project is to be constructed have been allocated for roads in	outlined impacts on parks, lakes, etc. This will have crucial impacts on the urban design and forms of the city, and shows how there is no effort to adapt the design of the project to existing urban forms and designs. As such, there is no basis for the 1st Respondent to claim that the highway completely conforms to the RMP 2015.

				the Master Plan. In fact, the Project consists of elevated highway corridors that are to be built above the existing roads, so as to ease traffic conditions. Hence, there is no question of the same being in violation of the Master Plan. The Project is in consonance with the zoning regulations and the land use inasmuch as the Project has been proposed on the existing road alignment and as such, no change in land use is required for the purposes of implementation of the Project. The construction of the elevated highway corridors does not change the master plan in any manner whatsoever.	

21	9.8	What are the likely effects of the building activity in altering the micro-climates? Provide a self-assessment on the likely impacts of the proposed construction on creation of heat island & inversion effects? - Answer provided is : As the elevated corridor project is following the existing internal roads of Bangalore city do not have significant impact on creation of heat islands and inversion effects	Felling of several thousand trees and converting green cover to concretized surfaces and increased plying of vehicles and attendant pollution, will affect micro climate significantly and extensively.	As has been explained above, it is submitted that there are no effects from the project activity in altering the micro climate and elevated corridor will reduce the traffic and pollution load will come down moderating micro climatic parameters.	The Appellants have given a detailed response on augmentation of heat island effect due to the project at Item 5.1 of this table; and on the increase in air pollution at Item III(11) of Form I.

Re: Generic Terms of Reference and EIA not Fulfilling ToR

25. The averments in para 70 to 71 of the 1st Respondent's counter statement are denied. The 1st Respondent has still not been able to show compliance with the Terms of Reference ("**ToR**") issued. The Appellants seek leave of this Hon'ble Tribunal to respond to the averments made in the table furnished at para 70 of the counter statement, through the following table:

Sl. No.	Sl. No. in Application	Items	Section	Comments in Appeal	Response in counter statement	Appellants' Response
1	2	Submit details of environmentally sensitive place, land acquisition status, rehabilitation of communities/ villages and present status of such activities	Refer to Section 4.7, Section 5.2.3 & 5.2.5 and Table No 5.10	4.7 is at pg. 4-92. Provides general description of the hydrology surrounding Bengaluru and even has some studies of water quality. However, these	It is submitted that Details of land acquisition status, rehabilitation of communities etc. have been addressed in the Social Impact and RAP report under chapter 7 of Volume 1 of the DFR. The environmentally sensitive areas under the project are addressed in	Chapter 7 on 'Social Impact and RAP' does not actually map the extent of land proposed to be acquired. It only provides unsubstantiated data on the number of structures and the names of wards likely to be affected. Details of a social screening survey are purported to have

				studies are not dated. 5.2.3 is at pg. 5-122. It also discusses impact of the project on water bodies. 5.2.5 Is at 5-128 considers the impact on air quality. Table 5.10 provides a list of noise sensitive receptors along the proposed corridors. Details of land acquisition status, rehabilitation of	chapter 5 of the EIA.	been provided at "plate 1" but cannot be found in Chapter 7. Further, no details on resettlement and rehabilitation ("**R&R**") are provided save for generally mentioning that resettlement frameworks shall be prepared in the future. This is a direct result of premature application for EC without finalisation of land acquisition. It is also mentioned that compensation will be provided at par with the

				communities and other environmentally sensitive places (except water bodies) have not been provided at the sections indicated.		Right of Fair Compensation and Transparency in Land Acquisition and Resettlement and Rehabilitation Act 2013, but there is no mention of R&R.

2	3	Examine baseline environmental quality along with projected environmental road [read as load] due to the project.	Refer to Section Chapter 4	Chapter 4 starts on pg. 4-33. It contains a description of Environmental baseline data. However, such data has been collected between November 2018 and January 2019 which is, the North-East Monsoon period. Data cannot be collected during Monsoon since it is not representative of meteorological conditions for the rest	It is submitted that Environmental Base Line data was collected post monsoon season (ie., from November 2018 to January 2019), pertinently, the baseline data so collected during the non-monsoon period has been accepted by committee.	Refer to para 26 of the rejoinder below. The fact that the baseline data was accepted at face value by the SEAC and SEIAA merely goes to show their non-application of mind and is not conclusive proof that the period of November-January is a non-monsoon period.

				of the year. Please refer para 21-24 below for detailed submissions on this issue. Projected Environmental Load of the project has not been provided. The details of modelling done has also not been provided. Please refer para 27-29 below for detailed submissions on this issue.		

3	4	Environmental data to be considered in relation to the project development would be (a) land, (b) ground water, (c) surface water, (d) air, (e) bio-diversity, (f) noise and vibrations, (g) socio economic and health.	Refer to Section Chapter 4	Chapter 4 starts on pg 4-33. The Environmental data collected and presented in this chapter is not according to the mandate of the sector specific EIA manual issued by the MoEF.	It is submitted that the environmental data collected and collected and presented is as per standard and exhaustive additional TOR issued by committee. Apart from alleging that the environmental data collected is not as per the EIA manual, the appellant has not been able to point out any lacunae in the environmental data collected and compiled by the 1st Respondent.	The MoEF Guidance Manual on Highways provides useful guidelines for the comprehensive collection of environmental data from a study area. Many of the details specified in Chapter 4 of the EIA Report pertain to the general features of Bengaluru and not to the specific study area as required by the MoEF Guidance Manual on Highways. For instance, the manual requires a list of endangered and endemic species to be provided with specific reference to the chainage of the proposed road (as outlined in Table 4.13 of the manual). However, Section 4.12 of Chapter 4 of

						the EIA Report only provides a generic list of flora and fauna in Bengaluru city. Another example is that according to the manual, "Details of villages, survey numbers of the area, tehsil, districts and states, elevation above mean sea level & latitude and longitude of important locations and existing drainage system throughout the proposed highway alignment should be collected". This has not been mentioned anywhere in the EIA Report.

4	5	Submit a copy of the contour plan with slopes, drainage pattern of the site and surrounding area. Any obstruction of the same by the project	Refer to Section 4.7	4.7 starts at pg. 4-92. Contour map has not been submitted. Project admittedly cuts through water bodies and impinges on their drainage area.	As has been explained above, the project is aligned on existing road and the elevated structures with the help of piers generally at 40 meter interval and the proposed project does not cut through water bodies and does not impinge on their drainage area. The Project proposes to harvest the Rain water and implements rain water harvesting on the Elevated Corridor, thereby recharging the ground water reserve. The Project does not add any additional water load to the drainage system and as such, the existing drainage systems is	Refer to the Appellants' response for Item 1.5 in the above table on Form IA (Sl. no. 8) and para 39 of the rejoinder below on impact on lakes and hydrology.

					not affected by the Project.	
5	6	Submit the details of the trees to be felled for the project.	Refer to Section Annexure 5	Annexure 5 is not found along with the EIA Report. Index at pg vi states "Error! Bookmark not defined"	The complete EIA report has been uploaded on the official website of the 1st Respondent However, the Respondent No.1 has annexed the EIA report along with this Statement of' Objections and the details of the trees to be felled for the project is given in Annexure-5 of' EIA Report.	This information was not available in the public domain during the appraisal process. Further, since the alignment itself has not been finalised, these lists can hardly be taken as conclusive and cannot form the basis of impact assessment.
6	7	Submit the present land use and permission required for any conversion such as forest, agriculture etc.	Refer to Section 4.10	Section 4.10 is at pg. 4-109. Permission for conversion of land use (mandatory under form 1A) has not been	It is submitted that the project is aligned along the existing road alignment and acquisition of land for marginal widening is only envisaged. The details of land proposed acquisition	No detailed land acquisition plan has been submitted in Chapter 7. The 1st Respondent is glossing over the fact that land acquisition for even "marginal widening" will require permission for

				provided in this section.	and plan thereto are furnished in chapter 7 of Volume 1 of DFR and the detailed land acquisition plan has also been prepared It is submitted that the conversion of agriculture/forest land for the proposed Project does not arise.	change in land use. Also refer to the Appellants' response for Item 2 of this table (at Sl. no. 1).
7	9	Ground water classification as per the Central Ground Water Authority.	Refer to Section 4.9	Section 4.9 is on pg. 4-106. Groundwater Classification has not been provided. Suppression of the fact that entire Bengaluru Urban area has been classified "Overexploited". In fact,	Existing Ground water condition as per central ground water board for Bangalore Urban area is brought out in EIA Report. In absence of sufficient surface water source alternatives available in the vicinity, source of· water requirement should have to be met from	In Section 4.9, it is only stated that "Studies have been done on the ground water quality for Bengaluru Urban district by Central Ground Water Board based on hydro-chemical data of network hydrograph stations wells and exploration bore wells. Results show wide variations in its

				the EIA report describes plans to source water requirements from bore wells despite of this classification (in section 5.2.3).	bore wells. However, EIA mandates use of treated sewage from the STPs The Project also addresses recharge of ground water by guiding surface runoff from elevated road through recharge pits between the piers along the median after suitable treatment. The detailed plan in this regard has been provided at chapter 6 of the EIA.	chemical composition." This is followed by certain observations on the nature of ground water in the city. But there is no indication of any classification as per the Central Ground Water Authority.
8	10	Examine the details of Source of water, water requirement, use of treated waste water and prepare a water balance chart.	Refer to Section 5.2.1	Section 5.2.1 at pg. 5-123 deals only with the impact on topography. Source of water and	Identification of sources of water for the project will be done by the contractor at the time of implementation with due consultation with	Refer to the Appellants' response for Item 2.1 and 2.4 (at Sl. no. 9 and 12) in the table on Form IA.

				water balance has not been provided even at 5.2.3 where water requirement has been stated as 266 million litres.	the Environmental Engineer of· the Respondent No.1 Consultancy service after due consideration of quantity/quality/distance. However as per the mandatory condition of Environmental clearance issued, a condition will be imposed for the usage of treated sewage water for construction.	
9	13	Examine details of solid waste generation treatment and its disposal.	Refer to Section 5.2.2	5.2.2. At pg 5-123 is titled "Impact on Soil". It considers the impact of construction on soil erosion. It does not provide details of	It is submitted that the details of Solid waste (Soil Debris) is exhaustively covered in Section 5.2.2 and Table 5.4 and Section 5.2.9- Impact on Land Environment. At the time of implementation of the project,	The Appellants have already submitted that Section 5.2.2 does not deal exhaustively with the issue of solid waste disposal. Table 5.4 pertains to the quantity of debris generated. Section 5.2.9 refers to generation of construction waste,

				solid waste generation including construction waste and municipal solid waste. It briefly mentions some mitigation measures for how debris should be disposed of.	measures will also be imposed for disposal of solid wastes in environmentally sustainable manner, as prescribed in law.	and mentions that the unserviceable construction waste will be disposed of in abandoned quarries in and around Bengaluru. It is submitted that the disposal of construction waste in abandoned quarries is in violation of the criteria for site selection for disposal of construction waste as per Rule 7 read with Schedule I of the Construction and Demolition Waste Management Rules, 2016. It is also pertinent to mention that the BBMP has been censured by the Hon'ble High Court of Karnataka in W.P. No. 24739 of 2012 and connected matters for dumping of waste in

						abandoned quarries without obtaining requisite clearances from the Karnataka State Pollution Control Board and complying with the Solid Waste Management Rules, 2016, vide several orders such as order dated 15.10.2019 and 06.03.2020.
10	15	DG sets are likely to be used during construction and operational phase of the project. Emissions from DG sets must be taken into consideration while estimating the impacts on air environment. Examine and submit details.	Refer to Section 5.2.5	Section 5.2.5 is at pg. 5-128. Emissions from DG sets have not been modelled or considered.	Emission from DG Sets are expected during construction stage which will be mitigated by using low emission DG's and impact will be reduced by using Chimneys of required height The impacts will be short term and limited in nature. Proper site selection, appropriate location of plant and regular	The 1st Respondent has made a generic statement that impacts from DG sets will be short term and limited in nature. But in the absence of modelling of emissions from DG sets, there is no reliable estimate of how the air environment will be impacted with or without emission mitigation measures. This is critically

					maintenance and monitoring will be insisted during implementation in order to minimize such impacts. The details with regard to mitigating measures have been provided in chapter 5 of the EIA report	important given that scientific studies have shown the high impact of DG sets on PM 2.5, PM 10 and SO2 levels and its contribution to air pollution. The Appellants are annexing studies to this effect, conducted in Gurugram and Faridabad, at **Annexure A45 colly**.

1 1	1 6	Examine road/ rail connectivity to the project site and impact on the traffic due to the proposed project. Present and future traffic and transport facilities for the region should be analysed with measures for preventing traffic congestion and providing faster trouble free system to reach different destinations in the city.	Refer to Section 5.2.4	5.2.4 is at pg. 5-128 and deals only with Traffic Diversions.	The claim of the Appellants is not true inasmuch as a detailed traffic analysis has been conducted by the Respondent No.1 and the same is a part of the DFR, which has been annexed herewith.	The 1st Respondent has not analysed rail and road connectivity to the project through integration of different modes of transport such as metro, buses, etc. As submitted earlier, at Section 4.7.1 of the DFR Volume I Main Report it is admitted that the Elevated Corridor will not solve traffic congestion issues. Refer to para 15 above. Further, Chapter 4 of the DFR Volume I Main Report only contains general traffic analysis. Traffic forecast at Section 2.8 (at page 2-9) of the EIA Report refers to

						growth of registered vehicles.
12	17	A detailed traffic and transportation study should be made for existing and projected passenger and cargo traffic.	Refer to Section 2.7, 2.8 & 2.10	2.7 at pg. 2-4 is titled "Proposals for the Elevated Corridor". 2.8 titled "Traffic Forecast" at pg. 2-9. 2.10 at pg. 2-12 is titled "Corridor of Impact". 2.7 discusses functional aspects of the project, 2.8 reproduces CTTP figures of Bengaluru's projected Traffic Growth and 2.10 discusses the dimension		Refer to response for Item 16 (Sl. No. 11) above.

				specifics of the proposed Elevated Corridor and briefly alludes to the impact on traffic. It also mentions that a detailed traffic study report has been prepared. However, this study is not found as a part of the EIA report. As such, no evidence of a detailed traffic and transportation study is found.		

13	19	Examine separately the details for construction and operation phases both for Environmental Management Plan and Environmental Monitoring Plan with cost and parameters.	Refer to Section Chapter 8	Chapter 8 is at pg. 8 - 166. The report itself states "A detailed EMP is to be prepared during DPR stage to address specific impacts of the project." The EMP provided at page 8 - 167 - 174 is generic and non-specific. concerns of pollution from the project and mitigation measures are not provided.	It is submitted that the Environmental Management Plan and Environmental Monitoring Plan with cost parameters has been conducted in detail. The proposed mitigation measures have been enumerated in chapter 5 of Environmental Impact and Mitigation Measures at EIA report. The Appellant is making assertions against the EMP without spelling out the alleged irregularity in the study conducted by the 1st Respondent.	The budgetary provision for the implementation of the Environmental Management Plan of the Elevated Corridor project is presented in Table 8-6. This table does not capture the costs of various activities mentioned in the Environment Management Plan at Table 8-1, including demolition/relocation of structures and physical properties, utility shifting, and sanitation and waste disposal at construction camps, to name a few.

14	20	Submit details of a comprehensive Disaster Management Plan including emergency evacuation during natural and man-made disaster.	Refer to Section 8.1.3 & 8.1.4	8.1.3 is on pg. 8-179. It agrees with the need for a disaster management plan but does not provide it. 8.1.4 starts on 8-179. It outlines the need for an Oil Spill Contingency Plan and identifies the contractor as being responsible for doing so.	For Comprehensive disaster management plan including emergency evacuation have been described an Oil Spill under described under section 8.1.13 and 8.1.114 Though the section mentions that the Contractor has to come up with the contingency I emergency plans, it is pertinent to note that the EIA prescribes the requisite parameters the plans should contain and as such, the contention that the Respondent No.1 has passed its responsibility on the contractor is contrary to the records	As submitted previously, claims such as this completely defeat the purpose of environment impact assessment. Failure to furnish the required information in the form of "details of a comprehensive Disaster Management Plan" raises the presumption that the decision to grant clearance was based on inadequate information and also that the conditions imposed for mitigating adverse impacts are insufficient.

1 5	2 2	The cost of the Project (capital cost and recurring cost as well as the cost towards implementation of EMP should be clearly spelt out.	Refer to Section 8.10 & Table 8.6	8.10 is at pg. 8-195 and refers to table 8.6 at pg. 8-196. Table contains cost for the implementation of the Environment Management Action Plan. Capital Cost of the project is not provided in this section.	It is submitted that the assertion made by the Appellants are untrue inasmuch the Capital and recurring cost with respect to Environmental management is detailed in Table 8.6 of EIA Report.	This ToR is not merely limited to the cost of the Environmental Management Plan, but extends to the cost of the entire project itself.

16	23	Any further clarification on carrying of the above studies including anticipated impacts due to the project and mitigative measure project proponent can refer to the model ToR available on Ministry website http://moef.nic.in/Manual/Townships.	Referred	The entire section from the model ToR considering alternatives is missing. When read with the sector specific Manual, the alternatives to be considered include other transportation systems. None of this has been considered. It is also surprising that a manual for townships has been referred for an Elevated	It is submitted that	-

				Highway Project.		
Sl. No		Additional ToR:	Section			
17	1	The applicability of the Hon'ble National Green Tribunal order dated 4th May 2016 in O.A No.222 of 2014 on buffer zone for water bodies and nalas may be studied and submitted.	Refer to Section 3.11 and 4.7	3.11 is at 3-27 and effectively reiterates the order of the Tribunal. 4.7 at pg. 4-93, states that it is impossible not to violate the requirements of the Order.	It is submitted that Order of the Hon'ble NGT in OA 222/2014 is applicable for the building projects wherein, the total obstruction of flow and drainage is going to be affected, The present project is the elevated structure aligned above the existing road with the help of Piers generally at 401n interval and it will not cut through water bodies and do not affect the existing drainage and therefore the said order of' the	The 1st Respondent admits that the NGT Order is applicable for all construction projects within the buffer zones of water bodies like Ulsoor Lake, Varthur Lake, Agara Lake and Vrishabhavathi Stream/River and their rajakaluves. As submitted elsewhere, it is evident that the project construction passes through the buffer zone of the various lakes and their rajakaluves mentioned above. Refer to the

					NGT has no applicability to the instant case. Moreover, the EC specifically mandates compliance to the Order of the DRT in OA 222/2014.	Appellants' response for Item 1.5 in the above table on Form IA (Sl. no. 8) and para 39 of the rejoinder below on impact on lakes and hydrology. Thus, the question of non-applicability of the NGT order does not arise.
18	2	As per the proposal about 12 Lac cum of earth required to be brought from outside. The proponent should work out the alternative scheme to reduce the earthwork requirement.	Refer to Section 5.2.2, 8.1 and Apendix 1	5.2.2 is at pg 5-123. It only discusses the impact on soil during the construction phase and makes a recommendation to source the soil from infertile lands. 8.1 is at pg. 8-179. It	The Respondent No.1 has recognized that soil/debris will be generated during foundation excavations tor pile construction and the debris so generated will be carefully and safely disposed of. The debris generated at the pile foundation location will be partially utilized for construction of ramps and rehabilitation of	The 1st Respondent's proposal pertains to barely 2 lac cum of the total external earthwork requirement of 12 lac cum. Apart from this, there is no alternative scheme to reduce the earthwork requirement.

				only deals with resettlement plan, construction water management plan, emergency response plan and oil spill contingencies plans. Therefore they have not worked out a way to reduce the earthwork requirement. Appendix 1, is titled "Disposal Site Management" but is not found along with the EIA report.	quarries and burrow pits. The details pertaining to the debris are given in chapter 5.2.9 of EIA report.	

19	3	Scientific handling of earthwork generated during construction may be detailed and submitted keeping in view best possible mitigation measures for dust.	Refer to Section Appendix 1	Appendix 1, is titled "Disposal Site Management" but is not found along with the EIA report. Document is also not found uploaded at http://environmentclearance.nic.in/onlinesearch_state.aspx?type=TOR&status=19&statename=Karnataka	Details are given in chapter 5.2.9 of EIA report.	Section 5.2.9 does not provide details on scientific handling of earthwork, and instead suggests illegal methods of debris disposal. Refer to Item No. 13 (At Sl. No. 9) of this table. Details on soil erosion mitigation are actually provided at Section 5.2.2.

20	5	Impact on the nearest water body and archaeological structures may be studied properly and submit.	Refer to Section 4.7, 5.2.3, 5.2.10, 3.1 & Table 8.1	4.7 is at pg. 4-92. Deals only with water environment. Impact on water bodies due to construction activities and during operation have not been studied. 5.2.3 is at 5-125. Simply says that impact can be avoided by careful planning of construction activity. Does not contain a study. 5.2.10 is at pg. 5-141. There is no study on	The details are provided in para 5.2.3 & 5.2.8 for water bodies along with mitigation measures. Table 8.1 of Chapter 8 of EIA Report discusses on impact and management measures on water resources and the of quality, 5.2.10 (Archaeological buildings); However, during implementation, the mitigation measures/conditions imposed by the concerned authorities will be followed. These are all policies and regulatory frameworks and its applicability are made as per the	With respect to impact on water bodies, see Appellants' response for Item 1.5 in the above table on Form IA (Sl. no. 8) and para 39 of the rejoinder below on impact on lakes and hydrology. It is admitted in Section 5.2.10 that construction of the East-West Corridor falls within 100m of Tipu Sultan's Palace, and thus violates the protected area of the monument. Though it is mentioned in the mitigation measures that permission from the National Monument Authority shall be taken before construction in the prohibited area,

				impact, but merely states that two notified archaeological structures are within the prohibited distance of the East-West Corridor. 3.1 is titled "Constitutional Provisions" at pg. 3-22. The relevance is not known. 8.1 is at pg. 8-167. It is the Environment Management Plan. It does not deal with a study of the impact.	basic constitutional provisions.	Section 20A(4) of the Ancient Monuments and Archaeological Sites and Remains Act, 1958 (amended in 2010) clearly states that no permission for construction may be granted in a protected area after the 2010 amendment receives Presidential assent (which was accorded on 29 March 2010). Thus, no permission can be granted for construction within 100m of the Tipu Sultan Palace.

21	9	Carbon foot print to be studied and suitable offsets may be suggested.	Refer to Section 6.7	6.7 is at pg. 6-160. No study of carbon footprint is provided. However, an arbitrary calculation of emissions and offset is made available.	Carbon Footprint and carbon emission studies conducted, and the results are presented in Page No.6-160 to Page No. 6-163 of the EIA report. The Appellants have contended that the studies conducted by the Respondent No.1 to be an arbitrary calculation however the appellants have failed to demonstrate any arbitrariness in the studies conducted.	In Section 6.7, a mention is made of 'emission inventory' but the same is not provided. Figure 6-7 (represented numerically in Table 6-5) on estimated carbon emission is purportedly based on IPCC 2006 methodology, but the methodology is not explained. There is a formula provided for the estimates given, but the calculations and the underlying estimates are not explained (such as how Activity Data and Emission Factors are calculated). It is also stated that the estimates are subject to validation. Table 6-6 (CO_2 Emissions for various speeds changing with implementation

						of project) erroneously assumes increase in vehicle speeds to project reduction in CO2e emissions. This is because it does not account for the phenomenon of induced demand. See response in Item III(11) in the table on Form I.
22	10	Steps taken to reduce the energy embodiment of the materials used may be detailed.	Refer to Section 6.8	6.8 at pg. 6-162 discusses the projected Carbon Emissions of traffic in Bengaluru before and after the Elevated Highway Project. It only considers emission	One of the main reasons for proposing the project was to minimise traffic woes in Bangalore city. There are no study or report that indicates that construction of elevated corridor would prompt the citizens of Bangalore to buy more vehicles and such a presumption made	Section 6.8 deals with Carbon emission studies only. The table at Section 6.9, page 6-164 provides the embodied energy of the different materials proposed in the project. No steps have been taken to reduce the energy embodiment of the materials. Reduction in embodied energy can be made only by

				rates at different speeds of traffic and assumes optimistically that speeds of traffic will increase. It fails to account for the increase in the number of vehicles on the road due to the Elevated Highway. Has no relevance to reducing energy of the materials used.	by the Appellants is unfounded.	comparing alternative materials and choosing them based on an analysis of energy requirement, distance of procurement site, distance from source of materials etc.

2 3	1 1	Changes to the micro climate to be modelled and simulation studies to be submitted.	Refer to Section 4.5.2	4.5.2 at pg. 4-73 is titled "Air Quality Modelling for the Project Area". As is apparent, there is no consideration of the general micro climate. Simulation studies have not been conducted. Micro-climatic conditions depend on several factors like heat, tree canopy, humidity, wind, etc. and are not limited to air quality.	Air quality Modelling has been done considering micro climatic conditions as presented in 4.5.2 of EIA.	The 1st Respondent is misleading this Hon'ble Tribunal by stating that Section 4.5.2 accounts for micro climatic conditions. There is no evidence that the air quality modelling provided in that section has accounted for the micro climatic conditions in any way. In any event, micro climatic modelling is completely different from air quality modelling, as already submitted.

				In addition, the basis of the air pollution modelling is questionable as no methodology has been shared to explain the values arrived at.		
24	12	List of trees to be felled, pruned, retained along with details of locality along with budget backup for plantation and its maintenance at least for 10 years.	Refer to Section Annexure 5 Section 8.10	Annexure 5 is not found along with the EIA Report. Index at pg vi states "Error! Bookmark not defined" 8.10 is at pg. 8-195. It contains the Environmental Budgetary Provisions.	It is submitted that the list of trees to be felled can be found at in Annexure-5 of EIA report and the said document was duly uploaded on the 1st Respondent's website. A copy of the EIA report has already been Annexed to the instant statement of objections.	The 1st Respondent has not shown how the budgetary provisions for 5 years satisfy the ToR mandate requiring details for 10 years.

				The budgetary provisions are also only for a period of 5 years. There is no list of trees available.		
25	13	To propose suitable location details to take up compensatory plantation with budget details.	Refer to Section 6.3 & 8.10	6.3 is at pg 6-155 and 8.10 is at pg. 8-195. 8.10 contains no details of location. 6.3 contains general statements like "plantation of trees will be taken up in the upcoming new layouts in the suburbs of Bengaluru City, parks and forest	The List of Forest land available in Bangalore Urban Division to take up compensatory plantation is given in section 6.3 of EIA. The concerned tree committee of the forest department will suggest the locations for compensatory plantation as per the availability and the suitability for the recommended tree species which are to be planted as procedure laid down	The 1st Respondent has not provided even a rough estimate of how much land is required for compensatory afforestation. No estimate has been provided on the area requirement per tree based on the different sizes of trees. The general statement that plantation will be taken up in upcoming layouts, or existing forests, etc. also does not give a clear picture of how

				under Bengaluru Urban Division shown in table".	by forest department, Budgetary provision of 10 Crores has been earmarked for rising compensatory plantation which shows the commitment of project proponent towards conservation of environment.	much total land is actually available for afforestation. Even Table 6-3 at page 6-155, though mentioning the extent of forest land, does not clearly indicate whether the area mentioned is the total extent of the forest, or free area available for compensatory afforestation.
26	16	Land use land cover analysis of project corridor area using high resolution satellite data.	Refer to Section 4.10	4.10 is at pg. 4-109. Maps provided are illegible and copies to scale have not been provided in the EIA report.	Detailed Land use land cover analysis for the project corridor is done in section 4.10 from Page No. 4-109 to 4-112 of the EIA.	High resolution satellite imagery has not been provided. Figure 4-19 provides a land use map from the CDP Bangalore 2015, but no land use analysis has been done on this basis. For instance, the details of residential, commercial, heritage areas, schools, hospitals, green

						zones, etc. that are affected by the project are not clear from the provided maps. Only a pie chart depicting the percentage of a few broad categories of affected lands is given at Figure 4-21.

Re: Alleged Flaw in Baseline Data Collection

26. The averments in para 72 to 74 of the 1st Respondent's counter statement are denied. It is submitted that the 1st Respondent is deliberately trying to mislead this Hon'ble Tribunal by projecting that the South West Monsoon is the only period of monsoon in Bengaluru, whereas it is common knowledge that the city also receives significant rainfall from the North East Monsoon. Moreover, it is also evident from Table 4.1 of the EIA Report 'Month wise rainfall and annual total rainfall data for Bangalore urban district' that Bengaluru receives heavy rainfall in the month of November. Further, the rains received this year, which have extended way beyond the South West monsoon period, are indicative of the situation that is likely to become the norm due to the impacts of climate change.

26.1 Further, the Appellants have at para 20 of the appeal already submitted data on the North East Monsoon in Bengaluru from the Indian Meteorological Department (MC Bengaluru) covering a period of October-December. It is submitted that it should have been self-evident to the 1st Respondent and the consultants conducting the EIA that the requirement in the Terms of Reference for collecting baseline data from a non-monsoon period referred to both the South West and the North East Monsoons. During monsoon, due to the wash-out effect, the true footprint of existing levels of pollutants cannot be recorded. This is the reason why baseline data should not be collected during monsoon periods. The forecast in the EIA report is based on this flawed data and hence cannot be accepted.

Re: Alleged Non-modelling and Non Study of Impact on Environment

27. The averments in para 75 to 80 are denied. The 1st Respondent has averred in para 76 and 78 of its counter statement that the Appellants have ignored the study on air pollution produced at Section 4.5.1 of the EIA Report. It is submitted that para 26 of the appeal deals extensively with the studies on air pollution produced in Section 4.5.1 and 4.5.2

(produced at Chapter IV of the EIA Report (DFR Volume IV)), and as such the averments of the 1st Respondent in this respect are liable to be ignored.

28. Further, the 1st Respondent has stated at para 79 of its counter statement that the averment at para 26 of the appeal that the values of PM 2.5 and PM 10 are uncharacteristically low is unsubstantiated. It is submitted that the averments are not unsubstantiated, since it is not in dispute that data was collected during the monsoon period, which would have led to the masking of the true value of air pollutants.

Re: Violation of Constitutional Mandate by Bypassing of Metropolitan Planning Committee

29. The averments made by the 1st Respondent in para 84, 88 and 89 of its counter statement are denied. It is submitted that the 1st Respondent is contradicting itself by claiming at para 84 and 88-89 of its counter statement that the objective of the Constitution (Seventy-fourth Amendment) ("**74th Amendment**") was only to promote coordinated planning in Metropolitan Regions and not to promote local self-government, while simultaneously admitting at para 87 that the Statement of Objects for the 74th Amendment includes the objective of putting the relationship between State Governments and Urban Local Bodies on a firmer footing. It is submitted that even a cursory glance at this Statement of Objects reveals that the whole premise of the 74th Amendment is to strengthen local bodies.

30. The averment in para 85 and 91 of the counter statement of the 1st Respondent is denied. The 1st Respondent is misrepresenting the argument of the Appellants, in as much as we have never argued that the Metropolitan Planning Committee ("**MPC**") is the sole instrumentality vested with the powers of urban planning and development or has the power to override the plans prepared by urban local bodies. Rather, we have argued that the consent of the MPC is mandatory before submitting

a developmental project for prior EC, as we have submitted at para 35-36 and 39-41 of the appeal. At the same time, the Appellants have argued in the appeal that the consent of the MPC is to be secured only *after* due consultation with Ward Committees, and needs to be accompanied by adherence to the procedure for public disclosure and consent under other applicable laws such as the KTCP Act (and the newly enacted Bruhat Bengaluru Mahanagara Palike Act, 2020). In any event, it is submitted that the 1st Respondent's interpretation of Article 243ZE(3)(a)(i) that the MPC cannot contravene plans prepared by the local planning authority has no basis in the text of the article, which reads: "*Every Metropolitan Planning Committee shall, in preparing the draft development plan, (a)* ***have regard to*** *(i) the plans prepared by the Municipalities and the Panchayats in the Metropolitan area*" (emphasis supplied), as is also admitted by the 1st Respondent at para 92 of its counter statement.

31. With respect to the 1st Respondent's submission at para 86 of its counter statement that consideration of the Elevated Corridor project is pending before the Hon'ble High Court of Karnataka as part of the proceedings in W.P. No. 48720 of 2014 (***Namma Bengaluru Foundation v. State of Karnataka & Ors.***), it is submitted that even though the matter might be pending before the Hon'ble High Court, the Hon'ble Court had previously in W.P. No. 31791-31792 of 2016 c/w W.P. No. 33081 of 2016 (***Rajeev Chandrashekhar & Ors. v. State of Karnataka & Ors.***) affirmed the primacy of the Metropolitan Planning Committee. As such, the 1st Respondent cannot hide behind the pendency of W.P. No. 48720 of 2014 to negate the reality that it bypassed the statutory norms for land use planning, development and review that existed at the time it applied for and obtained clearance. Moreover, W.P. No. 48720 of 2014 was already pending at the time EC was given to the Elevated Corridor and the tender for Engineering, Procurement and Construction issued. Propriety required that the 1st Respondent should have waited for the matter to be disposed of before proceeding with the Elevated Corridor project. The factum of

such pendency in 2018-2019, it is submitted, only strengthens the Appellants' case that the Elevated Corridor project was promoted with undue haste and in a manner ignoring statutory requirements.

32. With respect to the 1st Respondent's averment in para 90 of its counter statement, it is submitted that the Appellants are in full agreement that there is no conflict between the 74th Amendment and the provisions of the Karnataka Municipal Corporations Act, 1976 ("**KMC Act**"). The Appellants have explained at para 40 of the appeal how the 74th Amendment led to amendments in the KMC Act to incorporate provisions on the ward committees and the Bengaluru MPC, as has also been admitted at para 93 of the counter statement of the 1st Respondent. None of these bodies have been consulted by the 1st Respondent in the instant case.

33. The contents of para 94 to 95 of the counter statement of the 1st Respondent are denied as false. As submitted at para 19 of this rejoinder, it is abundantly clear that there is gross variation in the initial Government Approval and the financial sanction granted to the Elevated Corridor Project, and therefore it cannot be said that any valid consent from the State Government has been accorded to the project.

Re: Social Impact Assessment under the 2013 Land Acquisition Act Not Conducted

34. The contents of para 96 to 98 of the counter statement of the 1st Respondent are denied. As has already been submitted above, it is not open to the 1st Respondent to argue that it was not required to finalise the details of land acquisition and social impact assessment before applying for prior EC. EIA and social impact assessment studies are specific to the alignment and if the alignment is changed, then the studies on record become redundant. The EC issued cannot be valid for a changed alignment. Further, it is submitted that the 1st Respondent cannot wash

off the contradictory claims it made regarding the statutory framework under which land acquisition and rehabilitation was supposed to be conducted at the time of applying for prior EC, which revealed the hurried nature of the application and the lackadaisical approach taken at that time, by claiming now that the Karnataka Industrial Area Development Board Act, 1966 will be applicable.

Re: Conversion of Cubbon Park and Other Parks

35. The averments in para 99 to 103 of the counter statement of the 1st Respondent are denied as false in as much as they suggest that no conversion of public parks will result from the Elevated Corridor project. The Appellants' arguments on the impact on parks are based not on surmise and conjecture, but on material furnished by the 1st Respondent in Form IA. Item 1.3 thereof clearly mentions that public parks would be impacted and need to be demolished. This is elaborated in para 47 of the appeal. Further, at para 50 of the appeal we have referred to page 5-137 of the EIA Report which also clearly mentions that 120 trees in Cubbon park and 47 trees in Cole's park are proposed to be felled.

36. The 1st Respondent's averment that there is no conversion of public parks is baseless because conversion is not limited to acquisition or encroachment of the park, but includes tangible adverse impacts on the park area. The 1st Respondent cannot be permitted to undertake large-scale felling of heritage trees in public parks and evade the ambit of the strict propositions laid down by the Hon'ble Apex Court referred to at para 54-55 of the appeal, prohibiting alienation and encroachment of such spaces, by claiming that the Elevated Corridor being a raised structure will not require any acquisition of land in public parks. It is also submitted that the prohibition under Section 38A of the BDA Act is not only on *alienation* of land allotted to public parks. This section also states that the BDA shall not "*otherwise dispose of any area reserved for public parks*". It is submitted that permitting the felling of trees for the construction of an

overhead elevated highway amounts to "*disposal*" as envisaged in Section 38A of the BDA Act and hence is prohibited.

37. Further, it is submitted that even if no land from public parks is acquired for the Project, the admitted extensive felling of trees and loss of green cover will still fall foul of the judgments of the Hon'ble High Court of Karnataka pertaining to the protection of Cubbon Park referred to in para 48 of the appeal, which prohibit "*covering the open area within the limits of the park*" without obtaining the clearance of the Court, and remain subject to the procedure for tree felling outlined by the Hon'ble High Court in W.P. No. 7288/2011 and W.P. No. 17841/2018 referred to at para 57-58 of the appeal.

Re: Loss of Greenery and Biodiversity Increases Air Pollution

38. The averments in para 104-105 of the counter statement of the 1st Respondent are denied as false. The possibility of the choking of the Elevated Corridor due to induced demand has been clearly admitted at page 4-27 of Ch 4 in the DFR prepared by Deloitte and submitted by the 1st Respondent, as cited above at para 15. Moreover, the DFR submitted by the 1st Respondent has at no point undertaken a cost-benefit analysis of the Elevated Corridor's significant adverse impact on greenery and biodiversity versus the alleged benefits of the project, so as to justify the massive tree felling it is proposing, or shown why the same benefits could not be derived through other means. As such, the proposal of mitigation measures cannot be said to have given adequate consideration to the importance of greenery and biodiversity.

Re: Impact on Lakes and Hydrology

39. The averments in para 106 to 111 of the counter statement of the 1st Respondent are denied to the extent they suggest that there will be no impact on the natural drainage patterns of lakes and no construction in the lakes or their buffer zones. The averments at para 106, 107 and 110

of the counter statement of the 1st Respondent are at variance with the averments in the EIA Report. As already cited at para 65 of the appeal, it is recorded at page 4-93 of the EIA Report that stretches of the alignment will pass through the buffer zone, and construction of piers is even proposed within the lakebed of Ulsoor Lake, which is also evident from the satellite image provided at page 10-203 of the EIA Report. Further, at page 5-139 of the EIA Report, at Table 5-13, it is clearly detailed that the pier foundations of the Elevated Corridor project will pass through the buffer zones/rajakaluves of Hebbal Lake, Ulsoor Lake, KR Puram Lake, Varthur Lake, Agara Lake and four others. The satellite images of these lakes detailing the distance of the Elevated Corridor project from these water bodies can be found at page 10-202 to 209 of the EIA Report.

Re: Failure to Consider Alternatives

40. With respect to the averments made by the 1st Respondent at para 112-13 of the counter statement, it is submitted that if the SEIAA and SEAC did not find the need to explore alternatives to the project given its widespread social and environmental impacts and the massive investment it entailed, this only reflects a blatant non-application of mind on the part of these two bodies at the stage of scoping itself.

41. With respect to the averments made by the 1st Respondent at para 113-14 of the counter statement, it is submitted that the need to evaluate alternatives extends to both alternative *solutions* to the transportation problem and alternative *designs* for a selected project. This has been explained in para 70 of the appeal by referring to the MOEF&CC EIA guidance manual for highways. The 1st Respondent was therefore supposed to first explore alternatives to the Elevated Corridor project itself, and only if it found no feasible alternative, explore means to improve the alignment, etc. By the 1st Respondent's own admission, the former exercise has not been conducted.

Non-Application of Mind by SEAC and SEIAA

42. The averments in para 117 of the counter statement of the 1st Respondent, and in paras 2, 6, 7 and 9 of the counter statement of the 6th Respondent are denied as false. The 1st Respondent is trying to mislead this Hon'ble Tribunal by claiming that the Appellants have made unsubstantiated allegations against the SEAC and SEIAA. The Appellants have produced the minutes of several meetings of the SEAC and SEIAA which can be found at Annexure A5, A6 and A8 to the appeal. Further, the Appellants have also produced the order dated 01.03.2019 of the SEAC recommending the Elevated Corridor project for clearance and the order dated 02.03.2019 of the SEIAA issuing clearance to the project, as Annexures A9 and A10 to the appeal respectively. It is submitted that all these documents amply show how both the SEAC and SEIAA have abandoned their duty to verify from the material submitted to them whether clearance could have been accorded to the project, and furthermore, in what can only be called blatant illegality, have failed to assign any reasons whatsoever for the final orders issued. The complete absence of any "appraisal" of the project by the SEAC and the SEIAA vitiates the process. The failure to assign reasons and the absence of discussion on the EIA report, its impact, etc. are irrefutable evidence that the SEAC and SEIAA have failed in their statutory duty. They are envisaged as expert bodies and should speak in the manner of experts. The process of appraisal is central to effective environmental good governance and the failure of the SEAC and SEIAA to perform their duty has resulted in the project escaping scrutiny and appraisal and the 1st Respondent being rewarded with the impugned clearance.

Re: Public Hearing Not Conducted

43. The averments in para 123-124 of the counter statement of the 1st Respondent are denied as false. As has already been submitted above, prior EC for the Elevated Corridor project ought to have been taken under Clause 7(f) of the Schedule to the 2006 Notification. The only exception

for public consultation under this clause is for expansion of roads and highways which do not involve further acquisition of land. Since this requirement is not satisfied in the instant case, it is submitted that public consultation was indeed mandatory and failure to conduct it vitiates the clearance. By falsely classifying the project as a Clause 8(b) project, the 1st Respondent is attempting to escape the requirement of subjecting the project to public scrutiny.

44. The averments at para 125 of the counter statement of the 1st Respondent are denied as false. The 1st Respondent is attempting to mislead the Hon'ble Tribunal by misrepresenting the argument of the Appellants. Indeed, the 1st Respondent has admitted at para 108 of the counter statement that the Appellants have argued that the alignments given under the DFR are 'interim alignments'. The averment at para 110 of the appeal that the basis for alignment has not been stated has to be read in conjunction with the rest of the appeal to refer to the 'interim' alignments proposed for the project. At no point have the Appellants argued that the project does not have any alignment at all; the Appellants argue that the failure to finalise the interim alignment and to complete issuance of notifications for land acquisition before applying for prior EC make the application for EC premature and vitiate the clearance. Thus, there is no question of any contradiction in the submissions made by the Appellants in this respect.

Unscientific Proposal of Open-Air Air Purifiers

45. Furthermore, it is submitted that the 1st Respondent cannot shake off the responsibility to back up its technological interventions for air pollution mitigation (in this case air purifiers) with scientific evidence by shifting the burden onto the Appellants to prove that the said intervention is unscientific. In any event, the Appellants are submitting literature which indicates the absence of scientific evidence on the efficacy of

open-air air purifiers and smog towers in air pollution mitigation, annexed herewith at **Annexure A46 colly**.

46. The suggestion in para 126 of the counter statement of the 1st Respondent that the Appellants are trying to misconstrue the DFR are denied as false. The Appellants have submitted in the appeal and above in this rejoinder that there is a contradiction between the submissions of the 1st Respondent regarding the applicable statutory framework. In para 113 of the appeal, the Appellants only sought to bring on record one such instance where there was lack of clarity about the applicable statutory framework.

47. The avernments in para 127 of the counter statement of the 1st Respondent are denied as false. It is submitted that apart from issuing a generic denial, the 1st Respondent has not brought on record any material to dispel the doubts raised about the quality of construction. These doubts have been raised not in the form of media reports speculating about poor quality of construction, but reports about the 1st Respondent's own conduct by guaranteeing the project for a suspiciously short duration of time.

48. It is humbly submitted that the 1st Respondent's argument that the appeal is premature and untenable, and that there is no irregularity or illegality in the issuance of the impugned clearance, is not only grossly contrary to the jurisprudence laid down by the Hon'ble Apex Court and this Hon'ble Tribunal, but also strains against the law of the land and all canons of common sense. The averments in para 129 to 130 of the counter statement of the 1st Respondent are hereby denied.

It is therefore prayed that this Hon'ble Tribunal be pleased to allow the appeal as prayed and thus render justice.

Bhargavi S. Rao

ENVIRONMENT SUPPORT GROUP®

Appellants

VERIFICATION

We, Bhargavi S. Rao, Trustee of the 1st appellant herein, and Leo F. Saldanha, 2nd appellant, do hereby verify that the contents of the above paragraphs are true to the best of our knowledge, that the grounds are based on legal advice, and that we have not suppressed any material fact.

Date: 14.12.2021

Place: Bengaluru

Bhargavi S. Rao

Signature of the 1st appellant

Signature of Bhargavi S. Rao & Leo F. Saldanha

ATTESTED BY ME

H.G. PADMANABHA RAO
ADVOCATE & NOTARY PUBLIC
GOVERNMENT OF INDIA
Apt. F2, Rashmi Enclave,
22nd Main, Padmanabha Nagar
BANGALORE - 560 070

14 DEC 2021

ENVIRONMENT SUPPORT GROUP®

Signature of the 2nd appellant

NOTARY GOVT. OF INDIA
H.G. PADMANABHA RAO Reg. No. 12454 Padmanabha Nagar, Bangalore Exp. 08.01.2022

Environmental Social
Justice
&
Governance Initiatives

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Email: esg@esgindia.org
Web: www.esgindia.org

01 July 2021

Annexure A37 colly

Resolution of Environment Support Group

ESG Trust in a meeting held today, online due to COVID travel restrictions, resolved as follows:

1. The Trust deeply grieves the untimely passing away of its Trustee Dr. Shirdi Prasad Tekur on 16th May 2021.
2. In continuing with the operations of the Trust, such as operating of ESG's bank accounts (including operating them via internet banking facilities), any financial transactions and for attending to legal matters, the Trust herewith designates the following Trustees, whose signatures are affixed here below, in conformance with the Deed of Trust:

Mr. Leo F. Saldanha

Ms. Bhargavi S. Rao

The undersigned Trustees affix their signatures in approval of this Resolution.

Robert John Chandran

Joe Athialy

Suprabha Seshan

Bhargavi S. Rao

Leo F. Saldanha

ENVIRONMENT SUPPORT GROUP

ESG is a Public Charitable Trust with clearance per Foreign Contribution Regulation Act and eligible for tax exemptions per Sec. 80G and 12A of the Indian Income Tax Act.

ನಂ. ಬಿ.ಬಿ.ಎಂ.ಪಿ.
No. B.B.M.P. 1302910

ನಮೂನೆ – 6
Form - 6

Government of India
ಕರ್ನಾಟಕ ಸರ್ಕಾರ
GOVERNMENT OF KARNATAKA
ಜನನ ಮತ್ತು ಮರಣಗಳ ಮುಖ್ಯ ರಿಜಿಸ್ಟ್ರಾರರು
Chief Registrar of Births and Deaths

ಮರಣ ಪ್ರಮಾಣ ಪತ್ರ

(ಜ.ಮ.ಸೋ ಅಧಿನಿಯಮ, 1969ರ 12/17ನೆಯ ಪ್ರಕರಣ ಹಾಗೂ ಕ.ಜ.ಮ.ಸೋ. ನಿಯಮಗಳು 1999ರ ನಿಯಮ 8/13ರ ಮೇರೆಗೆ ಕೊಡಲಾದ)

DEATH CERTIFICATE

(Issued Under Section 12/17 of the RBD Act, 1969 and Rule 8/13 of the KRBD Rules, 1999)

ಈ ಕೆಳಕಂಡ ವಿವರಣೆಯನ್ನು ಕರ್ನಾಟಕ ರಾಜ್ಯದ ಬೆಂಗಳೂರು ಜಿಲ್ಲೆಯ ತಾಲ್ಲೂಕಿನ ಬಿ.ಬಿ.ಎಂ.ಪಿ (ಗ್ರಾಮ/ಪಟ್ಟಣ)ದ ರಿಜಿಸ್ಟರಿನಲ್ಲಿರುವ ಮರಣ ಸಂಬಂಧವಾದ ಮೂಲ ದಾಖಲೆಯಿಂದ ತೆಗೆದುಕೊಳ್ಳಲಾಗಿದೆಯೆಂದ ಪ್ರಮಾಣೀಕರಿಸಲಾಗಿದ

This is to certify that the following information has been taken from the original record of death which is the register for **BBMP** (village/town) of **Bengaluru district of Karnataka State**

1) ಹೆಸರು		*2) ಲಿಂಗ*	ಗಂಡು
Name	DR SHIRDI PRASAD TEKUR	*Sex*	Male
3) ಮರಣದ ದಿನಾಂಕ	16/05/2021	*4) ಮರಣದ ಸ್ಥಳ*	
Date of Death		*Place of Death*	*ST JOHNS MEDICAL COLLEGE HOSPITAL, BBMP,,Bengaluru,Karnataka*
5) ತಾಯಿಯ ಹೆಸರು		*6) ತಂದೆಯ ಹೆಸರು*	
Name of Mother	KAMALA TEKUR	*Name of the Father*	S M TEKUR
7) ಗಂಡನ / ಹೆಂಡತಿಯ ಹೆಸರು			
Name of the Husband/Wife	B V VIMALA		
8) ಮರಣದ ಸಮಯದಲ್ಲಿ ಮೃತರ ವಿಳಾಸ:	ಬಿ.ಬಿ.ಎಂ.ಪಿ, , ಬೆಂಗಳೂರು, ಕರ್ನಾಟಕ 560109	*9) ಮೃತರ ಖಾಯಂ ವಿಳಾಸ*	ಬಿ.ಬಿ.ಎಂ.ಪಿ, , ಬೆಂಗಳೂರು, ಕರ್ನಾಟಕ 560109
Address of deceased at the time of death:	BONITAS CANDOR, 1ST MAIN ROAD JUDICIAL LAYOUT , 2ND PHASE OFF KANAKAPURA MAIN ROAD, BBMP,,Bengaluru,Karnataka 560109	*Permanent address of the deceased:*	BONITAS CANDOR, 1ST MAIN ROAD JUDICIAL LAYOUT , 2ND PHASE OFF KANAKAPURA MAIN ROAD, BBMP,,Bengaluru,Karnataka 560109
10) ನೋಂದಣಿ ಸಂಖ್ಯೆ:	**803162/B/D/2021/036747**	*11) ನೋಂದಣಿ ದಿನಾಂಕ*	21/05/2021
Registration No.:		*Date of Registration:*	
12) ಪರಾ(ಯಾವುದಾದರು ಇದ್ದಲ್ಲಿ)		*13) ಅನುಮೋದನೆಯ ದಿನಾಂಕ*	28/05/2021
Remarks(if any)	.....	*Date of Approval*	
14) ಪ್ರಮಾಣ ಪತ್ರ ಕೊಡುವ ಪ್ರಾಧಿಕಾರಿಯ ಸಹಿ		*15) ಪ್ರಮಾಣ ಪತ್ರ ಕೊಡುವ ಪ್ರಾಧಿಕಾರಿಯ ವಿಳಾಸ*	
Signature of Issuing Authority		*Address of the issuing authority Medical Officer*	BTM LAYOUT, Bengaluru District
		Date of Issue	28/05/2021

"ಪ್ರತಿಯೊಂದು ಜನನ ಮತ್ತು ಮರಣದ ನೋಂದಣಿಯನ್ನು ವಿಚಿತಪಡಿಸಿಕೊಳ್ಳಿ"
ಈ ಪ್ರತಿಯಲ್ಲಿ ನಮೂದಾದ ವೈಕ್ತಿಯಲ್ಲಿ ಮರಣದ ಕಾರಣಗಳ ಬಗ್ಗೆ ಬಹಿರಂಗಗೊಳಿಸುವಂತಿಲ್ಲ. ಪ್ರಕರಣ 17(1)ರ ಪರಂತುಕ ನೋಡಿ

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NOTARY
H.S. DHARMA PRASAD
Bangalore City
Karnataka
Reg. No. 12281
Exp: 25-12-2021
GOVT OF INDIA

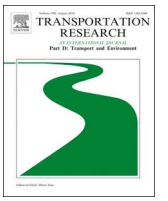
Transportation Research Part D 69 (2019) 90–106



Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd



Effects of urban road capacity expansion – Experiences from two Norwegian cases



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ARTICLE INFO

Keywords:
Road capacity expansion
Land-use effects
Induced traffic
Congestion
Urban areas
Planning

ABSTRACT

This article presents nuanced and context-related empirical research on the traffic-inducing effects of urban road capacity expansion two Norwegian cities. It focusses on the indirect and long-term land-use effects and on land-use planning and policies, that are not well covered in existing literature. Unsurprisingly, results show traffic-inducing land-use development in the period after the road capacity expansions. Differences in planning policy and practices affected how traffic-inducing the land-use development was. The traffic growth was stronger in the affected road corridors than expected, and as compared with Norway. No or only short-term congestion relief was found. It is concluded that the road capacity expansions were necessary conditions for the land-use sprawl, and consequently, contributing causes for the traffic growth. Ex-ante analyses seem not to have included the land-use effects, and this is understood as part of the explanation for the discrepancies between ex-ante expectations and actual development. In both cases, municipal and regional authorities currently attempt to steer land use development in directions contributing to stop traffic growth, in accordance with national policies. Meanwhile, road authorities plan for new capacity expansions in the investigated corridors. Land use effects of the capacity expansions seem, again, not to be included in the assessments.

1. Introduction

Reducing traffic growth and greenhouse gas (GHG) emissions from transport are long-held objectives in many countries and cities, but they have proven to be difficult to achieve (European Environment Agency, 2018; European Commission, 2011; Owens and Cowell, 2002; Norwegian Environment Agency, 2015; UN Habitat, 2013). These objectives are also high on the agenda in the Norwegian Parliament's climate agreement and the National Transport Plan, as well as in many regional and municipal plans. According to these policy documents, increasing transport demands caused by the rapid population growth in Norwegian urban regions should not cause growth in road-traffic volumes, and this is often termed the *zero-growth objective* (Ministry of Local Government and Modernisation, 2012, Ministry of Transport and Communications, 2013, 2017). Other motivations for zero-growth than reducing GHG emissions are improving urban transport efficiency, liveability, public health and the local environment, as well as reducing congestion and the need for infrastructure investments.

Achieving the zero-growth objective, as the population in the urban region grows, requires that the average inhabitant reduces his or her average daily traffic volume by making fewer trips, shorter trips and/or a lower share of trips as a car driver. A main strategy for achieving this is developing land-use and transport systems in directions contributing to reduced transport demand and shifts in the modal split toward less car usage (Ministry of Local Government and Modernisation, 2015). This strategy largely leans on

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https://doi.org/10.1016/j.trd.2019.01.024

Available online 05 February 2019
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theoretical and empirical knowledge concerning how and why the spatial structure (Hurlimann and March, 2012; Newman and Kenworthy, 1989, 2015; Næss, 2012; Næss et al., in press; Rode et al., 2017), as well as absolute and relative qualities of the transport-systems (Cairns et al., 2001; Downs, 1962, 2004; Fishman et al., 2014; Litman, 2018; Noland and Lem, 2002; Walker, 2012), affect travel behaviour and traffic volumes. Based on such insights, there seems to be a relatively widespread agreement on how land-use and transport systems ought to be developed to reduce or delimit urban road-traffic volumes: (i) land-use development as central, urban densification and transformation rather than sprawl; (ii) improving public transport services and conditions for walking and bicycling; (iii) physical and fiscal restrictions on private car traffic (see, for instance, Downs, 2004; Banister, 2008; Newman and Kenworthy, 2015; Rode et al., 2017; Tennøy, 2012). This understanding also includes that expanding road capacity in pressured urban road systems has traffic-inducing effects and contribute to traffic growth that would otherwise not occurred (as we discuss below).

It is an interesting paradox that road capacity expansions currently are planned and constructed in cities across Norway, despite the strong focus on the zero-growth objective, and that Norwegian planners know about the traffic-inducing effects of road capacity expansions (Tennøy, 2010, 2012). Previous research has found that this among other things can be explained by fragmented organization and the power distribution in land-use and transport planning and policy, combined with goal conflicts (e.g. Flyvbjerg, 1998; Bryson et al., 2015; Hull, 2008; Stead and Meijers, 2009; Tennøy and Øksenholt, 2018; Tønnesen, 2015), and deficiencies of transport model and cost benefit analyses (see e.g. Flyvbjerg et al., 2005; Litman, 2018; Metz, 2017; Cervero, 2003; Næss et al., 2012; Nicolaisen and Næss, 2015; Tennøy et al., 2006), which are not in focus here. Another strand of research suggest that the ways planners acquire and use knowledge when making plans, could be part of the explanation (Krizek et al., 2009; Næss et al., 2013; Tennøy et al., 2016). Tennøy (2012) found that even though planners *knew of*, for instance, mechanisms involved in induced traffic, few knew and understood this deep and well enough to use the knowledge in planning and tough discussions, or to explain the complex and often counter-intuitive interrelations between transport systems development, land-use, travel behaviour, traffic volumes and congestion to political decision makers and others. Planners seldom read up on research-based knowledge, and they explained that this was partly due to lack of what they perceived as understandable, relevant and applicable research and documentation. Previous studies on induced traffic mainly rely on aggregated statistical analyses or modelling (see, e.g. Noland and Lem, 2002 or Litman, 2018 for reviews), that are not necessarily easily accessible or useful in planning practice and policy making. Further, few previous studies include land-use effects of capacity expansions. As a result, this knowledge is often ousted or disregarded in planning and decision-making processes (Næss et al., 2013; Tennøy, 2012; Tennøy et al., 2016), as also found in recent analyses and plans relevant in this article (National Public Roads Administration (NPRA), 2013a, 2013b, 2016a).

The aim of this article is to contribute to existing literature with more nuanced and context-related empirical investigations of traffic inducing effects of road capacity expansions in pressured urban road systems, focusing on the less researched land-use effects, and including reflections on how differences in land-use planning and policy affect interrelations and development. Through analyses of longitudinal empirical data in two cases of urban road capacity expansions, as well as document studies and interviews with relevant practitioners, we present more disaggregated analyses of the mechanisms involved than most previous studies have done. We think our analyses and findings also have the potential to inform practitioners and policymakers about how road capacity expansions affect land-use, travel behaviour, and traffic, as well as the implications for land-use and transport planning if sustainability goals are to be achieved, possibly resulting in these mechanisms being more consciously addressed in future analyses and plans. We also discuss alternative policy responses to congestion and perceived demand for road capacity expansions, based on findings concerning current planning and ideas in the case cities.

We seek to answer the following research questions: *How have urban road capacity expansions affected land-use development, consequently affecting traffic volumes and congestion levels, in the cases? How have land-use planning and policy affected the land-use effects of road capacity expansions? How do road capacity expansions affect the potential to stop traffic growth in urban areas?*

The article is organised as follows: Section 2 presents the theoretical understandings forming the basis for the empirical investigations and analyses, while Section 3 delineates the research design, methods, data, and the main challenges experienced. Section 4 describes the two cases and results. The main conclusions are presented in Section 5, followed by a discussion of the significance of the results.

2. How urban road capacity expansions affect traffic volumes

Previous research has presented explanations and evidence on how road capacity expansions in pressured urban road systems induce traffic, and contribute to traffic growth that would otherwise not have occurred (see, e.g. Cairns et al., 2001; Cervero, 2003; Committee on Trunk Road Assessments, 1994; Downs, 1962, 2004; Duranton and Turner, 2011, Goodwin, 1996; Litman, 2018; McCoy and Stephens, 2014; Mogridge, 1997; Noland and Lem, 2002). This is understood as being the result of combined mechanisms, working at different time scales, where the interactions between land-use development, transport-systems development and travel behaviour play important roles.

Direct mechanisms, which may be *activated almost immediately* and often strengthened later on, are modal shifts from other modes to cars when travelling by car becomes relatively faster, more comfortable and so on compared with other modes of transport, and longer car journeys as time and cost of travel per km are reduced. These mechanisms are well understood and documented (see, e.g. Cairns et al., 2001; Committee on Trunk Road Assessments, 1994; Downs, 1962; Goodwin, 1996; Mogridge, 1997; Noland and Lem, 2002; Twitchett, 2013), so we do not focus on them. Instead, we focus on the less investigated *indirect land-use mechanisms*, working in a *longer time perspective.* As illustrated in Fig. 1, these include that road capacity expansions in congested urban road systems result in reduced travel time by car, triggering relocations of households and businesses in existing built structures in more transport-

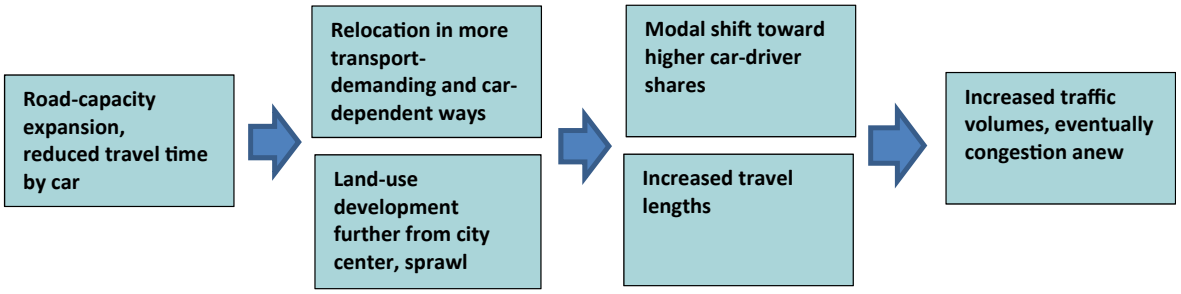


Fig. 1. Illustration of mechanisms involved when urban road capacity expansions cause more transport-demanding and car-dependent land-use development, resulting in higher car shares, longer journeys and increased traffic volumes per capita and in total.

demanding and car-dependent ways, as well as increased pressure on developing housing, workplaces, retail and so on at the outskirts of cities and urban regions (Cervero, 2003; Downs, 2004; Noland and Lem, 2002; Wägener and Fürst, 2004). This is a development toward more sprawled and car-dependent urban areas, causing modal shifts towards higher car-driver shares and increased travel lengths, and consequently to increased traffic volumes (vehicle kilometres, vhkm) per capita and in total (Næss et al., in press; Newman and Kenworthy, 2015).

In urban areas with high potential for sprawl, these processes continue until traffic growth causes renewed congestion, reducing the attractiveness of development in the more peripheral urban areas and making the private car less competitive as a mode of transport. This is also a situation where there are more people 'stuck in traffic' than there were before (Downs, 2004), an urban structure that is harder to serve by other modes than cars and a perceived demand for road capacity expansions or other infrastructure investments to ease congestion and improve accessibility.

How the mechanisms play out depends on land-use planning and policy. To a large extent, land-use development is steered by public authorities, in Norway as in most European countries, although the market decides what is built and when within the limitations of the plans decided by the authorities (Nadin et al., 2018; Owens and Cowell, 2002; Tennøy and Øksenholt, 2018). The land-use effects of road capacity expansions will hence be influenced by public land-use planning and policies. If planning authorities limit growth in peripheral urban areas and steer land-use development toward dense structures in areas with good access to daily services and competitive public transport accessibility, the traffic-inducing effects of road capacity expansions are expected to be weaker than if planning authorities allow strong, sprawled and car-dependent land-use development in peripheral urban areas. We investigate land-use planning and policies, as well as how these affected development, in our cases.

Diverted traffic, that is, shifts in timing and routes, may increase traffic volumes on expanded roads and concentrate more traffic to rush hours, contributing to increase congestion without being induced traffic (Downs, 2004). Other mechanisms, such as changes in economy, demography and road tolling, also affect traffic volumes (see, e.g. Downs, 2004; Noland and Lem, 2002), but we do not focus on these mechanisms in our study.

3. Research design, methodology and data

The research questions, together with the multi-causal nature of the problem, and our focus on investigating the mechanisms involved, call for in-depth case studies, longitudinal studies and a mixed-methods approach (Yin, 2003). We selected two cases of urban road capacity expansions in pressured urban road systems for our study. One is located in the medium-sized city (in a Norwegian context) of Ålesund, with 46 000 inhabitants, which is the main city in its region. The other is located in the Norwegian capital, Oslo, with about 700 000 inhabitants in the municipality and about 1 000 000 inhabitants in the city region. In aspects other than city size, the cases share similarities: The roads are located in the outer parts of the cities and reducing congestion and traffic on parallel roads were important motivations for constructing them. Thus, they could be understood as the same *type* of road capacity expansions. Our aims were to investigate how the mechanisms studied act out in these different contexts, as well as how conditions related to land-use planning and policies affect this. We were also inspired to include a case in a medium-sized city because we knew that that research in and on small and medium-sized cities is scarce. Due to differences in city size, the Ålesund case is analysed at the city level, while the Oslo case is considered at the regional level.

The road constructions were completed in 2002 (Ålesund) and 2009 (Oslo), which we expected would be far enough back in time for studying the long-term and indirect land-use effects of road capacity expansions, and at the same time, recent enough to allow access to data before, during and after the road capacity expansions and for doing longitudinal analyses. The effects of the mechanisms discussed in Section 2 were empirically investigated and analysed in each case, using multiple qualitative and quantitative data sources and methods, before they were compared in an analytical discussion.

The main data sources were register data of various kinds, documents and interviews. *Documents*, mainly plans and analyses related to the road projects, municipal and regional master plans, and 13 semi-structured *interviews* with knowledgeable practitioners (eight in the Ålesund case and six in the Oslo case; see list of interviewees in Appendix A and interview guide in Appendix B), provided data concerning motivations for the road projects and the context in which they were implemented. These sources were also important when describing land-use planning regimes and practices in relevant municipalities before and after the road capacity expansions, as well as how the current situation is perceived. *Traffic data* from the Norwegian National Road Administration (NPRA)

were used for analysing changes in traffic volumes and congestion levels. *National Travel Survey data*, comprising reports from about 60 000 persons nationwide, were used in analyses of changes in modal splits (Hjorthol et al., 2014). *Register-based commuting statistics* at the census tract level from Statistics Norway (SN, 2016) were used in analyses of changes in commuting distances, and all commutes shorter than 200 km were included. The commuting statistics included all commutes, regardless of transport mode. *Geo-coded data* from the Central register of enterprises (SN, 2017a), including all units in Norway with economic activity, were used when analysing the number of workplaces in different areas, while *population statistics* (SN, 2017b) were employed when analysing population development.

The main challenges in this study were data availability and to clearly define whether the identified changes were effects of the road capacity expansions. Data from SN (2016, 2017a, 2017b) were available only back to 2001, 2002 and 2002 respectively, meaning that we could not identify potential significant changes in trends caused by the capacity expansions. Several of the interviewees were active when the plans for road capacity expansions were made, but this was a long time ago, so they could not answer all our questions in detail. The other interviewees were not involved at the time, but they could answer questions concerning policy and development after the road capacity expansions. For both cases, establishing reliable reference cases, preferably other road corridors in the same cities, proved difficult, mainly because potentially comparable corridors were affected by the road project and/or other major changes. We decided to use the general development in Norway as reference, to rule out potential significant effects of changes in national economy, taxes, regulations, and the like on traffic and land-use development. In the analyses, distinguishing clearly between the causal effects of the road capacity expansions and effects of 'other things going on' is problematic. This is a recurrent problem when studying interrelations between land-use development, development of transport-systems, travel behaviour and traffic volumes, since they are influenced by each other and other factors of different kinds. The need for longitudinal studies to capture the long-term and indirect mechanisms, often going decades back in time, enhances this problem. These challenges reduce the precision and strength of our findings. We still find that the study provides novel, interesting and more nuanced insights into mechanisms that have not been well covered in previous research, which is also relevant for researchers and practitioners striving to facilitate sustainable urban mobility.

4. Results

4.1. The Ålesund case

4.1.1. Case description

The Ålesund case involves a road capacity expansion at the outer parts of the city. A two-lane tunnel was built in 2002, in parallel to the existing two-lane road (E39) linking the city to its hinterland, thereby increasing the capacity from two to four lanes. In addition to the road tunnel that is our case, the road system in the nearby 'Moa area' was upgraded and improved, with a short tunnel, several roundabouts and pedestrian crossings. The projects were expected to reduce severe rush hour congestions expected to worsen due to population and traffic growth; reducing traffic on the existing road; and facilitating housing and retail development (Ålesund Municipality, 1993, 2001). It was thought that the planned new road system would have substantial capacity reserves for handling future traffic growth. 30% traffic growth was used in the calculations, but the documents available do not mention which year this

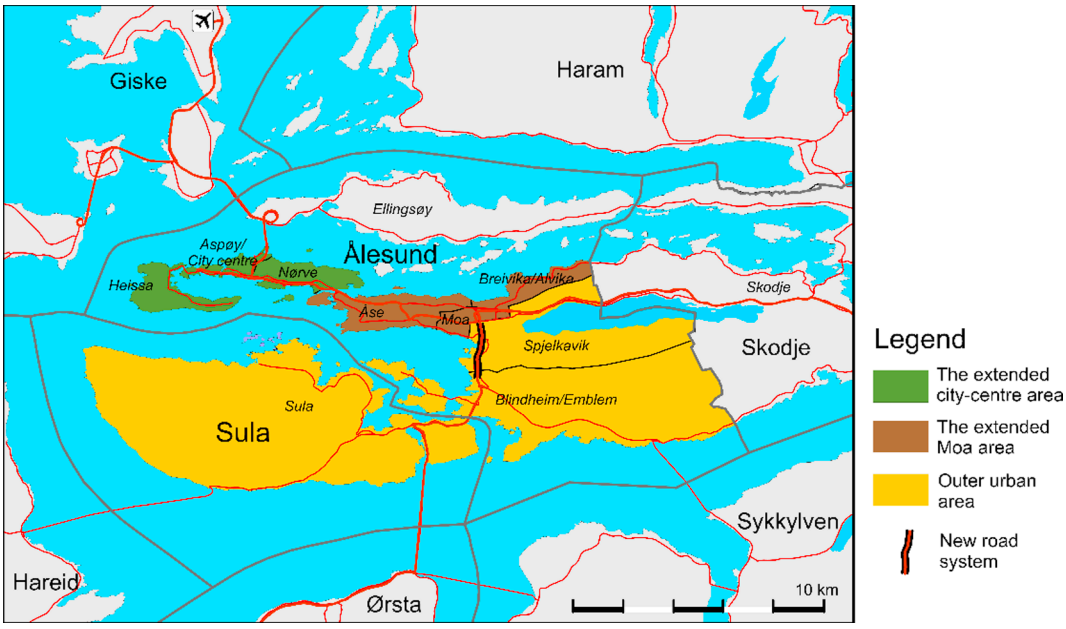


Fig. 2. Ålesund case. Overview, zones and location of the new tunnel.

Table 1
Population within geographic zones.
Source: Statistics Norway (2017b).

Area	Population 2002	Population 2009	Population 2016	Changes 2002–2009	Changes 2009–2016	Changes 2002–2016	Change (%) 2002–2016
Extended city centre area	15 268	15 844	17 218	576	1374	1950	12.8
Extended Moa area	11 027	11 759	12 892	732	1133	1865	16.9
Outer urban area	18 329	20 446	22 862	2117	2416	4533	24.7
Ålesund area total	44 624	48 049	52 972	3425	4923	8348	18.7
Norway total							15.2

refers to.

When analysing this case, we compared three main geographical zones, as illustrated in Fig. 2. The *outer urban area* is located upstream from the main bottleneck in the road system in the 'before' situation, and it was expected to benefit the most from the road capacity expansion. The *extended Moa area* was expected to benefit from improvements in the transport system in the Moa area, while, the *extended city centre area* was not expected to benefit directly from these projects.

4.1.2. Land-use development, planning and policy

When analysing land-use development in Ålesund from 2002 to 2016, we find a clear sprawling tendency, with higher percentages of inhabitants living in areas located farther from the main city centre in the 'after' than in the 'before' situation. The relative population growth is weakest in the extended city centre area and strongest in the outer urban area (see Table 1). 67% of the new housing units built in the period 2007–2017 were detached houses and rowhouses, while 33% were flats in apartment buildings (SN, 2018a).

We find similar tendencies when analysing the location of workplaces. The extended city centre area experienced far less growth than the other areas did in the period of 2002–2016 (see Table 2). The growth was strongest in the extended Moa area. The outer urban area also experienced a strong growth in number of jobs. As a result, the percentage of workplaces located in the extended city centre area decreased from 48% in 2002 to 41% in 2016. Further, retail studies revealed a strong increase in the Moa area's share of turnover, and a clear decrease in the city centre, between 2004 and 2012 (Dalen and Lynum, 2014). Moa has grown to become the third largest shopping-destination in Norway (NPRA, 2013a).

The statistics above describe a situation with a strong growth in population and workplaces at the outskirts of the urban area in the period after completion of the road capacity expansion, and most housing is built with rather low densities (detached houses and rowhouses), which we understand as a sprawling tendency. There are clear indications of causal relations between the road capacity expansion and the land-use development. Facilitating growth in the extended Moa area and the outer urban area was an argument for constructing the new tunnel, and increased pressure for constructing new housing in these areas was expected (Ålesund Municipality, 2001). This understanding is confirmed by the interviewees (planning authorities and developer), describing a 'before' situation where road authorities would make formal complaints if developers or municipal authorities suggested developments that would worsen congestion, while this was no longer an issue after the capacity expansion. The interviewees stated that the changed traffic situation, together with the shifts in location patterns, also seems to have triggered a trend of relocating offices from the city centre to an area adjacent to Moa, mainly to buildings previously used for other activities.

The interviews with planning authorities and the developer confirm that there has been a strong, steady pressure for constructing new housing and workplaces in the extended Moa area and the outer urban area in the period after the road capacity expansion. Planning authorities have not restricted this development or steered it in directions contributing to keep transport demand and car dependency low. In the interviews, the developers claim that lack of suitable building sites and high property prices in central urban areas left them no alternatives for large developments than the outer urban areas, and politicians wanted to facilitate population growth. Some of the land-use changes were not planned or expected, as in the relocation of offices from the city centre. The strong growth in work-places in the outer urban area was not mentioned in the municipal plans, and the figures suggested for expected population growth were more modest than shown by our data.

Table 2
Number of workplaces within geographic zones.
Source: Statistics Norway (2017a).

Area	Employees 2002	Employees 2009	Employees 2016	Change 2002–2009	Change 2009–2016	Change 2002–2016	Change (%) 2002–2016
Extended city centre area	11 218	11 667	11 795	450	128	578	5.1
Extended Moa area	5949	7393	8722	1444	1329	2773	46.6
Outer urban area	5980	7833	8144	1854	311	2164	36.2
Ålesund area, total	23 146	26 893	28 662	3748	1768	5516	23.8
Norway							14.2

Table 3
Car-driver shares (%) on all trips and work trips made by people living in the Ålesund area (the municipalities of Ålesund and Sula) and in Norway. N for the Ålesund survey, all trips: 2001;719, 2005; 704, 2009; 1061, 2013/14; 2225.
Source: National Travel Survey (Hjorthol et al., 2014).

Car-driver shares	2001	2005	2009	2013/14
All trips				
Ålesund-area	54.0%	57.9%	48.2%	60.9%
Norway	52.5%	54.2%	51.5%	54.4%
Work trips				
Ålesund area	68.8%	63.2%	58.6%	69.2%
Norway	62.9%	65.4%	61.3%	61.2%

4.1.3. Changes in travel behaviour

According to theory, the sprawling land-use development described above is expected to result in higher car-driver shares and longer travels. Data from the National Travel Survey show that the share of trips completed as car drivers in the Ålesund area increased from 2001 to 2013/14, with a stronger increase for all trips than for work trips (see Table 3). Compared with figures for Norway, Ålesund has had a stronger growth in shares of trips done as car drivers. There are surprisingly large variations from year to year, making us suspect uncertainties in the results, especially for 2009.

When analysing commuting statistics from SN, we find a 19% (1.7 km) increase in the average commuting distance from 2001 to 2017 for people living in the Ålesund area (see Table 4). This is a strong increase when compared to the average for all commutes in Norway (0.5 km, 3.6% increase). The increase in commuting distance was strongest on commutes done by those living in the extended city centre and weakest among those living in the outer urban area. One explanation for this could be the strong growth in the number of workplaces in the extended Moa area and the outer urban area, if more people living in the extended city centre now work at workplaces in those areas.

Analyses of commuting distances to workplaces located in the Ålesund area show a far smaller increase in average commuting distance in the period 2001–2015 (0.1 km, 0.5% increase; see Table 5). This is lower than that in Norway in the same period. The average commuting distance to jobs located in the extended city centre area was reduced in the period, while there was a strong growth in commuting distance to jobs located in the outer urban area. This could indicate that workplaces attracting employees from the larger city region have relocated away from the city centre to other areas. The difference in changes in commuting distances when focussing on the location of jobs and on where inhabitants live probably indicates that more people living in the Ålesund area commute to workplaces located outside our study area than did before.

4.1.4. Traffic volumes and congestion levels

Knowing the development as described above, it comes as no surprise that there has been a steady traffic growth in the area. Focussing on the road capacity expansion that is our case, traffic data from the NPRA (2016b, 2017) show a steady increase in total traffic volumes (on the new and the existing road) from about annual average daily traffic (AADT) 18 400 vehicles per day in 1998 (existing road only) to about 28 100 in 2016 (53% in total for both roads; see Fig. 3). In comparison, road passenger transport (vhkm) in Norway increased by 30% from 1998 to 2016 (SN, 2018b). Traffic on the existing road was reduced from about AADT 18 400 vehicles per day in 1998 to about 6700 in 2016 (64%), meaning that the local road has been relieved from through traffic, as planned. The 53% traffic growth in the corridor is considerably stronger than the 30% suggested in planning documents from Ålesund Municipality (1993, 2001). The planning documents did not specify which year they anticipated that traffic would have grown to 30% (about AADT 24 000). Fig. 3 shows that traffic had grown to this level around 2008, only six years after the new tunnel was opened, which we understand as sooner than expected.

We do not have data for congestion levels before the new road was built, but the interviewees and documents describe a situation with what was perceived as severe congestion problems (Ålesund Municipality, 1993). The congestion could last for more than an hour, especially when driving from the areas upstream of the tunnel toward the city centre in the morning rush. The interviewees stated that, in the first period after the road capacity expansion, congestion and delays were substantially reduced, almost down to zero, before the congestion slowly returned. Measures of congestion levels in 2012 show some delays in the section including the new tunnel in the morning rush hours going toward the city centre (average speed, 29–37 km/h compared with the 60–70 km/h speed

Table 4
Average commuting distances (km) for inhabitants living in different geographic zones in the Ålesund area (one way).
Source: Statistics Norway (2016).

Area	2001	2008	2015	Changes 2001–2008	Changes 2008–2015	Changes 2001–2015	Change (%) 2001–2015
Extended city centre area	8.1	10.2	11.0	2.1	0.8	2.9	35.1
Extended Moa area	7.9	8.7	9.3	0.8	0.5	1.3	16.5
Outer urban area	11.0	11.3	12.0	0.3	0.7	1.1	9.6
Ålesund area total	9.3	10.3	11.0	1.0	0.7	1.7	19.0
Norway	14.6	15.5	15.2	0.9	–0.3	0.5	3.6

Table 5
Average commuting distances (km) for employees to jobs located in different geographic zones (one way).
Source: Statistics Norway (2016).

Area	2001	2008	2015	Changes 2001–2008	Changes 2008–2015	Changes 2001–2015	Change (%) 2001–2015
Extended city centre area	15.0	14.0	14.2	−1.1	0.2	−0.9	−5.7
Extended Moa area	12.9	12.9	13.4	0.0	0.5	0.5	3.6
Outer urban area	10.2	11.4	12.1	1.3	0.6	1.9	18.6
Ålesund area total	13.3	12.9	13.3	−0.3	0.4	0.1	0.5
Norway	14.6	15.5	15.2	0.9	−0.3	0.5	3.6

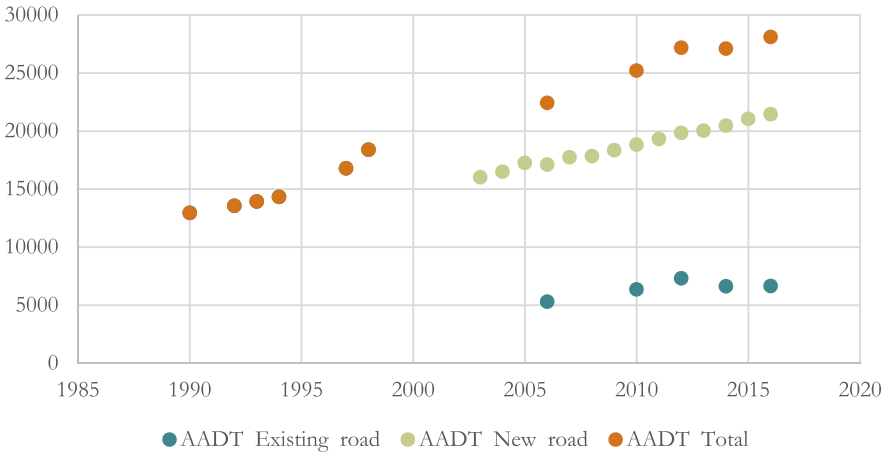


Fig. 3. Annual average daily traffic (AADT) in the existing road, the new road, and in total for both roads. All available data are presented in the figure. The new tunnel was opened in 2002.
Source: Norwegian Public Roads Administration (2016b, 2017).

limit) and in the Moa area (Levin, 2012 for the NPRA). The most severe delays are found closer to the city centre and in the city centre itself. The respondents were mixed in terms of whether this development was anticipated, but they seemed to agree that the congestion returned faster than expected.

4.1.5. Current situation and plans

The current traffic situation is understood as congested, and planning is underway to expand the road capacity with additionally two lanes (NPRA, 2013a). Goals listed in the planning document include, among other things, reducing the share of trips done as car drivers and keeping congestion levels down. The document states that a congestion-free future transport system cannot be expected. The indirect land-use effects discussed in this article are not mentioned in the preliminary impact assessment (NPRA, 2013a). In their 2017 municipal plan, the planning authorities in Ålesund focus on steering future land-use development in directions intended to stop the traffic growth, shift more of the transport to other modes than the private car and increase public transport competitiveness (Ålesund Municipality, 2017). The interviewees reported that it is hard to find ways of solving this, due to the sprawled land-use structure.

4.2. The Oslo case

4.2.1. Case description

The case in Oslo is an expansion of the main road connecting Oslo with its hinterland in south-east and south-eastern parts of Norway, as well as Sweden and Europe (E6). The road between Sweden and Norway was expanded and improved over a longer time. The last parts, crossing the borders of Oslo municipality, were between Klemetsrud and Assurtjern (7 km; construction period, 2002–2004) and between Assurtjern and Vinterbro (5.5 km; construction period, 2006–2009), see Fig. 4. The road was expanded from two to four/five lanes and upgraded with two-level interchanges. The main arguments for expanding the road capacity can be summarised as: To reduce congestion levels, which were predicted to worsen due to steadily increasing traffic volumes; to improve traffic safety; relieve a parallel road from through traffic; and improve the road connection to Sweden (NPRA, 1998).

The impact assessment calculated with a 30% traffic growth from 2003 to 2025 and assumed specifically that the capacity expansion would not cause induced traffic of significance (NPRA, 1998:102). An analysis by NPRA (2009) concerning further development of the transport system after the road capacity expansions were completed, suggested an 8% growth in inhabitants and a negative growth in number of work places in the Follo area from 2003 to 2015. The impact assessment found that the road capacity expansion would reduce congestion, and predicted significant travel time savings, even though it warned that there would probably

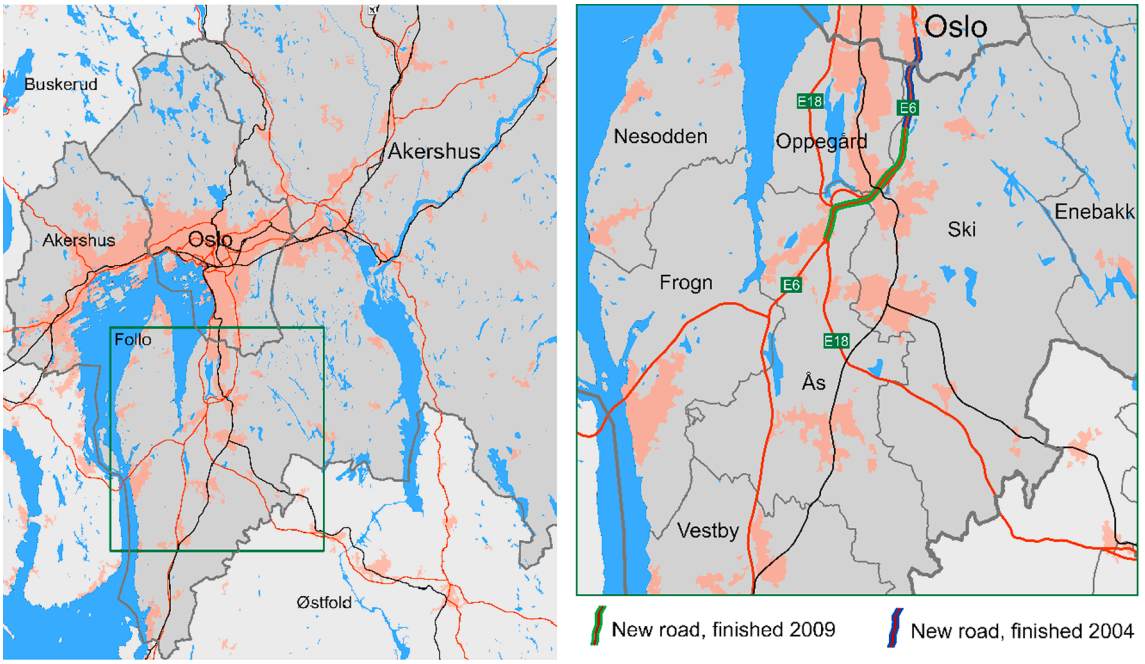


Fig. 4. Oslo case. The left image shows the location of the Follo area in Akershus, while the right image shows municipalities in the Follo area and the location of the road capacity expansions.

still be some delays in the morning rush hours (NPRA, 1998).

When analysing land-use development and changes in travel behaviour, we focus on development in the Follo area (about 125 000 inhabitants), since this area is located upstream of the road capacity expansion and is expected to have benefitted the most from increased accessibility due to the road capacity expansion (see Fig. 4). We study the development in four municipalities in Follo, located at different distances from Oslo city centre. Oppegård is the neighbour municipality, and that closest to Oslo (centre located 15 km from Oslo's city centre), followed by Ski (30 km from Oslo), Ås (40 km from Oslo) and Vestby (43 km from Oslo). We also compare development in the Follo area with development in Akershus County, to which Follo belongs, and in Norway.

4.2.2. Land-use development, planning and policies

When analysing land-use development in the Follo area in the period 2002–2016, we find a strong (21.9%) population growth (see Table 6). The growth is weaker than in Akershus (24.6%) and stronger than in Norway (15.2%). The relative population growth was strongest in the municipalities located furthest from Oslo (Ås and Vestby). We understand this as a sprawling tendency, since a higher percentage of inhabitants in the Follo area lives in areas further from the main city centre in the 'after' than did in the 'before' situation.

The number of new housing units is highest in the two most peripheral municipalities, and the shares of new housing built as flats in apartment buildings decreases with the distance from Oslo (see Table 7).

There has also been a strong growth in the number of workplaces (24.8%) in Follo in the period 2002–2016, which is higher than that in Akershus (18.5%) and throughout Norway (14.2%; see Table 8). Vestby, located furthest from Oslo, had the strongest growth, and almost a doubling of number of jobs.

In sum, these figures draw a picture of strong growth in population and jobs in the Follo area after the road capacity expansions,

Table 6
Population within geographic zones.
Source: Statistics Norway (2017b). The Follo area includes all municipalities in Follo.

Area	2002	2009	2016	Changes 2002–2009	Changes 2009–2016	Changes 2002–2016	Changes (%) 2002–2016
Oppegård	23 152	24 612	26 792	1460	2180	3640	15.7
Ski	25 763	27 699	30 261	1936	2562	4498	17.5
Ås	14 037	15 863	18 992	1826	3129	4955	35.3
Vestby	12 515	14 095	16 732	1580	2637	4217	33.7
Follo area	**113 171**	**123 986**	**137 965**	**10 815**	**13 979**	**24 794**	**21.9**
Akershus	**477 325**	**527 625**	**594 533**	**50 300**	**66 908**	**117 208**	**24.6**
Oslo	512 589	575 475	658 390	62 886	82 915	145 801	28.4
Norway	**4 524 066**	**4 799 248**	**5 213 913**	**275 182**	**414 665**	**689 847**	**15.2**

Table 7
Number of dwellings built in four Follo municipalities in the period 2007–2017, and percentages built as low-density development (detached houses, row-houses, etc.) and high-density development (apartment buildings). Dwellings designated for the elderly, students and so on are excluded. Data from Statistics Norway (2018a). Data only go back to 2007.

Municipality	Number of new dwellings 2007–2017	Share as detached houses and rowhouses (%)	Share in apartment buildings (%)
Oppegård	1350	35.0	65.0
Ski	1258	44.9	55.1
Ås	1702	58.5	41.5
Vestby	1746	63.1	36.9

Table 8
Number of employees at workplaces located within geographic zones.
Source: Statistics Norway (2017a).

Area	2002	2009	2016	Changes 2002–2009	Changes 2009–2016	Changes 2002–2016	Change (%) 2002–2016
Oppegård	9018	9135	8729	117	–406	–289	–3.2
Ski	10 881	13 610	14 235	2730	624	3354	30.8
Ås	6714	7374	8488	660	1115	1774	26.4
Vestby	3619	5056	6743	1437	1687	3124	86.3
Follo area	**39 475**	**45 515**	**49 278**	**6040**	**3763**	**9803**	**24.8**
Akershus	**210 240**	**246 331**	**249 116**	**36 091**	**2785**	**38 876**	**18.5**
Oslo	421 521	436 359	454 006	14 839	17 646	32 485	7.7
Norway	**2 256 948**	**2 514 597**	**2 576 578**	**257 649**	**61 981**	**319 629**	**14.2**

with a stronger growth in the most peripheral parts of the region, and housing development in the outer parts taking place mainly as low-density development (detached houses and rowhouses).

The causal relations between the road capacity expansions and the land-use development are also evident in this case. The main planning documents foresee growth in the number of inhabitants (but not jobs) in the Follo area and increased congestion if the road is not expanded; however, they do not mention the traffic situation as restricting this growth (Oslo Municipality and Akershus County, 1997; NPRA, 1998, 2009). The planning documents reveal a strong awareness of the potential for induced traffic following from the capacity expansion, and they are clear in their recommendations for steering land-use development to areas well served by public transport, especially by railway, to delimit traffic-inducing effects of the road capacity expansion. Still, the impact assessment is specific in stating that land-use development will not be affected by the capacity expansions (NPRA, 1998:102). The municipal master plans state a willingness to steer more of the development toward areas well served by public transport, but they also clarify that they will keep large, car-based development areas in their plans (Oppegård Municipality, 1994; Ås Municipality, 1995; Ski Municipality, 1995).

Interviewees at planning authorities in Oppegård and Ski, located closest to Oslo, claim that the road capacity expansion has not affected land-use planning and development in their municipalities much. They have experienced a high pressure on housing development for a long time, including before the road capacity expansion. They have been restrictive with respect to how much housing they have allowed built because physical and social infrastructure needs to be provided accordingly, among other reasons. Developments has mainly been allowed in and close to already built-up areas and centres with good rail services, often as densification and transformation, and more than before as flats in apartment buildings. An example showing that the road capacity expansion *has* affected land-use development is that Ski defined a large area for workplace development close to the expanded E6, which would not have been established if the road had not been expanded.

The restrictive land-use policy is followed even more strictly today (Oppegård Municipality, 2011, 2016; Ski Municipality, 2011), in accordance with the regional land-use and transport plan (Akershus County and Oslo Municipality, 2015) and developers' demands. Rail services to Oppegård and Ski will substantially improve in a few years, as a new line opens, and developers buy land and properties close to main railway stations since it is believed that these areas will become more attractive and valuable. The municipalities hope the improved rail accessibility will also attract more office- workplaces to their centres.

Planning authority interviewees in Ås and Vestby, located further out in the urban structure, reported a strong relationship between the road capacity expansion and land-use development and policies in their municipalities. A previous summer-cottage area located far from the centre and the railway station in Ås has grown to become the second most populous housing-area in the municipality. According to one interviewee, the road capacity expansion was a necessary condition and strong contributing cause of this. The interviewee in Vestby explained that municipal politicians saw the improved road accessibility as an opportunity for growth and development, and the municipality bought large tracts of land in areas close to the main roads. These areas were clarified for development, awaiting developers and businesses. This was a success, as reflected in the strong growth in the number of workplaces in the municipality, mainly related to logistics and regional retail.

In Ås and Vestby alike, the strong population growth is explained by the high housing and property prices in Oslo, causing especially young families to look for other options, as well as the municipalities' land-use policies. They have facilitated a range of different options with respect to housing development in their municipal plans, often based on proposals from landowners and

Table 9
Shares of trips taken as car drivers (%) of all trips and work trips starting or ending in the Follo area, Akershus in total, Oslo and Norway. N for Follo, all trips – 2001: 1420, 2005: 1253, 2009: 2078, 2013/14: 4525.
Source: National Travel Survey (Hjorthol et al., 2014).

Car-driver shares	2001	2005	2009	2013/14
All trips				
Follo area	58.3%	53.5%	52.5%	54.1%
Akershus total	57.7%	58.0%	57.5%	57.8%
Oslo	37.0%	33.6%	28.1%	29.4%
Norway total	52.5%	54.2%	51.5%	54.4%
Work trips				
Follo area	59.7%	61.0%	62.5%	59.2%
Akershus total	65.2%	69.7%	63.5%	63.1%
Oslo	44.1%	40.4%	32.8%	30.4%
Norway total	62.9%	65.4%	61.3%	61.2%

developers (Ås Municipality, 2017; Vestby Municipality, 2016). As a result, housing has largely been developed as detached houses and rowhouses, often on new land, and not within walking distance of the main railway stations. Both municipalities now aim at shifts in land-use policies, steering more of the growth toward areas in and close to their centres with railway stations, where they plan for several thousand dwellings, mainly as apartment buildings. Vestby is currently in the process of removing several planned housing areas on new land from their municipal plan. Both municipalities consider that the municipal plans in progress will be quite different from the current municipal plans (Ås Municipality, 2017; Vestby Municipality, 2017). The main explanations for these shifts are clear steering signals in the regional plan and demand from developers, who now are almost exclusively interested in developing central areas close to rail stations. Ås and Vestby alike expect that improved rail accessibility will enhance their attractiveness, and they hope to attract more workplaces.

4.2.3. Changes in modal splits and commuting distances

We have seen that there has been strong growth in the numbers of inhabitants and workplaces in the Follo area, especially in the outer areas, and that municipalities have had different policies and practices when it comes to steering land-use development. Hence, it is a bit surprising when data from the National Travel Survey show a decrease in the share of all trips completed as car drivers by people living in the Follo area, from 58.3% in 2001 to 54.1% in 2013/14 (see Table 9). In comparison, the situation was stable in Akershus in the same period, while there was an increase in Norway. The shares of work trips starting or ending in the Follo area carried out as car drivers were stable in the period, as they were in Norway, while the car shares were somewhat reduced in Akershus. The 2013/14 survey had high enough numbers of respondents (all trips) to allow for analyses at the municipal level. These figures show that Vestby had the highest car shares, with 65%, while Oppegård had the lowest, with 49%.

Commuting data show only a small increase in the average commuting distance for people living in the Follo area from 2001 to 2015 (0.3 km, 1.5%; see Table 10). This is lower than in Akershus and in Norway. We find increased commuting distances in the municipalities Ås, Oppegård and Ski, and reduction in Vestby. Commuting lengths increase with increasing distance from Oslo in the 'before' as well as in the 'after' situation.

When analysing commuting distances to workplaces located in the Follo area, we found a strong increase in the period 2001–2015 (3.5 km, 23.1%; see Table 11). This is far stronger than in Akershus and Norway in the same period. The increase in commuting lengths is strongest in Vestby and weakest in Oppegård. Commuting lengths to jobs do not vary much between municipalities.

This leaves us with a somewhat confusing picture of how the land-use development in the Follo area has affected travel behaviour. One explanation for the reduction in shares of car drivers on all trips could be related to the congestion combined with strong improvements of the public transport services since 2001 (PROSAM, 2014). However, we would expect this to have the strongest effects on work trips, in which we do not find a significant reduction. Another explanation could be that land-use development in parts of the Follo area has contributed to densification in ways allowing for higher percentages of the local trips being done by modes

Table 10
Average commuting distances (km) for inhabitants living in different geographic zones in the Oslo area (one way).
Source: Statistics Norway (2016).

Area	2001	2008	2015	Changes 2001–2008	Changes 2008–2015	Changes 2001–2015	Change (%) 2001–2015
Oppegård	15.4	15.7	16.3	0.4	0.6	0.9	6.1
Ski	17.7	17.7	18.4	–0.1	0.7	0.6	3.5
Ås	17.8	19.2	19.5	1.4	0.3	1.8	9.9
Vestby	28.6	26.4	26.8	–2.3	0.4	–1.8	–6.3
Follo area	**21.3**	**21.3**	**21.7**	**0.0**	**0.3**	**0.3**	**1.5**
Akershus	**17.8**	**18.0**	**18.4**	**0.2**	**0.4**	**0.6**	**3.2**
Oslo	8.9	9.3	9.6	0.4	0.3	0.7	7.8
Norway	**14.6**	**15.5**	**15.2**	**0.9**	**–0.3**	**0.5**	**3.6**

Table 11
Average commuting distances (km) to jobs located in different geographic zones (one way).
Source: Statistics Norway (2016).

Area	2001	2008	2015	Changes 2001–2008	Changes 2008–2015	Changes 2001–2015	Change (%) 2001–2015
Oppegård	17.3	17.1	19.3	–0.2	2.2	1.9	11.2
Ski	15.9	17.4	20.2	1.5	2.8	4.2	26.7
Ås	15.9	16.4	19.0	0.6	2.6	3.1	19.8
Vestby	15.8	19.1	21.0	3.2	1.9	5.2	32.7
Follo area	**15.2**	**16.2**	**18.7**	**1.0**	**2.5**	**3.5**	**23.1**
Akershus	**18.4**	**18.3**	**18.8**	**–0.1**	**0.5**	**0.4**	**2.3**
Oslo	20.3	18.6	17.8	–1.7	–0.8	–2.5	–12.4
Norway	**14.6**	**15.5**	**15.2**	**0.9**	**–0.3**	**0.5**	**3.6**

other than the private car.

4.2.4. Traffic volumes and congestion levels

Returning to the road capacity expansion that is our case, and analysing data from the NPRA, we find that total traffic volumes on the expanded and relieved roads (E6 and E18) increased from about AADT 52 300 in 2001, before the first phase of the construction works started, to about 68 000 vehicles per day in 2015 (30%; see Fig. 5). Total traffic volumes were stable in 1999–2003, while they increased by 9% in the period from 2003 (just before the first part of the road project was completed) to 2009 (just before completion of the last part) and 19% in 2009–2015 (after completion of the last part). This growth is stronger than the 30% growth in the period 2003–2025 as predicted in the impact assessment. Traffic on the E18, meant to be relieved from traffic, was reduced from AADT 23 900 in 2001 to 17 300 in 2015 (by 28%), while traffic on the expanded road increased from AADT 28 400 in 2001 to 50 561 in 2015 (by 78%). The total traffic growth in Norway was 22% in the same period (SN, 2018b).

Focussing on congestion levels, speed measuring done for the NPRA on a route starting south of the outermost part of the road-expansion project and ending in Oslo city centre, via E6 and E18, shows that the average speeds on the two roads were about the same or lower in rush hours in 2013 (the last available measurement) compared with 2003 (just before completion of the first part of the road capacity expansion; PROSAM, 2015; see Fig. 6). The average speed in afternoon rush hours increased after completion of the first part of the expansion on E6 and E18 and started to decline shortly after. The data show no increase in average speed after completion of the last part of the expansion. We see the lack of congestion relief on the expanded road as a result of the growth in traffic volumes. The relieved road was reorganised with public transport lanes, lower speed limits and so on, which could partly explain the lack of congestion relief here. We hence have a situation with more traffic congestion in 2013 than in 2003, since there are more cars on the road in the congested periods in 2013, with the same delays as in 2003. We understand this as less congestion relief than anticipated in the ex-ante analyses.

The interviewees at the NPRA agreed that the congestion level in rush hours had not improved, but they claimed that delays were substantially reduced at other times of the day. We do not have data to test whether this is the case.

4.2.5. Current situation and plans

The current congestion situation is understood as problematic. NPRA have plans underway to expand road capacity in the same corridor, closer to the city centre, to reduce congestion, delays for commercial traffic and local pollution (NPRA, 2016a, 2016b).

All four municipalities now see a shift in land use planning and policies. They aim at facilitating for land-use development in and close to their centres, where the main railway stations are located, and they are more restrictive with respect to low-density development on new land farther from the centres. This is a response to the 2015 regional plan and increased interest from private actors in developing areas close to the railway stations, as the rail connection toward Oslo will substantially improve in the coming few years.

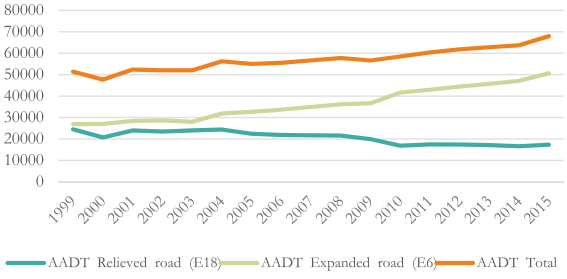


Fig. 5. Annual average daily traffic (AADT) on the expanded road (E6), on the relieved road (E18), and in total for both roads. Source: Norwegian Public Roads Administration (NPRA, 2015, 2018a, 2018b; PROSAM 2005a, 2005b).

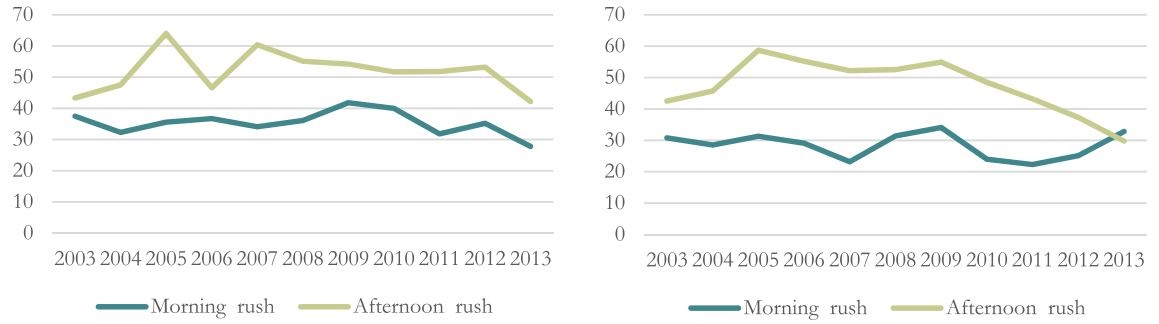


Fig. 6. Average speed (km/h) in 2003–2013, in rush hour directions in morning and afternoon rush, on the expanded road (E6; left) and relieved road (E18; right). Based on data from PROSAM (2015).

5. Case comparison and conclusions

One aim of this study was investigating whether and how the mechanisms described in Section 2 act out in different contexts, in the present research, a small and a large city. Leaning on the overview of the main findings from the case study, summarised in Table 12, we compare the two cases and conclude by answering the research question posed in Section 1.

5.1. Effects of road capacity expansions

In both cases, we found a strong growth in population and jobs in the areas getting improved accessibility due to the road capacity expansions, and the relative growth was stronger in the outer parts of the areas investigated. Much of the new housing has been built as low-density detached housing, and in Follo, the share of new housing built this way and on new land increased with the distance to the main city. In both cases we understand the overall development as sprawl, since higher percentages of jobs and inhabitants are

Table 12
Summary of the main findings in the two cases.

Indicator	Oslo case	Ålesund case	Norway
Land-use development, population, 2002–2016	Strong population growth (21.9%), the growth is stronger and more car-based with increasing distance from the core city	Strongest population growth in the outer urban areas (24.7%), lower in the extended city centre area (12.8%); most of the growth as low-density development and on new land	–
Land-use development, work-places, 2002–2016	Strong growth in number of jobs (24.8%), relatively stronger in outer parts of the urban region	Strongest growth in jobs in the extended Moa area (46.6%) and outer urban area (36.2%), less in extended city centre area (5,1%)	–
Land-use planning and policy in the period	Varying in Follo municipalities. All allowed for strong population growth. Less strict steering of land-use development in more peripheral municipalities, with the result that the share of housing allowed built as low-density development on new land increases with distance from Oslo	Allowed for strong growth in populations and jobs located outside extended city centre area, weak steering, much left to developer and landowners	–
Current land-use planning and policy	Stricter land-use policy, steering growth toward areas close to centres with good rail connections, discussing road projects to reduce congestion	Trying to steer growth towards densification in already built areas, plans for further expanding our case road underway	
Car-driver share, all trips	Decreased from 58.3% (2001) to 54.1% (2013/14) in the Follo area	Increased from 54% (2001) to 60.9% (2013/14)	Increased from 52.5% (2001) to 54.4% (2013/14)
Car-driver shares, work trips	Stable: 59.7% (2001) and 59.2% (2013/14)	Stable: 68.8% (2001) and 69.2% (2013/14)	Decreased from 62.9% (2001) to 61.2% (2013/14)
Commuting distances, to/from home (2001–2015)	Increased by 1.5 km, 0.3%	Increased by 1.7 km, 19%	Increased by 3.6 km, 0.5%
Commuting distance to/from job (2001–2015)	Increased by 3.5 km, 23.1%	Increased by 0.1 km, 0.5%	Increased by 3.6 km, 0.5%
Traffic volumes, total for expanded road and parallel relieved road	30% increase (2001–2015)	53% increase (1998–2016)	22% increase (2001–2015) 30% increase (1998–2016)
Congestion levels in rush hours	Same in 2013 as in 2003	Congestion has returned but is probably less severe	–

located in peripheral areas in the 'after' than in the 'before' situation. The growth in population and jobs seem to have been stronger than anticipated in ex-ante plans and analyses.

The causal relationship between the road capacity expansion and land-use development was clear in both cases. It was most evident in Ålesund, where congestions in the 'before' situation clearly hampered development in the outer parts of the urban area. In Oslo, this relationship was weaker in the municipalities located closest to Oslo, who had experienced high development pressure in the 'before situation', and stronger in the more peripheral municipalities, who experienced higher pressure after completion of the capacity expansion.

These findings are in accordance with theory, as discussed in Section 2, and they are expected to result in longer trips and higher car-driver shares. We found increasing commuting distances within the areas studied in both cases. Car-driver shares (all trips) increased in Ålesund, which is in accordance with theory. In the Follo area, they decreased, and our best explanation for this was that the land-use development contributed to increased densities, allowing more of the local trips to involve other modes than the private car. Following from that, no or only short-term reductions in congestion levels in rush hours were observed. Traffic growth was stronger and congestion relief weaker than anticipated in ex-ante plans and analyses in both cases. In both cases, the intended traffic relief on parallel roads was achieved.

In both cases, the NPRA has plans underway to expand road capacity in the corridors investigated, to reduce congestion.

In conclusion, our first research question *'How have urban road capacity expansions affected land-use development, consequently affecting traffic volumes and congestion levels, in the cases?'* can be answered as follows: We found that the road capacity expansion was a contributing cause for a more sprawled and car-dependent land-use development than what would otherwise have occurred, as well as longer commutes, in both the smaller and the larger city. This contributed to stronger traffic growth in the road corridors than would otherwise have occurred, and no or only short-term reductions in congestion levels in rush hours.

5.2. How the land-use effects were affected by land-use and policy

The cases clearly demonstrate that land-use planning and policy influence the land-use effects of road capacity expansions. This is most evident when comparing municipalities located close to the main city in the Oslo case with those located furthest away. Planning authorities in the municipalities closest to Oslo steered land-use in ways that resulted in higher shares of new housing units built as apartment-buildings, close to centres and rail stations. In the more peripheral municipalities, authorities left more to landowners and developers. As a result, much of the new housing was built on new land and as detached houses and rowhouses. This leaves the municipalities closest to Oslo with a less transport-demanding and car-dependent spatial structure than the more peripheral municipalities have. In the Ålesund case, the planning authorities allowed housing and workplace development in outer parts of the urban area, and much of the housing was built as low-density housing, also on new land. A different strategy would have left them with a less transport-demanding and car-dependent city. In both cases, planning authorities and politicians now want to stop the sprawl and steer the development of housing and workplaces toward centres and areas with excellent public transport services. In Follo, this is a response to strong signals from developers related to upcoming improved accessibility by rail, and it is in accordance with the regional plan.

On this basis, our second research question *'How have land-use planning and policy affected the land-use effects of road capacity expansions?'* can be answered as follow: The traffic-inducing land-use effects were weaker where municipalities took a strong position and steered toward high-density land-use development in areas close to centres with excellent public transport accessibility, and stronger where municipalities allowed landowners and developers to build on new land, with lower densities, in areas with poor public transport accessibility.

5.3. How road capacity expansions affect the chances to stop traffic growth in urban areas

Based on our analyses, we find in both cases that the road capacity expansions were a necessary condition for the traffic-inducing land-use development, which in turn contributed to traffic growth and returned congestion. Thus, the answer to our third question *'How do road capacity expansions affect the potential to stop traffic growth in urban areas?'* would be that these findings add to the body of studies concluding that expanding urban road capacity is more of a part of the problem than the solution for cities striving to achieve more sustainable urban mobility and more adequate policy responses are needed, and that this also is valid for smaller cities.

6. Discussion

To succeed in making cities more liveable, climate-friendly and efficient, planners and decision makers need to do things differently than before. A *reframing* of the problems as well as of the strategies and means considered to solve the problem is required (Owens and Cowell, 2002, Tennøy, 2010), as is a deep understanding of the complex interrelations between the development of land-use, transport systems, travel behaviour and traffic volumes.

The aim of this research has been to contribute to this understanding by empirically documenting effects of road capacity expansions on land-use, travel behaviour and traffic volume in more disaggregated, context-related and nuanced ways than seen in previous studies, and by including how land-use planning and policy influence the traffic-inducing effects. Findings were held up against ex-ante expectations at the time the projects were planned.

In the smaller as well as the larger city, main findings were that the road capacity expansions were contributing causes to land-use sprawl, increased commuting lengths and strong traffic growth, resulting in no or only short-time congestion relief. Consequently,

new road capacity expansions aimed at reducing congestion levels are currently under planning or discussion. In both cases, traffic growth was stronger than described in planning documents, and the congestion relief weaker. Ex-ante analyses seem not to have included the indirect land-use mechanisms discussed here, and this could be one explanation why there are discrepancies between ex-ante expectations and the actual development.

A question arising from these findings is how *current* planning processes relate to this knowledge. Document studies and interviews reveal that ongoing planning processes in the two case cities suggest only alternatives including road capacity expansions in plans aimed at reducing congestion and traffic-related local environmental problems, and that the indirect land-use mechanisms discussed here are not taken into consideration (NPRA, 2013a, 2013b, 2016a). This indicates that planners and authorities still have the understanding that expanding road capacity is a way of solving the problems, and that they disregard the land-use effects of road capacity expansions.

Another interesting question is the contrafactual one: What could or would have happened if the road capacity was not expanded in the two cases? One answer could be that the land-use would have developed as documented anyhow, followed by car usage increasing to the same volumes as we see today, leading to intolerable congestion. An alternative understanding could be that congestion, combined with authorities steering land-use development in less car-dependent directions, while substantially improving public transport services, facilitating bicycling and walking and introducing fiscal and physical restrictions on car usage, could have shifted travel behaviour toward less car usage (as discussed, for instance, by Banister, 2011; Nicolaisen and Næss, 2015; Litman, 2018; Rode et al., 2017; Verma, 2018). The probability of the latter scenario is strengthened by the findings in the Oslo case, where all four municipalities currently experience that upcoming improved rail accessibility make central areas close to railway stations highly attractive for developers. If the rail accessibility had been improved before or instead of the road accessibility, as several authorities argued in the planning process (NPRA, 1999), land-use in the Follo area could have developed in less transport demanding and car dependent ways, resulting in less traffic and congestion, and contributing to achieving the zero-growth objective. Seen in the light of goals related to reducing car-dependency, congestion and GHG-emissions from transport in countries and cities across the globe (European Environment Agency, 2018; UN Habitat, 2013), this is an interesting possibility that could be considered as an alternative in future planning processes.

Reframing understandings of how traffic and congestion problems could be solved and changing current practices is, however, not an easy task. It requires that new knowledge and ideas are understood and applied in complex planning processes, with multiple actors from different levels and sectors, who often have different goals (Bryson et al., 2015; Flyvbjerg, 1998; Hanssen et al., 2013; Tennøy, 2010; Zellner and Campbell, 2015). By presenting empirical findings in disaggregated, context-related and nuanced ways, our aim has been to contribute with relevant and understandable knowledge, that might contribute to the necessary reframing and change of planning practice and policy if prioritised societal goals are to be achieved.

Acknowledgements

The authors wish to thank Professor Petter Næss, Professor Emeritus David Banister and Assistant Professor Anssi Joutsiniemi for valuable inputs and comments on previous versions of the article. We would also like to thank the editor and the two anonymous reviewers for valuable inputs. We are grateful to the interviewees for sharing their knowledge, insights and understandings with us.

This work was financed by the Norwegian Research Council, the KLIMAFORSK programme, grant number 235859.

Appendix A. Interviewees

Interviewee	Case
Planner, Ålesund Municipality	Ålesund
Senior Architect, Ålesund Municipality	Ålesund
Planner, Ålesund Municipality	Ålesund
Planner, Sula Municipality	Ålesund
Retired Planner, Norwegian Public Roads Administration	Ålesund
Planner, Norwegian Public Roads Administration	Ålesund
Developer, Ålesund	Ålesund
Head of Planning Department, Oppegård Municipality	Oslo
Head of Planning Department, Ås Municipality	Oslo
Senior Planner, Ski Municipality	Oslo
Retired Planner, Vestby Municipality	Oslo
Director, Road Directory, Norwegian Public Roads Administration	Oslo
Director, Planning Department Road Directory, Norwegian Public Roads Administration	Oslo

Appendix B. Interview guide

The ‘before’ situation

- What was the situation at the time when the road was planned with respect to the road itself, traffic, land-use, planning, etc.?
- What were the main motivations for expanding the road capacity?

– What were the expectations for congestion reduction, traffic growth, land-use development, etc., resulting from the capacity expansion?
– Were other options than expanding the road considered to solve the problems experienced?

Development after the road capacity expansion

– How did the traffic and congestion change after completion of the road? (On the new and old roads)
– How has land use developed after the road capacity expansion? How do you explain this development?

Current planning and plans

– What are the main land-use strategies in the current plans and plans in progress, at the municipal and regional levels? What are the motivations for this?
– Are there any current plans or plans in progress for road constructions? What are the motivations for this?

Appendix C. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trd.2019.01.024.

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Transport Policy 76 (2019) 57–66

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

If you build it, they will drive: Measuring induced demand for vehicle travel in urban areas

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ARTICLE INFO

JEL classification:
R41
R48

ABSTRACT

This paper examines the causal link between highway capacity and the volume of vehicle travel in US urban areas. Estimates from a dynamic panel model suggest that highway capacity expansion generates an exactly proportional increase in vehicle travel. Moreover, induced vehicle travel is expected to revert traffic speeds to pre-expansion levels in approximately five years. To address the simultaneous relationship between lane mileage and highway capacity, this paper develops an identification strategy to account for possible endogeneity bias. A set of instrumental variables measures the degree of influence that state delegations have had on key transportation committees in the US congress. The instruments strongly correlate with highway capacity and are plausibly exogenous, considering the idiosyncratic legislative process in the US. These findings cast doubt on the effectiveness of expanding highways to eliminate traffic congestion, as the speed-related benefits of new capacity tend to be short-lived.

1. Introduction

The distribution of federal highway funds has long been the subject of intense debate among policymakers at all levels of government, and for good reason. Abundant evidence suggests that roads have had wide-ranging effects on, among other things, productivity (Fernald, 1999), trade (Duranton et al., 2014; Allen and Arkolakis, 2014), land use within cities (Baum-Snow, 2007; Duranton and Turner, 2012), and automobile externalities (Parry et al., 2007). Highway infrastructure spending has also played an important role in countercyclical fiscal policy and was a significant part of the 2009 stimulus bill (Leduc and Wilson, 2014). Although highways generate undeniable economic benefits, they are costly to build and spawn a host of negative externalities when they are not managed efficiently. Hence, transportation planners must carefully consider the behavioral response of drivers when expanding highway capacity. How will additional highway capacity change the volume, temporal distribution, spatial distribution, and speed of vehicular travel? This paper measures one such factor: the effect of highway expansion on the volume of vehicle travel in US urban areas.

There is little dispute among transportation researchers that expanding highway capacity increases vehicle use. This phenomenon is commonly known as *induced demand*, and it demonstrates a fundamental economic principle: individuals tend to consume more of a good as the price of the good falls. In other words, wider highways increase traffic speeds and reduce the time cost of driving, thereby inducing additional vehicle travel. In the short run, when residential and employment locations are fixed, faster peak period highway speeds attract drivers from alternate routes, modes, and times of day. Then, in the long-run, faster speeds encourage additional social and economic behavior in areas made more accessible by the new highway capacity, which further increases traffic volumes.

Research studies since the 1960s have suggested that, because of induced demand, the hoped-for benefits from highway expansion tend to be short-lived and do not provide lasting relief to traffic congestion. Early studies by Downs (1962), Smeed (1968), and Thomson (1977) go so far as to argue that, over time and without any other offsetting deterrent, rush-hour traffic speeds tend to revert to their pre-expansion levels. The finding has even been dubbed the *Fundamental Law of Road Congestion* (Downs, 1962), which asserts that the elasticity of vehicle miles traveled with respect to lane mileage is equal to one, implying that driving increases in exact proportion to highway capacity additions.

A related strand of research examines the direct effect of travel-time savings on the demand for vehicle travel. Road improvements in congested areas induce additional travel indirectly, as drivers ultimately benefit from reductions in the generalized cost of driving brought about by faster traffic speeds (For a review of the literature, see Wardman (2012).). Thus, the elasticity of vehicle mileage with respect to travel-time may serve as a better predictor of future traffic volumes, as some

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https://doi.org/10.1016/j.tranpol.2018.12.006
Received 6 August 2018; Received in revised form 5 December 2018; Accepted 16 December 2018
Available online 19 December 2018
0967-070X/ © 2018 Published by Elsevier Ltd.

road improvements occur in uncongested areas and have little impact on the speed of traffic. But accurately measuring that elasticity is challenging as travel times can vary widely across the hours of the day and the days of the week. These practical difficulties have prompted many researchers to use lane mileage as a proxy for time-savings. Hence, induced demand elasticities based on capacity expansions should be correctly interpreted as average effects applying to the road types included in a given study.[1]

The existing literature on induced demand is extensive and includes case studies as well as analyses based on aggregate cross-sectional and time series data. Though rich in detail, findings from individual case studies can be hard to generalize and may have a limited ability to predict the effects of highway expansion in other metropolitan areas. Moreover, highway expansion impacts travel on a city's entire transportation network and may alter traffic on any secondary roads excluded from a case study. In contrast, studies that measure induced demand for a cross-section of metropolitan areas over many years can yield generalizable lessons that are relevant to the national highway policy debate. Nevertheless, estimates of the induced demand elasticity differ considerably across studies and depend on the time horizon, unit of measurement, and empirical model employed. Research using county or state-level panel data generate elasticity estimates that vary widely both within and across studies (Cervero, 2002). For other reviews of the induced demand literature see Goodwin (1996), Noland and Lem (2002), and Graham and Glaister (2004).

Many of these earlier studies, however, do not provide clear identification strategies, making it difficult to uncover the causal links between highway capacity and vehicle travel. Although capacity and travel are highly correlated, it is not plausible to assume that causality flows in a single direction. Transportation planners, for example, do not randomly select which highways to widen. Instead they prioritize improving highway segments with unacceptable levels of traffic congestion or in areas expecting economic growth. Initially, a newly widened highway will attract drivers from other routes, modes of travel, and times of day. Over time, however, vehicle speeds tend to regress as traffic increases, eroding the sought-after congestion relief and encouraging further capacity expansion. Thus, it is not plausible to assume that causality flows in a single direction: highway capacity itself is endogenously determined by the volume of vehicle travel and other factors.

Failing to control for endogeneity in a travel demand model will likely generate biased estimates of the induced demand elasticity, which casts doubt on the validity of studies lacking a credible identification strategy. That said, instrumental variables (IV) has been the prevailing approach to estimating the causal effects of highway expansion. The earliest IV-based studies proposed a variety of instruments for highway capacity, which include lagged values of highway capacity growth (Fulton et al., 2000), the amount of urban land area (Noland and Cowart, 2000), and a combination of political and environmental measures (Cervero and Hansen, 2002). But, good instruments have proven difficult to find and the reliability of the induced demand estimates from these early studies is uncertain, as none tested for bias from weak or invalid instruments.

There are, however, studies that focus attention on the causal relationship between vehicle travel and highway capacity. For example, Duranton and Turner (2011) used an early plan of the US Interstate highway system from 1947 along with a set of rail and exploration routes from the 1800s to generate instruments for urban area lane mileage. Their instrumental-variable based estimates of the induced demand elasticity range from 0.92 to 1.04, which are consistent with the fundamental law. In a set of related studies, the road mileage depicted on the 1947 plan serves as an instrument in much the same way — Baum-Snow (2007) estimates the effect of highway provision on suburbanization, Michaels (2008) looks at trade barriers and labor market outcomes, and Hymel (2009) examines the effect of traffic congestion on metropolitan employment growth. In those studies, a key argument for instrument validity is the long span of time separating the 1947 highway plan from economic outcomes occurring decades later. Revisiting the map-based approach of Duranton and Turner (2011), Hsu and Zhang (2014) generate instruments from a map of planned highways in Japan, and also find induced demand elasticity estimates that support the fundamental law of road congestion, ranging from 1.24 to 1.34. Other studies have addressed causality with Granger causality tests (Fulton et al., 2000; Melo et al., 2012), simultaneous equations models Noland (2001); Hymel et al. (2010), and propensity scores (Graham et al., 2014). Table 1 summarizes the methodologies and research findings of induced demand studies that controlled for endogeneity bias by using instrumental variables.

To help disentangle causality, this paper examines how scarce highway funds are allocated across competing projects. Policymakers at the federal, state, and local level all exert influence over the distribution of highway funds. A key funding mechanism in the US is the Federal-Aid Highway Program, which redistributes motor-fuel tax revenue put into the Highway Trust Fund. Using a statutory formula, the program apportions federal funds among states to help pay for a variety of surface transportation programs. Key factors in the formula include the size of each state's road network, the amount of vehicle travel, fuel tax revenues, and air pollution levels.[2] Ultimately state and local transportation departments decide where to spend their own portion of the funds.

Do these formulas, written by Congress, accurately reflect highway transportation needs? If so, the funding formulas present further evidence that road building is not exogenous to vehicle travel. However, legislative politics can also create inefficiencies if the formulas redirect funds towards places with influential members of congress and away from places with high priority road projects. To answer that question, this paper develops a set of instrumental variables that measure the degree of influence each state's congressional delegation has had in the US House of Representatives and US Senate.

The remainder of this paper is organized as follows. Section 2 provides background information about highway finance and its relation to politics in the US. Section 3 describes this paper's identification strategy and provides evidence demonstrating the exogeneity and predictive strength of the instrumental variables. To estimate the induced demand elasticity, Section 4 develops a dynamic panel model of urban travel demand across US states between 1981 and 2015. The model addresses important statistical issues including unobserved heterogeneity, endogenous highway capacity, and the dynamic response of vehicle travel to highway capacity expansions. Section 5 presents a robust set of estimates which suggests that, over the long run, highway expansions generate an almost one-for one increase in vehicle travel. That is, the most trustworthy estimates of the induced demand elasticity are very close to one and add further support for the fundamental law of road congestion.

2. Background

Surface-transportation spending bills have historically been contentious, and there is little doubt that members of Congress have strong incentives to secure federal funds for their constituents and to oblige campaign contributors (Levitt and Poterba, 1999; Knight, 2005). Highways are tangible, long-lived, and conspicuous. Because of those features, members can, without much difficulty, point to a popular highway improvement and claim credit for securing the federal funds

[1] Hereafter the term *elasticity* refers to the response of vehicle travel with respect to highway capacity, unless otherwise noted.

[2] The US Federal Highway Administration reports the prevailing funding formula in its annual *Highway Statistics* publication.

Table 1
Induced demand elasticity estimates from earlier IV-based studies.

Study	Sample	Identification strategy	Estimator	Elasticity range	Time period
Internal instrument					
Fulton et al. (2000)	Counties in the US Mid-Atlantic (1969–1996)	Lagged growth in highway capacity	FE 2SLS FE	0.56–0.59 0.46–0.51	Short run Short run
External instruments					
Noland and Cowart (2000)	US urbanized ureas (1982–1996)	Urbanized land area inverse population density	2SLS FE 2SLS FE	0.28 0.90	Short run Long run
External instruments					
Cervero and Hansen (2002)	Urban counties in California (1976–1997)	Measures of geography, politics, and air quality	3SLS FE	0.79	5 year
External instruments					
Duranton and Turner (2011)	US Metropolitan Statistical Areas (1983–2003)	The 1947 US Interstate Highway system plan and mapped rail and exploration routes from 1835 to 1898	OLS FE 2SLS ML	0.82–0.86 0.95–1.12 0.94–1.03	10 year 10 year 10 year
Internal instruments					
Melo et al. (2012)	US urbanized ureas (1982–2010)	Lagged levels and differences of the dependent & independent variables	GMM	0.98	Long run
External instruments					
Hsu and Zhang (2014)	Urban employment areas in Japan (1990–2005)	Japan's 1987 National Expressway Network Plan	OLS FE 2SLS ML FE	1.02–1.17 1.13–1.14 1.24–1.34	3–5 year
Internal instruments					
Graham et al. (2014)	US urbanized ureas (1985–2010)	Lagged levels and differences of the dependent & independent variables	PS RE OLS FE GMM	0.77 0.76 0.53 0.61	Long run Long run Long run Long run

Notes: Studies typically reported results using multiple estimators and model specifications. The following conventions distinguish the different estimators employed in a given study: OLS = pooled ordinary least squares; 2SLS = two-stage least squares; 3SLS = three-stage least squares; GMM = generalized method of moments; ML = Maximum likelihood; PS = propensity scores; FE = fixed effects; RE = random effects. The elasticity range refers to the minimum and maximum elasticity estimate for a given estimator across different model specifications. Time horizon refers to the length of time a study assumes will transpire before the effects of induced demand will play out.

that helped finance it (Grimmer et al., 2012). Moreover, members of congress who steer funds to their home districts, do so to court voters and win reelection (Levitt and Snyder, 1997). For example, drivers who endure intense traffic congestion would likely benefit from additional highway capacity funded by federal tax dollars. Likewise, individuals residing in congestion-free areas may also derive benefits from highway projects, which can stimulate regional economies and generate employment.

That said, increased federal funding for highways may not appeal to the voters who bear the external costs of vehicle use (e.g., air pollution and noise). In addition, new highway capacity can increase accessibility and widen the spatial size of metropolitan area labor markets, which may redistribute jobs and other economic activity from one place to another. The uneven distribution of these costs and benefits across individuals suggest that expanding capacity will generate both winners and losers. Consider a member of congress who secures funds for a highway project in their home district. Among that member's constituents, the number of winners (i.e., those deriving positive net benefits from the project) would be expected to exceed the number of losers. For one, paying for a local highway project with federal funds spreads the capital costs across all US taxpayers, while the district's constituents enjoy most of the benefits. That imbalance incentivizes members of congress to obtain federal funding for projects back home that would otherwise fail benefit cost tests. Moreover, incumbents seeking reelection would be unwise to sponsor highway projects that a majority of their electorate disapprove of.

Members of Congress use a variety of legislative maneuvers to secure Federal-Aid Highway funds for their constituents. First and foremost, members shape the funding formulas through the political process, which rewards states or districts with senior, high-ranking, and majority party members (Moore and Hibbing, 1996). Although the funding formulas calculate each state's allocation of highway funds using objective measures, Congress can also rewrite or adjust the formulas, and has typically done so when drafting long-term highway funding bills (Shatz et al., 2011). Members of key transportation-related committees wield even more influence because they can markup or add amendments to any highway-related bill and can directly earmark funds for specific projects in their home district.

Groups from across the political spectrum have assailed both the formulas and earmark spending for inefficiently distributing highway funds. Estimates by Knight (2004) suggest that the annual cost of federal highway spending exceeds benefits by $7 billion while Cooper and Griffith (2012) estimate that nearly one quarter of formula funds were distributed according to factors unrelated to objective transportation needs in 2010. Instead the federal government distributed more than 10 billion dollars through a set of complicated bonuses and minimum guarantees, which were intended to promote equity across states.[3] The factors used in the funding formula have also been criticized for being poor indicators of actual highway needs. For example, prior to 1980, the formula used a state's total number of center-line road miles to measure the extent of the highway system. Although important, that variable does not adequately measure urban highway capacity, which depends not only on length, but also the number of lanes a road has.

Furthermore, the funding formulas have also created so-called “donor” and “donee” states, which result from the difference between fuel tax revenues a state pays into the highway trust fund and what it gets back in the form of grants. Between 1956 and 2016, the cumulative grant allocations given to eight predominantly rural states were more than twice as large as their cumulative payments into the trust fund (Zhu and Brown, 2013).[4] As many critics claim, the perennial imbalance between tax payments and highway grants suggests that the

[3] The apportionment formulas in effect during 2015 can be found at https://web.archive.org/web/20170831060313/https://www.fhwa.dot.gov/policyinformation/statistics/2015/fa4a.cfm.

[4] Of those eight donee states, six were mostly rural: North Dakota, South Dakota, West Virginia, Alaska, Vermont, and Montana. The two mostly urban states were Rhode Island and Hawaii.

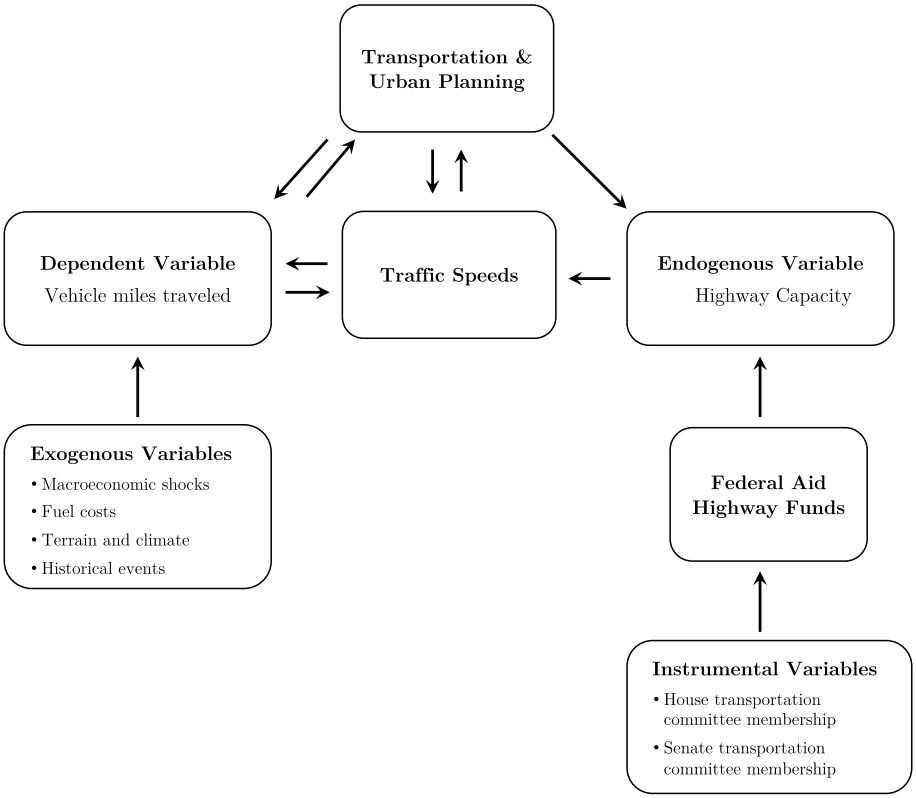


Fig. 1. Hypothesized causal relationships between the empirical model's key variables.

formulas are not efficiently allocating funds to the states where highway needs are greatest (Knight, 2004; Coopert and Griffith, 2012).

Although susceptible to manipulation and inefficient, the highway funding formulas distribute federal money to states based on a set of observable measures, which are straightforward to include in a regression model. Obtaining unbiased estimates of the induced demand elasticity, then, depends more critically upon accounting for unexplained variation in vehicle travel that correlates with the explanatory variables. The byzantine nature of the US legislative process bolsters the identification strategy developed in this paper: earmarks, vote-trading, and omnibus spending bills all serve to divert highway funds away from the most beneficial transportation projects and towards districts with influential delegates.

3. Research design

To help motivate the empirical model and identify an appropriate set of explanatory variables, this section develops a conceptual framework to illustrate the relationships between highway capacity, vehicle miles traveled, and other relevant factors. Fig. 1 presents a directed graph depicting the hypothesized causal linkages between vehicle miles traveled and its determinants. Each of the diagram's arrows indicate the presence and direction of a first-order causal link between two variables. The absence of an arrow linking two variables implies that no *direct* causal relationship exists, although the two items may be indirectly linked through one or more intermediate variables.

Consider equilibrium traffic speed, which is simultaneously determined by highway capacity, the demand for vehicle travel, and other traffic-demand management programs. As Fig. 1 shows, the amount of highway capacity has a direct positive effect on traffic speed in the short-run. However, the reverse causal effect does not follow the same path, because traffic speed effects highway capacity through intermediate channels. For example, suppose there was an abrupt and permanent fall in fuel prices. Traffic congestion would worsen as individuals, responding to the price shock, undertake more vehicle travel. The decline in traffic speed would impact highway capacity indirectly, by influencing transportation officials' long-term plans for highway infrastructure improvements.

Developing an empirical model of these interrelated causal linkages is not straightforward, making it difficult to obtain credible estimates of the induced demand elasticity. To obtain precise and unbiased induced demand elasticity estimates, it is important to control for the many exogenous factors that help determine vehicle miles traveled. Exogenous variables that influence travel demand include macroeconomic and geopolitical events that occur at the national or global level. Such variables would include economic recessions, changes in US trade policy, and fuel price volatility.

The exogeneity of these variables, however, requires states to be *atomistic*. In other words, states must be numerous enough, such that a sizable economic shock occurring in one urban area will have little impact on the larger national economy. For example, suppose that mass layoffs at a single manufacturing plant cause that area's VMT to sharply decline. Atomism implies that the effect of the layoffs would remain localized, having no discernible impact on unemployment rates or VMT measured nationally. In the current context, a group of 51 states[5] spread over a wide geographic area is numerous enough to assume atomistic behavior and accept the exogeneity of variables measuring economic conditions. Specifications of the empirical model, described in the next section, include controls for fuel prices, per-capita income levels, and the rate of unemployment, which are reliable predictors of aggregate travel demand (Noland, 2001; Hymel et al., 2010).

Other exogenous factors that influence the demand for vehicle travel are fixed at the state level and remain relatively constant over a period of time. Examples of these so-called *fixed-effects* include a state's

[5] This figure counts the District of Columbia as a state.

terrain and climate, which influence the quality of alternate forms of transportation such as bicycling and walking. In a similar vein, historical events of the distant past can generate long-lasting effects because of path dependencies. Using panel data and the within-group estimator makes controlling for both state- and year-fixed-effects a straightforward task. Further details of the fixed effects approach are presented in Section 4 below.

3.1. Instrumental variables

Including a rich set of explanatory variables improves the precision of regression estimates and reduces omitted variables bias. But the key variable, highway capacity, is not exogenous, so obtaining unbiased estimates of the induced demand elasticity is challenging. To address the endogeneity of highway capacity, this paper uses an instrumental variables approach. A valid instrument for highway capacity must be strongly correlated with lane mileage and, conditional on the explanatory variables, it must also be exogenous to vehicle miles traveled. Measures of a state's level of political influence can serve as valid instrumental variables, and the evidence presented below demonstrates how they satisfy the strength and exogeneity requirements just mentioned.

In the US Congress, the House Committee on Transportation and Infrastructure (HCTI) and the Senate Committee on Environment and Public Works (SCEPW) yield the greatest influence over highway policy and the distribution of grants.[6] Members of these committees exert influence over highway legislation through two main channels: by shaping the funding formulas that distribute Highway Trust funds and by funding specific projects through earmark spending.

Procedural rules in the US House of Representatives give considerable control over the legislative agenda to individual committees. Acting as gatekeeper, each committee holds hearings and debates before approving (or rejecting) bills falling under its jurisdiction (Davidson et. al, 2013). Moreover, the HCTI retains the sole power to amend, revise, rewrite, or table a highway spending bill before moving it to the House floor for consideration by the full chamber. Once passed by the full chamber, legislation moves to the conference committee. At that stage, the HCTI regains a measure of influence as its members negotiate the final terms of highway spending bills with the SCEPW.

Institutional norms in Congress have also helped consolidate political power within committees. Historically, the House of Representatives has practiced *reciprocal deference*, a system of tacit vote-trading between committees (Krehbiel et al., 1987). In other words, expecting reciprocity, representatives would defer to the policy experts sitting on other committees and not oppose legislation outside of their own jurisdiction. As transportation is a relatively non-partisan issue, reciprocal deference would be expected to dampen opposition to distorted funding formulas and earmarked pet projects, thereby increasing highway funds allocated to HCTI members' districts. These idiosyncrasies of the US legislative system concentrate the power to shape highway policy within the HCTI and to a lesser degree the SCEPW. Indeed, research by Evans (2004), Knight (2002), and Lee (2003) find that members of key transportation committees garner more funding for their constituencies.

The predictive strength of the transportation committee instruments is also reinforced by intrinsic features of highway infrastructure. Urban highway investments and land-use decisions tend to restrict a city's subsequent infrastructure options, creating path dependencies. Consider adding a new link to an existing urban highway network. Some of the major roadway construction tasks – such siting, excavation and grading – permanently alter the terrain and have far reaching effects on future land use patterns, which makes rerouting or deconstructing urban highways impractical.[7] Furthermore, population growth increases land rents and population densities, both of which raise the cost of constructing new urban highways and limits opportunities for lane widening. Thus, the prevailing spatial structure of an urban highway network depends in large part on initial conditions and the actions of influential policy makers from the past.

These arguments suggest that legislators serving on one of the transportation committees during the inception and early years of the US Interstate highway system would have an outsized and enduring effect on their district's ability to expand highway capacity many years later. This line of reasoning is central to the exogeneity argument in many induced demand studies that rely on historical maps to construct instruments for highway capacity (see e.g., Duranton and Turner, 2011; Garcia-Lopez et al., 2015; and Hsu and Zhang, 2014).

Long time lags also tend to separate the debut of new highway capacity from its associated authorizing legislation. So, construction on an earmark-funded project could continue well beyond its sponsor's term in congress. Likewise, changes to the funding formula in a multi-year reauthorization bill would have little near-term impact on capacity, as states use already obligated funds to pay for road projects. Over time, however, changes to the formula would have a greater impact on capacity as states adjust their transportation plans to accommodate any changes in federal grants. Coupled with path dependency, the long duration of highway legislation, planning, and construction suggest using deeply lagged measures of political influence to instrument for future highway capacity levels. Thus, the cumulative delegate-years of House and Senate transportation committee membership will serve as the political influence instruments. The starting point for measuring committee membership is 1956, which marks the inception of the Interstate Highway System.

The first instrumental variable $H_{i,t}$ measures the cumulative years of HCTI membership possessed by state i between 1956 and year t.

$$H_{i,t} = \sum_{j=1956}^{t} \sum_{k=1}^{435} h_{i,j,k}$$

$$h_{i,j,k} = \begin{cases} 1 & \text{if representative } k \text{ from state } i \\ & \text{served on the House CTI in year } j \text{ otherwise.} \\ 0 & \end{cases}$$

Similarly, instrument $S_{i,t}$ measures state i's cumulative membership on the Senate CEPW in year t.

$$S_{i,t} = \sum_{j=1956}^{t} \sum_{k=1}^{100} s_{i,j,k}$$

$$s_{i,j,k} = \begin{cases} 1 & \text{if senator } k \text{ from state } i \text{ served on the Senate CEPW in year } j \\ & \text{otherwise} \\ 0 & \end{cases}$$

The assignment data used to construct these two instruments is drawn from committee rosters published by *Congressional Quarterly*.

The political process that assigns delegates to committees could pose a threat to this identification strategy. For example, delegates from

[6] The House and Senate appropriations committees determine overall funding levels for federal agencies and programs, but they exert less influence over how grants are distributed across the states.

[7] A meta-analysis conducted by Cairns et al. (2002) examined more than 70 European roadway reallocation projects. They conclude that, contrary to public perception, converting roadways to more pedestrian and transit-friendly uses can reduce automobile use, without degrading driving conditions on the surrounding roads. These projects were usually accompanied by improvements to nearby transit facilities, bus-only lanes, and sidewalks, which presumably served a portion of the displaced automobile traffic. However, some of these conversions also improved the quality of alternate modes of transportation, which makes it difficult to disentangle the causal effect of reducing capacity from the concurrent effect of any improvements to the surrounding area.

districts with high levels of urban traffic congestion may self-select onto or be matched to one of the key transportation committees. If delegates from the most congested districts are systematically assigned to the HCTI or SCEPW, the validity of the instruments is questionable. However, that argument is not supported by any strong empirical evidence.

Congressional delegates, from both urban and rural districts, have a strong incentive to “bring home the bacon” for their constituents when seeking reelection. Highway projects – being tangible, conspicuous, and firmly rooted in one place – make particularly useful examples on the campaign trail, and incumbents do take credit for procuring the requisite funds (Evans, 2004; Grimmer et al., 2012). These features increase the value of seats on the transportation committees because members can earmark federal funds for highways more easily than non-members. Hence, demand for a seat on the HCTI or SCEPW is not limited to delegates from congested urban areas – rural districts may also benefit from extra funds, as construction can boost both employment and the demand for locally-produced inputs.

Indeed, research by Lee and Oppenheimer (1999) found that smaller and more rural states have historically been overrepresented on the HCTI relative to more urbanized states where most congestion occurs. Similarly, each US state has equal representation in the Senate, which amplifies the political influence of committee members from sparsely populated states. These aspects of the committee assignment matching process in the House and the structure of the Senate, do not support the argument that delegates from the most congested districts are systematically assigned to the HCTI or SCEPW.

Many factors unrelated to urban traffic conditions help determine committee assignments, including the delegate's party affiliation, level of seniority, reelection prospects, and policy-area expertise (Frisch and Kelly, 2006; Kellerman and Shepsle, 2009). For example, in the absence of term limits, long-serving members of Congress may be loathe to relinquish their valuable committee posts. Low turnover on committees also reduces the likelihood of seating delegates from states with the most urgent highway needs. Similarly, party and committee leaders make members pay “party dues”, via fundraising, to secure a preferred committee assignment (Burgat, 2017). Such actions reward talented fundraisers instead of individuals with useful knowledge about transportation, and inhibits Congress from making intelligent highway policies. Together, these idiosyncratic aspects of the political process render arguments against instrument validity unconvincing.

First stage regression results, presented in Section 5 below, show that a state's cumulative years of representation on the HCIT and SCEPW are both reliable predictors of current lane-mileage, with the effect being stronger in the House. The relatively weaker effect of SCEPW representation is not surprising. The Senate, being more egalitarian, places less importance on member seniority than does the more hierarchical House, which in turn diminishes the importance of cumulative prior representation. Section 5 below presents further evidence from statistical tests supporting the exogeneity and strength of the instruments.

3.2. Data sources

The data used in this analysis include important transportation, geographic, and socioeconomic variables for US States and the District of Columbia measured between 1981 and 2015. The two key data series are drawn from the Federal Highway Administration's (FHWA) annual *Highway Statistics* publications. Highway capacity is measured as the total number of lane-miles residing within Census-defined urban areas in a given state, and is limited to freeways and other limited-access roads. The measure of highway use, vehicle miles traveled, is similarly limited only to driving in urban areas. Table 2 presents summary statistics.

For the early years in the sample, states typically estimated vehicle travel using a combination of fuel tax receipts, traffic counts, and survey data. Evaluating these data, Schipper et al. (1993) found the FHWA's aggregate vehicle miles traveled measures correspond with those calculated from the National Personal Transportation Survey, lending them credibility. Moreover, as technology has progressed, estimates of vehicle miles traveled have become much more precise. States now use loop detectors embedded in highways and GPS or cell phone tracking to collect a wealth of highly detailed spatial and temporal traffic data.

4. Empirical model and estimation

The main goal of this research is to estimate the induced demand elasticity, but doing so is made difficult by three primary factors. First, including highway capacity or another endogenous variable in a travel demand regression model generates biased coefficient estimates. So, to account for endogeneity bias, this paper employs an instrumental variables approach as described in Section 3.

Second, unobservable factors that influence travel demand are likely to exist, and if not controlled for, will lead to omitted variables bias. To limit such bias, the specifications will include observable travel-demand factors that vary over time and across states. Moreover, the panel nature of the data also permits testing different model specifications for several sources of unobserved heterogeneity. In most specifications, the within-group panel estimator will control for time-invariant state-specific fixed effects (e.g., geographic area, topography, etc.). A set of year dummy variables will control for time-varying effects that are common to every state, (e.g., macroeconomic shocks, oil crises, etc.). Alternatively, travel demand trends may also differ across states, and to account for such heterogeneity some specifications will include state-specific linear time trends.

The third factor complicating estimation stems from transaction costs or other barriers that inhibit drivers from quickly adjusting to shocks, which raises the risk of misspecification if the dynamic nature of travel demand is not correctly modeled. To account for the dynamic nature of vehicle travel and to model driver adaptation, a partial adjustment model will provide estimates of the short and long run induced demand elasticities.

To illustrate the need for a dynamic model, first consider a simple static model of travel demand,

$$V_{it} = \alpha_i + \gamma C_{it} + \beta X_{it} + \varepsilon_{it}; (t = 1, ..., T; i = 1, ..., N) \quad (1)$$

where V_{it} is urban vehicle-miles traveled for state i in year t, C_{it} is urban lane mileage, and X_{it} is a set of exogenous variables that help determine travel demand. The state-specific effect, α_i, which may be correlated with X_{it}, accounts for time-invariant factors such as a state's climate or topography. Variables V and C are measured in logarithms, so γ measures the induced demand elasticity.

Static model (1) implies that VMT immediately adjusts to its equilibrium level following an increase in highway capacity. But a rapid and complete adjustment may not be feasible if there are transition or learning costs that impede some individuals from altering their driving behavior. For example, a commuter might respond to faster freeway speeds by moving their residence or by changing jobs. But such long-term adjustments are costly and it may take several years for the full effect of a capacity increase to be realized.

The beneficial effects of highway capacity expansion may generate time savings that endure for more than one period, providing a stream of future benefits. Thus, the present discounted value of an expansion is directly tied to the adjustment speed of travel demand. Accurate measures of how rapidly (or slowly) drivers adjust to changes in the transportation network have important policy ramifications. For example, the total time savings generated by capacity expansion depends on the duration of congestion relief, so reliable estimates of the long-run induced demand elasticity are key factors in cost-benefit analyses and long-term transportation planning models.

Panel data sets (with suitably long time series) can help model the

Table 2
Summary statistics (1981–2015).

	Min.	Max.	Mean	Std. Dev.	Source
Vehicle Miles Traveled (millions)	2665	335,539	48,415	52,093	FHWA
Urban Area Lane Miles	1122	253,319	38,534	42,392	FHWA
Population (millions)	0.405	39.144	5.367	5.995	US Census
State Unemployment Level	2.30	17.80	6.08	2.10	BEA
Gas price with taxes (2015 cents)	125.85	467.27	251.05	72.49	EIA
Income per capita (2015 dollars)	7127	73,890	27,106	12,314	BLS
Number of delegates on HCTI	0	9	1.27	1.54	Congress. Quarterly
Number of delegates on SCEPW	0	2	0.42	0.52	Congress. Quarterly

Notes: The summary statistics are based on data measured annually at the state level for the 50 US states and the District of Columbia. HCTI stands for the US House of Representatives Committee on Transportation and Infrastructure, and SCEPW is the Senate Committee on Environment and Public Works.

dynamic aspects of induced demand and can generate useful short and long-run elasticity estimates. Consider the dynamic panel model below, which adds the one year lag of V to model (1):

$$V_{it} = \alpha_i + \phi V_{i,t-1} + \gamma C_{it} + \beta X_{it} + \varepsilon_{it}. \quad (2)$$

By including lagged VMT as an explanatory variable, the dynamic model can distinguish short-run changes in travel demand from long-run movement towards equilibrium in response to an increase in highway capacity. This model implies that the current level of VMT is not solely determined by contemporary factors, but also by the entire past history of the explanatory variables and error terms subsumed by the lagged VMT term. Hence, the coefficient for lagged VMT, ϕ, measures the year-to-year persistence of travel demand. A value of ϕ close to zero implies low persistence, while a value of ϕ close to one implies high persistence. In each of the partial-adjustment model specifications, vehicle miles traveled and lane mileage are measured in logs, so coefficient β measures the short-run induced demand elasticity, while $\frac{\beta}{1-\phi}$ measures the analogous long-run elasticity.

To control for unobserved heterogeneity common to each state, some specifications employ the within-group estimator, which demeans variables at the state level, wiping out the fixed-effects (α_i). Further, because ε_{it} is correlated with C_{it}, the strict exogeneity assumption does not hold, so (demeaned) model (2) will be estimated by two-stage least squares (2SLS) using the political influence variables (H_{it} and S_{it}) as instruments for endogenous highway capacity (C_{it}). To test the robustness of the results, other specifications of (2) include year dummies, a linear time trend, or state-specific time trends.

Drawing useful inferences from (2) crucially depends on the accuracy of the regression coefficients, and obtaining unbiased and consistent estimates of ϕ and γ is not straightforward. In (2) the fixed effect α_i appears in all observations for state i, and is thus correlated with $V_{i,t-1}$ making the lagged dependent variable endogenous. Taking first differences removes the state fixed effect:

$$\Delta V_{it} = \phi \Delta V_{i,t-1} + \gamma \Delta C_{it} + \beta \Delta X_{it} + \Delta \varepsilon_{it}, \quad (3)$$

where Δ is the lag operator (e.g., $\Delta V_{it} = V_{i,t} - V_{i,t-1}$).

Although first differencing (2) removes the state fixed effect, the operation reintroduces endogeneity because $\varepsilon_{i,t-1}$ is a part of $V_{i,t-1}$. Hence, $\Delta V_{i,t-1}$ is correlated with the differenced error term, which renders the within-group estimator both inconsistent and biased (Nickell, 1981). This prevalent problem, commonly referred to as *Nickell Bias*, motivated a large literature on dynamic panel econometrics and brought about a range of estimators that are well-understood and frequently used in micro and macroeconomic applications (Arellano, 2003).

Thus, to address the dynamic-panel endogeneity problem, Section 5 also considers estimates produced by the generalized method of moments (GMM) estimator developed by Blundell and Bond (1998). In short, a GMM estimator combines the information contained in an observed sample of data with a set of restrictions implied by theory known as *population moment conditions*. The method generates estimates by finding the parameter values that make a set of sample moments as close as possible to the corresponding population moments. As the name suggests, GMM is a very general estimation approach as it nests many common estimators (e.g., ordinary and two-stage least squares, maximum likelihood) along with the more complex dynamic panel estimators designed to address Nickell Bias. This useful property makes comparing the results from different models easier, as large-sample GMM estimators are consistent and asymptotically normal, provided both the dependent and independent variables are stationary (Newey and McFadden, 1994).

Although uncorrected Nickell Bias may lead to false inferences, the bias vanishes as the time dimension of the panel data set increases. So, with $T = 34$ annual observations per state, the degree of bias is expected to be small. Indeed, the calculated Nickel bias of the lagged coefficient when $T = 34$ and $\phi = 0.66$ equals -0.050 (Arellano, 2003). Nevertheless, results from the Blundell-Bond estimator will serve as additional robustness checks for the conventional least-squares based estimates.

5. Results

This section presents regression results and induced demand elasticities generated by the dynamic model using both least-squares and GMM based estimators. Across all models, urban vehicle miles traveled and urban lane mileage are in logarithmic form and measured per-capita. The set of control variables includes the state unemployment level, log income per-capita, and log real gas price. Some specifications also include year dummies, a linear time trend, or a set of state-specific time trends.

Table 3 presents estimates for various specifications of the dynamic panel model. Column (I) reports results from the pooled ordinary-least-squares (OLS) estimator, which ignores the panel nature of the data and fails to account for endogenous lane-mileage. That specification produces a statistically significant long-run induced demand elasticity estimate of 0.855, but otherwise performs badly. The unemployment and gas price coefficient estimates are not statistically significant and, contrary to expectations, the coefficient on the income variable has a negative sign. Estimates presented in column (II) are from the within-group estimator, which demeans each of the variables at the state level to control for fixed effects. The resulting long-run elasticity estimate falls slightly to 0.703, and coefficients for the other explanatory variables become statistically significant and take the expected signs.

The long-run induced demand elasticity estimates in columns (I) and (II) are similar in magnitude (0.855 and 0.703 respectively), but the component parts of the long-run estimate suggest substantially different adjustment speeds for drivers.[8] The lagged VMT coefficient from the pooled OLS model in column (I) equals 0.974, which implies that drivers adjust their behavior very quickly following a change in

[8] Recall that the expression for the long run elasticity is $\frac{\hat{\beta}}{1-\hat{\phi}}$ where $\hat{\phi}$ and $\hat{\beta}$ are the lagged VMT and lane-mileage coefficient estimates, respectively.

Table 3
Dynamic panel model estimates.

Model	(I)	(II)	(III)	(IV)	(V)	(VI)
Estimator	OLS	OLS	2SLS	2SLS	2SLS	2SLS
State fixed effects		Y	Y	Y	Y	Y
Year fixed effects				Y		
State specific trends						Y
Lagged dependent variable	0.974	0.744	0.663	0.653	0.656	0.639
	(210.93)	(54.92)	(15.99)	(13.06)	(11.38)	(6.41)
Log urban lane-miles per capita	0.0220	0.180	0.349	0.369	0.364	0.322
	(4.17)	(14.22)	(4.22)	(3.77)	(3.14)	(1.84)
State unemployment level	−0.0400	−0.310	−0.394	−0.232	−0.341	−0.331
	(-0.65)	(-4.40)	(-4.67)	(-2.14)	(-4.18)	(-2.91)
Log income per capita	−0.0145	0.0468	0.0463	0.0621	0.0832	0.161
	(-3.81)	(7.78)	(7.31)	(2.07)	(1.98)	(4.81)
Log gasoline price (2015)	−0.00577	−0.0261	−0.0438	0.0347	−0.0424	−0.0476
	(-1.11)	(-4.99)	(-4.32)	(0.96)	(-3.93)	(-3.09)
Linear trend					−0.00159	
					(-0.88)	
Long-run induced demand elasticity	0.855	0.703	1.038	1.063	1.056	0.892
IV diagnostic tests						
First-stage *F*-statistic			22.17	16.77	11.84	5.346
Sargan test statistic ~ χ^2			0.91	0.67	1.60	0.11
First-stage coefficient estimates						
HCTI members per capita			0.0107	0.00897	0.00622	0.0144
			(5.160)	(4.235)	(2.930)	(3.190)
SCEPW members per capita			0.00314	0.00328	0.00395	0.00350
			(1.933)	(2.108)	(2.468)	(0.836)

Notes: The dependent variable is the natural logarithm of urban vehicle miles traveled per capita. The *t*-statistics in parentheses are based on robust standard errors clustered at the state level. Coefficients for the estimated model intercept, year dummies, and state-specific time trends are excluded for brevity.

highway capacity. But the within-group estimates in column (II) yield a smaller lagged coefficient estimate of 0.744, which implies a much slower adjustment speed. Although endogeneity bias renders these baseline results untrustworthy, they serve as reference point to help illustrate the substantial impact that instrumental variables and controls for fixed effects have on induced demand estimates.

The two-stage least squares (2SLS) estimates of the dynamic model are shown in columns (III) through (VI) of Table 3. The specification in column (III) is estimated with the two-stage least squares within-group estimator, using the political-influence instruments. The estimated short and long-run induced demand elasticities are 0.349 and 1.038 (Wald-test p-value < 0.0001) respectively, which provides strong support for the fundamental law of traffic congestion. Additionally, the estimates provide a measure of how quickly traffic levels respond to changes in highway capacity. Following an expansion, urban VMT is expected to achieve 58.0%, 73.4%, and then 90.1% of its ultimate equilibrium level of growth after a span of two, three, and five years respectively. In other words, these estimates predict that the effects of induced demand will set in quickly and new traffic will consume more than 90% of the new highway capacity after just five years.

Columns (IV), (V), and (VI) present estimates from other specifications of the partial adjustment model, and include year dummies, a linear time trend, and state-specific time trends respectively. Overall, the results are robust and change little with additional explanatory variables. When year dummies are included, the estimated long-run induced demand elasticity increases slightly to 1.063 (Wald-test p-value < 0.0001) compared to the estimate of 1.038 from specification (III). Similar results hold for specification (IV), which includes a linear time trend instead of year dummy variables. That specification yields a long run elasticity estimate of 1.056 (Wald-test p-value < 0.0001), which is also nearly identical to the estimates based on specifications (III) and (IV). In specification (VI), the lane mileage and autoregressive coefficient estimates are 0.322 and 0.539 respectively. Together those estimates yield a long-run elasticity estimate of 0.892, which is smaller than the estimates from specifications (III), (IV), and (V). The most likely explanation for the smaller estimate would be the addition of 51 state-specific time trends, which significantly reduces the degrees of freedom and increases the likelihood of overfitting the model.

The lower panel of Table 3 presents the first-stage results and diagnostic tests to assess the predictive power and validity of the instruments. To make interpreting the coefficients easier, the political influence instruments are measured per 1,000,000 people, which is approximately twice the size of a congressional district in 1990.[9] The results suggest that a state's cumulative stock of HCTI members is a strong predictor of lane-mileage. The estimated coefficient from specification (III) equals 0.0107, which suggests that an additional seat on the committee increases urban lane-mileage per congressional district by 1.07 percent. The cumulative count of senators on the SCEPW has a statistically significant effect in specifications (IV) and (V), but the estimated coefficients are smaller than those for the HCTI instrument. The difference between the estimated coefficients is reasonable given the structure and institutional nature of Congress. For example, the US House of Representatives has historically possessed a greater share of authority over transportation policy, and during the 1974 to 2017 period, the House introduced 71% of the 1085 transportation-related bills that were eventually enacted into law.

Two diagnostic tests also provide support for the strength and exogeneity of the instruments. The first stage *F*-statistics for specifications (III)–(V), reported in the lower panel of Table 3 exceed the Stock and Yogo (2005) critical value of 8.68, showing no evidence of weak instrument bias. Furthermore, results from the Sargan test of the overidentifying restrictions also support instrument validity. The null hypothesis for the test states that the exclusion restrictions hold, and failure to reject the null hypothesis lends support to the validity of the

[9] The 1990 US Census counted 249.6 million people; dividing that number by 435 gives an average population per congressional district of 574,713.

Table 4
GMM estimator results.

	(GMM-I)	(GMM-II)	(GMM-III)	(GMM-IV)
Lagged dependent variable	0.786	0.906	0.854	0.828
	(64.24)	(343.98)	(66.41)	(40.72)
Log urban lane-miles per capita	0.187	0.0801	0.104	0.131
	(14.73)	(18.86)	(8.77)	(6.13)
Log income per capita	0.0309		0.0182	0.0624
	(6.91)		(4.14)	(3.47)
State unemployment level	−0.231		−0.179	−0.132
	(-15.38)		(-7.52)	(-5.21)
Log gasoline price (2015)	−0.0237		−0.0135	−0.0149
	(-10.87)		(-4.78)	(-4.61)
Linear trend				−0.00164
				(-2.68)
Long-run induced demand elasticity	0.874	0.852	0.714	0.758
External political instruments used?		Y	Y	Y
Sargan overidentifying restrictions				
– test statistic $\sim \chi^2$	49.64	50.68	48.94	47.29
– degrees of freedom	317	912	912	912
Second degree serial correlation				
– test statistic $\sim N(0,1)$	0.980	1.011	0.991	0.970

Notes: The dependent variable is log urban vehicle miles traveled per capita. The *t*-statistics in parentheses are based on robust standard errors clustered at the state level. Coefficients for the estimated model intercept, year dummies, and state-specific time trends are excluded for brevity. For the Sargan test, the overidentifying restrictions are valid under the null hypothesis. Arellano and Bond (1991) proposed the second degree serial correlation test for the first differenced errors and, under the null hypothesis there is no serial correlation. To reduce the number of instruments, each specification includes a maximum of 10 lags of any endogenous regressor in the instrument matrix.

instruments. None of the tests rejected the null hypothesis. To address potential bias in the standard errors, those reported in Table 3 are robust to heteroscedasticity and within state serial correlation in the error terms.

Overall, the results from the partial adjustment model are robust to adding year dummies or a linear time trend. The estimated urban lane-mileage coefficients for specifications (III), (IV), and (V) are 1.038, 1.063, and 1.056 respectively. Moreover, the three corresponding 99% confidence intervals all encompass the value 1.0, which lends support for the fundamental law of traffic congestion. With one exception, the estimated effects for the other control variables are all measured precisely and retain the expected signs. The gas price coefficient in specification (IV) is not statistically significant, but its effect is likely captured by the year dummy variables which control for shocks that are common across states in a given year.

5.1. Robustness checks

To further test the robustness of the partial adjustment model, Table 4 presents results generated by the GMM estimator of Blundell and Bond (1998) discussed above. In each of the specifications, the dependent variable is the natural logarithm of urban vehicle miles traveled per person. The two key explanatory variables are the one year lag of the dependent variable and the measure of urban lane mileage per person, also measured in logs. Only specification (GMM-I) excludes the political instruments, while (GMM-II) – (GMM-IV) utilize the instruments with different sets of control variables. Across all four specifications, coefficient estimates for the lagged dependent variable range from 0.79 to 0.90, suggesting that aggregate urban vehicle mileage exhibits strong persistence from year to year. This finding likely stems from the transaction costs associated with switching one's mode of transport, residence, or employment location. If these costs are substantial they would impede drivers from quickly adjusting their behavior in response to a change in lane-mileage.

The short-run effect of urban lane mileage on vehicle miles traveled is measured precisely and ranges from 0.13 to 0.19 across models. The corresponding long-run estimates presented in the bottom panel of Table 4 are more than 4 times larger than their short-run counterparts ranging from 0.71 to 0.87. Although these induced demand estimates are somewhat smaller than their analogous within-group counterparts, they still suggest that induced demand rapidly erodes the time-savings benefits from highway expansion.

6. Conclusion

These findings offer persuasive evidence supporting the fundamental law of traffic congestion, and indicate that capacity expansion is not a viable long-term solution to urban traffic congestion. Across specifications of the dynamic model that controlled for endogenous lane-mileage and state fixed effects, the within-group estimator generated long-run induced demand elasticities ranging between 0.892 and 1.063, all with very small standard errors. These elasticities, along with the other coefficient estimates, are robust to the addition of year dummies, linear time trends, and state-specific time trends. The specifications that excluded the instruments, however, produced considerably smaller long-run elasticity estimates of 0.703 and 0.855. These findings suggests that failing to account for endogeneity can introduce sizable downward bias in the lane-mileage coefficient estimates. Furthermore, results from the dynamic model suggest that after five years, induced vehicle travel is expected to grow to 90% of its equilibrium level, quickly decreasing traffic speeds on the new roadway capacity.

Expanding capacity may be a poor strategy for managing congested freeways, but that finding is not a sufficient rationale for summarily rejecting highway expansion as a policy option. The elasticity estimates in this paper show that capacity expansion in urbanized areas generates long lasting outcomes, both positive and negative. One such outcome is the increase in total vehicle throughput that an expanded highway can serve. Work commutes, deliveries, and social engagements make up much of the induced vehicle travel, which generates beneficial economic activity. At the same time, additional vehicle trips generate offsetting costs in the form of carbon emissions, air pollution, and congestion. And, although these findings support the fundamental law, alone, they do not imply that capacity expansion is wholly unwarranted. Rather, the findings identify and measure some, but not all, of the benefits and costs generated by highways and vehicle travel, and can help officials improve the efficiency of transportation systems in urban areas.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2018.12.006.

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Title
Induced Demand: An Urban Metropolitan Perspective

Permalink
https://escholarship.org/uc/item/5pj337gw

Author
Cervero, Robert

Publication Date
2001-03-01

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Induced Demand:
An Urban and Metropolitan Perspective

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Paper prepared for

Policy Forum:
Working Together to Address Induced Demand

U.S. Environmental Protection Agency
Federal Highway Administration, U.S. Department of Transportation
Eno Transportation Foundation, Incorporated

March 2001
Second Revision

Induced Demand:
An Urban and Metropolitan Perspective

Most studies of induced travel demand have been carried out at a fine to medium grain of analysis – either the project, corridor, county, or metropolitan levels. The focus has been on urban settings since cities and suburbs are where the politics of road investments most dramatically get played out. The problems assigned to induced demand – like the inability to stave off traffic congestion and curb air pollution – are quintessentially urban in nature.

This paper reviews, assesses, and critiques the state-of-the-field in studying induced travel demand at metropolitan and sub-metropolitan grains of analysis. Its focus is on *empirical* and *ex post* examinations of the induced demand phenomenon as opposed to forecasts or simulations. A meta-analysis is conducted with an eye toward presenting an overall average elasticity estimate of induced demand effects based on the best, most reliable research to date.

1. URBAN HIGHWAYS AND TRAVEL: THE POLICY DEBATE

Few contemporary issues in the urban transportation field have elicited such strong reactions and polarized political factions as claims of induced travel demand. Highway critics charge that road improvements provide only ephemeral relief – within a few year's time, most facilities are back to square one, just as congested as they were prior to the investment. Traffic is said to behave more like a gas than a fluid – it expands to fill available space. Regional transportation plans, such as in the San Francisco Bay Area, have been challenged on the very grounds that they failed to adequately account for the possibility new road investments might induce sprawl and the extra trips associated with it. Reflecting on the state of urban transportation policy in America, Wilfred Owens (1985, p. 366) echoed this sentiment: "Meeting the ever-growing needs for transport capacity has often proved to be a fruitless task, as the persistence in urban traffic jams attest".

The contention that "you can't build your way out of traffic congestion" has become a rallying cry of the Surface Transportation Policy Project (STPP). In a recent study of 70 metropolitan areas across 15 years, the Surface Transportation Policy Project (STPP, 1999) concluded that metropolitan areas that invested heavily in road capacity expansion fared no better in easing traffic congestion than metropolitan areas that did not. While this and similar analyses can be criticized for inferring causality from simple correlations, nevertheless such research often resonates with politicians because results are comprehensible and accessible. The downside of more sophisticated statistical analyses is that the results are often circulated among and appreciated by a fairly

small cadre of academic-types, not always the loudest voices shaping highway policies in America today.

The notion that new roads offer only short-term relief is today found in the popular media. A case in point is commentary by noted columnist Neal Peirce (1999) on the state of highway programs in metropolitan Washington, D.C.: "Widened roadways create excess capacity. Drivers anxious to cut their driving times switch from other roads. Where roads lead to less developed outer suburbs, homebuilders see opportunity, there's a rush of residents of the city and older suburbs, and congestion mounts."

As discussed in later in this paper, methodological issues pervade the induced demand policy debate. Emblematic is the issue of causality – might traffic growth induce road investments every bit as much as vice-versa? Some observers point out that for a good century or more road investments have not occurred in a vacuum but rather as a consequence of a continuing and comprehensive effort to forecast and anticipate future travel demand. Accordingly, road improvements act as a lead factor in shaping and a lag factor in responding to travel demand. A recent study by the Urban Transportation Center (1999) at the University of Illinois at Chicago lends anecdotal credence to this position. Using 60 years of data, the study showed that road investments in metropolitan Chicago could be better explained by population growth rates a decade earlier than vice-versa. For both the Tri-state Tollway (I-294) and East-West Tollway (I-88), the study concluded "major population gains occurred in proximity to the expressways over a decade before the construction of the respective expressways".

2. ANALYTICAL CHALLENGES

The study of induced demand at the project and corridor levels involves an *intra-metropolitan* scale of analysis. Studying travel between sub-areas (e.g., counties) or regions[1] involves *inter-metropolitan* comparisons. Both scales pose significant theoretical and methodological challenges. These include coping with issues related to: (1) Resolution; (2) Measurement; (3) Specification; and (4) Normative Significance. These challenges and what they imply for the study of induced travel demand are reviewed in this section.

2.1 Resolution

A fine-grain analysis of induced travel will often yield appreciably different results than a courser grain analysis. Lee *et al.* (1999, p. 71) reflect on how the resolution of analysis can influence induced demand estimates:

> If the demand is for a single facility, then induced traffic will appear large in relation to previous volumes, because most of the change will be from

> diverted trips. At the regional level, induced traffic …would be a smaller share of total traffic growth because only trips diverted from other regions, plus substitutions between transportation and other goods, make up the induced share.

When diverted trips are netted out of the calculations, however, the induced demand effect generally becomes bigger as the unit of analysis increases in size. This is because bigger geographical areas capture the impacts of an expanded artery on the capillaries that tie to it – i.e., the additional traffic on feeder routes within a tributary area. This is revealed by the work of Hansen *et al.* (1993) wherein the effects of road capacity on traffic were studied for road segments, counties, and metropolitan areas in California. At the road segment level, estimated elasticities of VMT as a function of lane-miles were in the ranges of: 0.15 to 0.30 over a four-year horizon; 0.30 to 0.40 over a 10 year horizon; and 0.4 to 0.6 over a 16 year horizon. At the county level, short-term elasticities were higher, in the range of 0.32 to 0.50. And at the metropolitan scale of analysis, short-term elasticities edged even higher: 0.54 to 0.61.

2.2 Measurement

Measurement problems abound in studying induced demand at the intra- and inter-metropolitan scales. Problems related to sources, spillovers, boundaries, and variable definitions are reviewed below.

Sources

Traffic growth comes from numerous sources, some related to increased supply of roads and some not (e.g., exogenous factors like increased labor-force participation – and commuting – among women). Conventional wisdom holds some of the traffic gains spawn by a new road facility are *generative* (e.g., suppressed trips being released) and some are *redistributive*. Sources also are thought to vary between the near-term and long-term. While it is easy to show road improvements are followed by increased traffic, it is not always easy to quantify the *magnitude* and *sources* of the increase.

In the near term and in reasonably congested settings, road improvements stimulate what Downs (1962, 1992) termed "triple convergence" – motorists switch modes, routes, and times of day to exploit available capacity. Among these redistributions, only mode shifts add new trips and are thus *bona fide* contributors to induced demand. While route and schedule switches may reduce some of the travel-time savings conferred by a project, they do not represent new vehicle travel (assuming trips do not become more circuitous). Trips might also lengthen as motorists opt to travel farther because of freer flowing traffic. Added to this are suppressed (and presumably lower value) trips that are unleashed by faster-moving traffic, also known as "latent" demand. New and longer trips are

also part of the induced demand equation. Over the long term, new roads induce structural shifts – namely, the realignment of land development and a tendency toward higher car ownership as a result of more auto-centric landscapes and the decline in transit services. These components are also elements of induced travel.

Most technical studies on induced travel have sought to exclude diverted trips, some more successfully than others. Most have embraced definitions of induced travel similar to that of Schmidt and Campbell (1956): "The added component of traffic volume which did not previously exist in any form, but which results when new or improved transportation facilities are provided".[2]

Short of placing an electronic tag on each traveler affected by a new road and monitoring his or her travel, disentangling the many contributors to increased travel – at least to a high degree of precision—can be a futile exercise (Bonsall, 1996). Accordingly most studies have ignored the sources of additional trips altogether, assuming that traffic gains are attributable to a host of factors. Regardless, some studies have tried their hand at sorting out the sources. Pells's 1989 literature review suggested most redistribution occurred via time-of-day shifts however another U.K. study (Howard Humphreys & Partners, 1993) maintained route shifts were the predominant form of redistribution. A study by Kroes *et al*. (1996) of the opening of Amsterdam's Ring Road and the elimination of a major bottleneck at a tunnel-crossing found, in the short run, significant amounts of diverted travel (from off-peak times and other routes) and little truly new travel (in the form of mode shifts or extra trips). Based on household surveys in California, Dowling and Colman (1995) suggested near-term redistributions are often a balance of both spatial and temporal shifts. DeCorla-Souza (2000) maintains the lengthening of trips, spawn mostly by land-use adjustments, is the most significant cause of induced travel (when measured as VMT), though no evidence is presented. Within a regional context, he contends the impacts of highway improvements on the number of motorized trips and modal shifts are fairly modest, and the impacts on route shifts and regional growth are negligible to non-existent. Most consistent across studies is the position that improved roads trigger shifts from the off-peak to the peak.

Evidence on the redistributive effects of road investments on transit usage is particularly slim. This is partly because inter-modal impacts of new highway construction likely unfold slowly and inconspicuously – e.g., transit service cuts prompted by a lowering of suburban densities spawn, in part, by highway-oriented patterns of development likely occur sporadically and over a number of years. Cross-elasticities of demand for transit as a function of highway travel times, experiences show, are quite varied – studies have recorded values of 0.36 in the San Francisco Bay Area, 0.42 in Montreal, and 0.84 in greater Chicago (Cervero, 1990). Cross-elasticities generally increase with congestion levels, metropolitan size, and quality of transit services. Few studies have traced the path between road expansion, faster automobile speeds, and drops in transit

patronage. A study of linking a major arterial and freeway in southeastern Melbourne, Australia found some evidence of modal shifts (Luk and Chung, 1997). Over a seven-year period spanning the opening of this critical network link in one of the region's fastest growing corridors, ridership on the Dandenong train line fell 14 percent compared to a regionwide decline of just 4 percent. Pells's (1989) study of the grade-separation of the Westway in London found a 12 percent increase in daily traffic and a 19 percent increase in peak traffic in the corridor. The greater increase in the peak period was attributed to mode shifting from rail, but no evidence was presented to support this.

Spillovers

Another measurement problem lies in the fact that the effects of expanding a particular highway segment can reverberate throughout a network, though how much and to what extend is generally unknown. Road facilities do not stand in isolation, but rather are links in a hierarchical network. The inter-dependency of roads means improvements on any one link inevitably have some repercussion on travel demand on other links that feed into it. To capture the spillover impacts of road improvements, many analysts have chosen to study induced demand impacts at either the metropolitan level or county level. At a metropolitan scale, virtually all route diversions will be internal to the unit of analysis.

Boundaries

To solve spillover problems, many recent analyses of induced demand have been conducted at an area-wide scale. Aggregation, however, poses potential bias problems since metropolitan and county boundaries are political artifacts that rarely correspond to true travel-sheds.

Another boundary-related problem is the focus on roads under state jurisdiction at the exclusion of those owned and maintained by lower levels of government. Rigorous modeling of induced demand requires rich time-series data of travel and road capacity, information that in most instances only state Departments of Transportation regularly and consistently maintain. Consequently, most metropolitan and corridor level studies have focused on how traffic changes along state owned and maintained highways (Hansen *et al*., 1993; Hansen and Huang, 1997; Noland and Cowart, 2000; Fulton *et al*., 2000; Cervero and Hansen, 2001). Many times, the collectors and arterials that feed into state highway are under local jurisdiction. By default, changes in travel on lower-level facilities get ignored altogether. This poses the possibility of spurious inferences since one cannot rule out that purported induced traffic generated on state highways are not matched by reduced travel and shifts from local facilities.

Variables

Nearly all metropolitan-scale analyses have measured the dependent variable, travel consumption, in terms of VMT (vehicle miles of travel). This is partly because VMT is thought to correlate strongly with the social costs of automobile travel. VMT is an imperfect measure for it ignores some elements of trip redistribution, such as re-scheduling of trips from the shoulders to the heart of the peak period. While time-of-day shifts do not constitute new trips, they can deteriorate levels of service and thus, one might argue, deserve attention in the induced demand debate. DeCorla-Souza and Cohen (1999) maintain negative impacts of auto-motoring do not vary significantly by time of day and thus the focus of induced demand studies should be on daily VMT. Some contend that policy concerns like air pollution and greenhouse gas emissions are at least as strongly tied to vehicle hours of travel (VHT) as they are to vehicle miles of travel (VMT), thus the effects of new roads on cumulative hours logged should also be considered (Ewing, 1996).

Supply-side variables used in induced demand studies also face measurement dilemmas. Lane-miles of capacity are commonly used to represent the benefit of a highway improvement. In truth, benefits are best expressed by outputs (e.g., travel-time savings) not inputs (lane additions). An additional half-mile of lane on a crowded bridge crossing will provide much more benefit than a half-mile of lane in the uncongested exurbs. The notion that lane-miles themselves capture supply improvements is presumptuous. The armature that accompanies a road improvement – e.g., width of shoulders, provision of attenuation barriers, channelization – will also have a bearing on capacity and travel speeds. In some corridors, improved signal timing, smart-highway provisions (e.g., real-time message boards), ramp-metering, or surface re-pavement might do as much to expedite traffic flows as adding two eleven-foot lanes.

Studies that have used lane-miles as a proxy of transportation benefit have usually compiled data only for state facilities. Some have pooled more than two decades of data on state highway capacity to predict traffic growth. Cohen (1995) cautions that re-designations to and from state highways can further introduce statistical noise.

Cohen (1995), DeCorla-Souza (2000), and others have criticized studies that have used lane-miles as predictors since travel demand is not tied directly to road capacity but rather the benefits it yields, generally expressed in travel-time savings. As discussed later, studies that have employed lane-miles as a predictor treat it as a stand-in, or proxy, for travel-time savings for practical reasons. Lane-miles can generally be measured with a fair degree of accuracy, however measuring travel time is fraught with difficulties.

When used in elasticity form to gauge benefits, all measures of road improvements fail to adequately account for the scale of projects. For example,

in an elasticity calculation, the proportional change in capacity of expanding a road from 4 to 6 lanes is expressed the same (in the denominator) for a one-mile road segment as a 20-mile road segment; in both instances, the relative increase is 50 percent. Surely, the traffic-inducing impacts of a 20-mile-long project will in most instances be greater than a 1-mile-long project.

2.3 Specification

Good, reliable research is based on well-specified, internally valid study designs – ones that are rooted in accepted theories and measure what they are suppose to measure (Hakim, 1987). Early studies of induced demand concentrated on gauging the traffic-producing impacts of new facilities. Induced demand was generally expressed as a percentage share of traffic growth. Most studies failed to control for the influences of exogenous factors that might have contributed to traffic increases.

More recent empirical work has sought to isolate out the effects of road expansions on travel demand by statistically removing potential confounding influences. This has generally been done through pooled time series/cross-sectional analyses – i.e., tracking trends in a panel of counties or metropolitan areas over multiple time points. A case in point is the work of Hansen *et al*. (1993) and Hansen and Huang (1997). They used econometric models to explain VMT as a function of lagged lane-miles of California highways, controlling for factors like population, personal income, residential densities, and gasoline prices. Fixed-effects dummy variables were employed to adjust for the idiosyncratic patterns of VMT growth for a particular county or metropolitan area unaccounted for by the models. Fixed-effect terms can be antidotes to model under-specification, helping to indirectly account for the influences of omitted (often exogenous) variables (e.g., female participation in the labor force) that likely have further propelled VMT growth.

One of the major specification problems confronted by all induced demand studies is the conflation of cause and effect. Until recently, efforts to measure induced demand effects could be criticized for ignoring issues of causality. Disentangling cause and effect in the interaction between road supply and travel demand is exceedingly difficult. Road investments are not made at random but rather as a result of conscious planning based on anticipated imbalances between demand and capacity. This implies that, irrespective of any traffic inducement effect, road supply will generally correlate with road use. Skeptics can easily claim that all or most of the observed relationships between traffic and road investment derive from good planning rather than traffic inducement.

The choice of control variables can also lead to spurious inferences. For example, a “transit service” variable might be used as a control since riding transit is an alternative to driving. However, one could also argue that poor transit service is an indirect consequence of road investments. In this case,

controlling for transit service could mask a potentially important traffic inducement mechanism.

2.4 Normative Significance

Another line of criticism questions the normative significance of research findings on induced demand. Even if estimated elasticities are essentially correct, lane-mile growth accounts for a small share of VMT growth (Kiefer and Mehndiratta, 1998; DeCorla-Souza, 2000). In a larger context, induced demand effects are generally swamped by the effects of mega-trends on VMT growth, such as rising car ownership, feminization of the labor force, and declining real costs of gasoline. To underscore this point, Heanue (1997) used historical data on travel speeds and a range of elasticity estimates by Goodwin (1996) to illustrate that induced demand accounted for between 6 and 22 percent of VMT growth in Milwaukee from 1963 to 1991. That is, over three-quarters of VMT growth was attributable to exogenous factors like maturing baby-boomers and declining real gasoline prices that had nothing to do with road expansion.

Another normative concern is that induced demand studies are partial, focusing only on the cost implications of road expansion. Presumably, the extra VMT induced by new roads is generating some additional surplus that may or may not offset congestion impacts (Small, 1992; Hansen, 1998; Lee *et al*., 1999). Whether new roads are on balance beneficial to society cannot be informed by studies of induced demand; such weighty questions require a full accounting of benefits and costs.

Normative questions also arise as to whether possible VMT increases that following road expansion are necessarily "bad". "One can certainly envision situations where adding lane miles, by removing some traffic bottleneck, results in both better traffic conditions and a higher VMT per state highway lane-mile ratio" (Hansen and Huang, 1997, p. 217). From an air quality standpoint, higher VMT certainly means more tailpipe emissions, however in some instances these impacts might be more than off-set by the air quality benefits of expediting flows and eliminating episodes of stop-and-go traffic.

3. TOWARD A NORMATIVE FRAMEWORK

A normative framework for gauging induced demand impacts is shown in Figure 1. The causal chain works as follows: a road investment increases travel speeds and reduces travel times (and sometimes yields other benefits like less stressful driving conditions, on-time arrival, etc.); increased utility, or a lowering of "generalized cost", in turn stimulates travel, made up of multiple components,

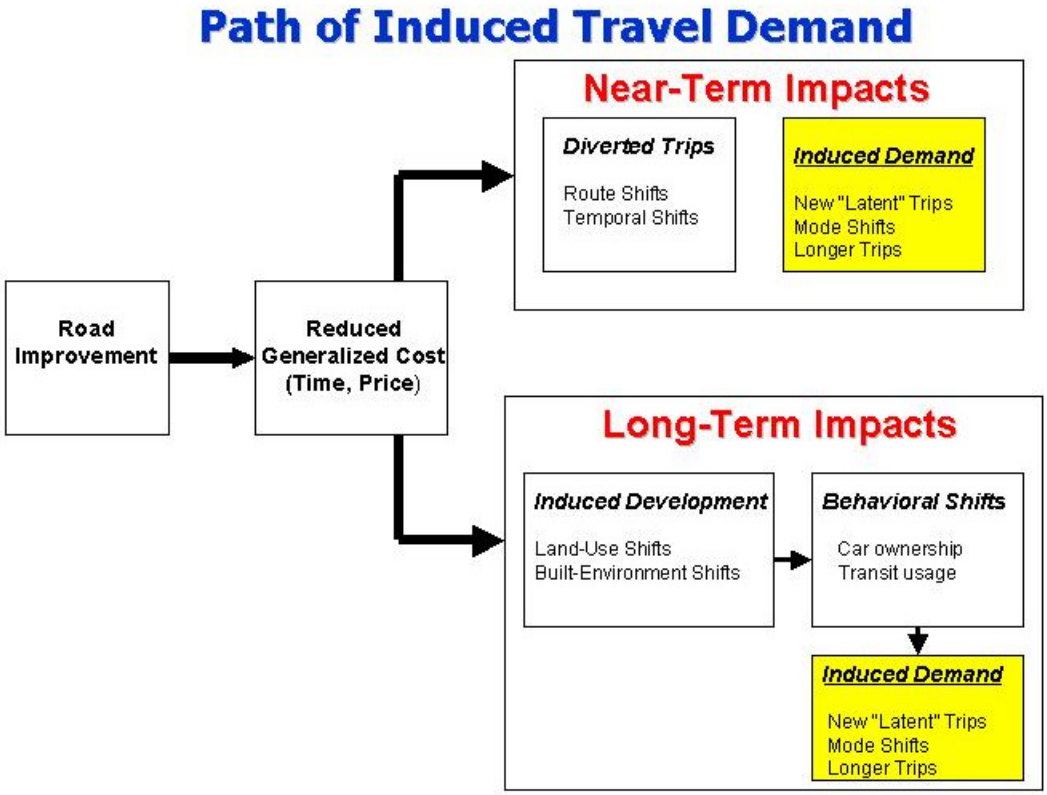


Figure 1. Normative Path of Induced Travel Demand

including new motorized trips (e.g., latent demand previously suppressed), redistributions (modal, route, and time-of-day shifts), and over the longer term, more deeply rooted structural shifts like land-use adjustments and increased vehicle ownership rates (that in turn increase trip lengths and VMT). Some of the added trips are new, or induced, and some are diverted. While evidence on the induced-growth effects of new highways is limited (Dunphy, 1996; Boarnet, 1997), roads and prominent fixtures of America's suburban landscape -- big-box retail, edge cities, and campus-style executive parks – that they serve are clearly co-dependent. While many contend that only newly generated traffic should be treated as induced travel (as portrayed in Figure 1), others maintain all traffic, including redistributions, needs to be counted to demonstrate the futility of trying to relieve traffic congestion through road construction.

Figure 1 embodies basic microeconomic principles that hold motorists travel more when they derive utility in the form of speedier and safer roads. This lowers the generalized cost of using a facility. Thus, induced demand should be measured directly as a function of travel-time savings, which itself should be

measured directly as a function of road improvements. That is, an intermediate causal relationship exists – the effects of road improvements are channeled through the intermediate step of lowering generalized costs which in turn affects travel demand. Notationally:

$$\eta = (\partial Q/\partial GC)(GC/Q) \qquad Q = f(GC, C);\ GC = g(S,C) \quad (1)$$

where: η = elasticity; Q = Quantity of trips; GC = Generalized Cost (including travel time); S = Supply of roads; C = Control vector.

In truth, empirical studies to date have relied on measures of induced demand that are either *proxies* or *partial*. As shown in Figure 2, proxy metrics have gauged changes in travel demand, Q, as a function of changes in road capacity, S, without weighing the fact that the effects of road investments get channeled through their impacts on generalized cost. That is, they overlook the intermediate step of the causal path. Proxy measures express elasticities as:

$$\eta = (\partial Q/\partial S)(S/Q) \qquad Q = f(GC, S) \quad (2)$$

Partial measures of elasticity can likewise be faulted for incomplete specification. Notably, they fail to weigh the relative role of road improvements in bringing about travel-time savings and to gauge how in turn this induces travel. While they model the intermediate step, they ignore the relative importance of road improvements (vis-à-vis other possible predictors) as the catalyst:

$$\eta = (\partial Q/\partial GC)(GC/Q) \qquad Q = f(GC, C) \quad (3)$$

No metropolitan-scale studies of induced travel demand, as far as I know, have specified relationships as shown in Figure 1. Accordingly, despite significant progress made in documenting induced demand effects over the past few decades, our knowledge of this phenomenon remains incomplete and partial.

4. RESEARCH FINDINGS

At the broadest level, metropolitan and sub-metropolitan research on induced demand falls into two main categories: empirical studies and simulations. This paper focuses on empirical analyses, mainly those carried out over the past two decades. Empirical studies break down into three general groups: (1) those of specific facilities or projects, what Hansen *et. al.* (1993) called "facility-specific" studies; (2) those that study general pattern over a larger geographic territory, what Ruiter *et al*. (1979) termed "area" studies; and (3) those that examine individual travel behavior.

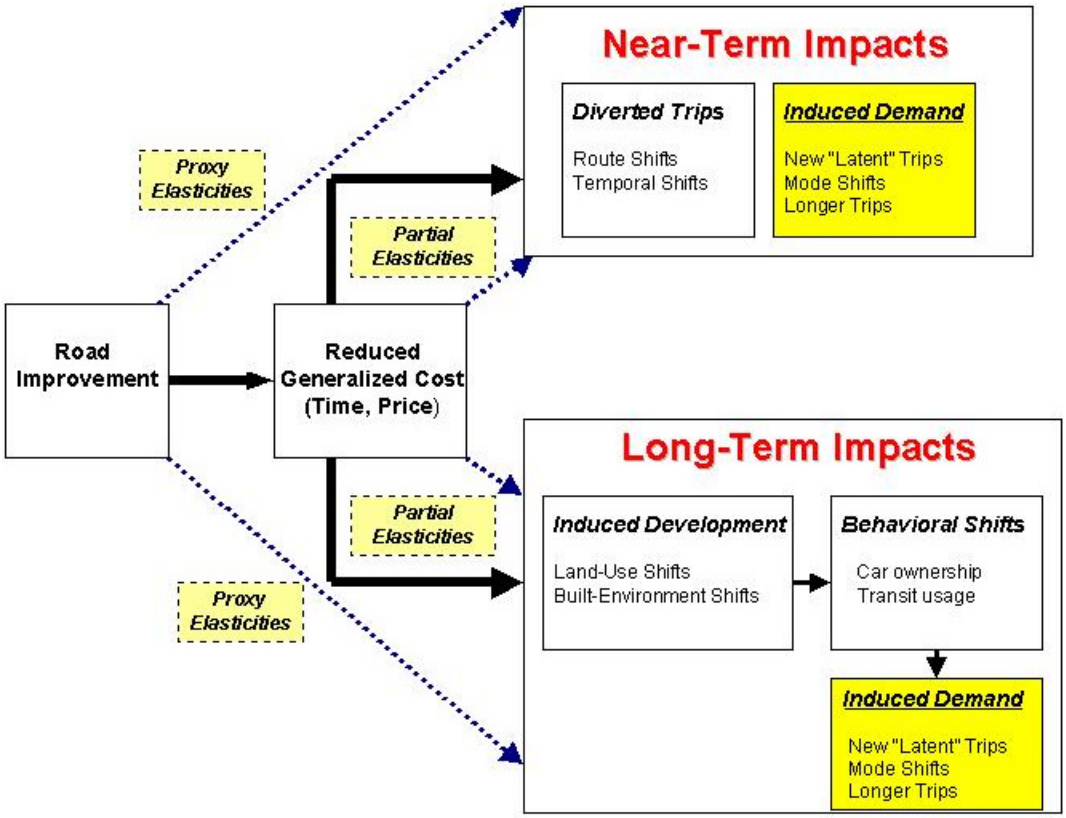


Figure 2. Approaches Used to Measure Induced Demand Elasticities: Proxy and Partial Elasticities

Facility-specific studies probe relationships at a disaggregate, intra-metropolitan scale whereas area studies involve aggregate, inter-metropolitan comparisons. In the past few years, even more disaggregate studies have been conducted, focusing on travel at the household level as a function of road supply, however even these studies measure supply at a highly aggregate, typically metropolitan, level.

Empirical findings are summarized below, broken down by six analytical approaches: (1) facility-specific analyses; (2) model forecasts; (3) simulations; (4) area studies based on proxy measures; (5) area studies based on partial measures; and (6) disaggregate models. Most of the findings summarized below are drawn from secondary sources – both original studies and a handful of syntheses of induced demand found in the urban transportation literature (Pells, 1989; Hansen, *et al*., 1993; Cohen, 1995; Goodwin, 1996; Noland and Lem,

2000). Findings are summarized in Tables 1 (facility-specific analyses) and 2 (aggregate-scale analyses with elasticity estimates).

4.1 Facility-Specific Analyses

The finest grain analysis of induced demand effects occurs at the project level. Most facility-specific studies compare observed traffic counts along an improved facility to what would have been expected had the project never been built. Expected volumes under the "null" might be based on trend extrapolation, travel-demand forecasts, or comparisons to a "control" corridor or regional trends. Results are not presented as elasticities but rather as percentages of traffic growth thought to be attributable to induced travel.[3] Measuring elasticities is difficult for brand-new facilities since, after all, it is difficult to express a proportion when starting from a base of zero.[4] Instead, elasticities are best suited for measuring impacts of lane additions – e.g., proportional change in VMT relative to a proportional change in lane miles (or the travel-time savings they induce).

Facility-specific studies generally rate low in terms of internal validity but get high marks for transparency and accessibility to laypersons. One problem with some before-and-after project-level analyses is they fail to sort out diverted trips from latent trips in gauging induced demand. Most project-level studies also ignore the repercussions of an expanded road segment on travel along lower order routes that connect to it. Since traffic increases on connecting and lower-order facilities are overlooked, project-level studies are thought to have generally misstated induced demand impacts.

Below, three types of facility-specific studies are reviewed: (1) Growth Comparisons; (2) Quasi-Experimental Comparisons; and (3) Regression Analyses. This order matches the degree to which potential confounding factors are controlled – from growth comparisons (the lowest) to regression analyses (the highest). Table 1 summarizes the research designs and findings of key facility-specific studies to date, particularly those that have sought to remove diverted trips from estimates. As shown, findings vary considerably across studies.

Growth Comparisons

A "growth comparison" is the simplest approach to estimating the incremental gains in traffic in the aftermath of a road improvement. Past traffic trends are indexed to another factor, like car registrations, and estimates are made of what traffic would have been without a road improvement by factoring off of known car registrations. Differences between recorded and expected volumes are considered to be newly generated traffic. In hopes of removing diverted trips from the estimate, some analyses have used wide screenlines that span across parallel, alternate routes as well.

Table 1. Summary of Facility-Specific Studies of Induced Travel Demand

Study	Setting	Data	Method	Facility Type	Variables		% Growth Attributable to Induced Travel		
					Demand	Supply	ST	IT	LT
Jorgensen (1947)	NY-CO	TS	GC	New parkway	ADT	New facility	25-30		
Lynch (1955)	ME	TS	GC	Turnpike	ADT	New facility			30
Mortimer (1955)	Chicago, IL	TS	GC	Expressway	ADT	New facility		3-33	
Frye (1964)	Chicago, IL	TS	MP	Expressway	ADT	New facility			11[a]
Frye (1964)	Chicago, IL	TS	MP	Expressway	ADT	New facility			7[a]
Holder, Stover (1972)	TX	TS	GC	Highways	ADT	New facility	0-21[a]		
Pells (1989)	London, UK	TS	MP	Highways	ADT	Widening			27[a]
Pells (1989)	London, UK	TS	MP	Highways	ADT	Widening		25	56
Pells (1989)	London, UK	TS	MP	Highways	ADT	Upgrade			80
Pells (1989)	London, UK	TS	MP	Expressway	ADT	New facility		77[a]	
Pells (1989)	London, UK	TS	MP	Tunnel	ADT	New facility			89[a]
Hansen et al (1993)	CA	TS/CS	GC/Reg	Highways	ADT	Widenings	--[b]	--[b]	--[b]
Kroes et al. (1996)	Amsterdam, NL	TS	MP	Tunnel	ADT	New facility		4.5	
Luk, Chung (1997)	Melbourne, AU	TS	MP	Freeway link	ADT	New facility	0		
Mokhtarian, et al. (2000)	CA	TS/CS	MP	Highways	ADT	Widenings	0	0	

Key:

TS = Time Series
CS = Cross-section
GC = Growth Comparison
MP = Matched Pairs
Reg = Regression
ADT = Average Daily Traffic
ST = Short-Term (< 1 year)
IT = Intermediate Term (1-5 years)
LT = Long Term (> 5 years)

Notes:

[a] Thought to include significant amounts of diverted trips

[b] Presented as elasticities: 0.2-0.3 for short and intermediate term; 0.3 to 0.6 for the long term

One of the earliest "growth comparison" studies, by Jorgenson (1947), studied traffic trends on two newly opened parkways connecting New York City and New Haven, Connecticut. Jorgenson showed that gasoline sales growth for the state of Connecticut followed traffic growth in the corridor quite closely prior to the opening of the parkways. Gasoline sales growth after opening was used to estimate what traffic would have been without the new facility. From this, Jorgenson estimated the new parkway increased traffic in the corridor 25 to 30 percent. Because the corridor included all significant alternate routes, it was presumed most of this gain represented new, not redistributed, travel. Another early study indexed traffic growth to increases in motor vehicle registrations to measure induced travel on a new expressway in Chicago (Mortimer, 1955). The expressway was estimated to have increased traffic by 3 to 33 percent along three screenlines, each 4 to 5 miles in length. While the wide screenlines meant some route diversions were probably internalized (i.e., captured by screenline

counts), the study could not rule out that some of the traffic growth migrated from routes beyond the screenlines.

Comparisons of forecasted and actual traffic have been widely used in the United Kingdom to estimate the induced demand effects of individual projects. In its comprehensive review of British experiences, the U.K. Standing Advisory Committee on Trunk Road Assessment issued a report that found travel forecasts were, on average, 10 to 20 percent below actual recorded traffic because induced traffic was overlooked (SACTRA, 1994). For a one-year forecast, the under-projection of traffic volumes along improved road facilities was found to be 5.7 percent. This compared to an average under-projection of 0.7 percent on alternative routes, suggesting induced demand represented about 5 percent of traffic growth (Goodwin, 1996). Over the long-run, induced demand effects were thought to be four times as high. How much of the forecast error was attributable to truly newly generated traffic versus forecast inaccuracies (beyond the failure to account for induced demand) was left unsaid.

While most project- and corridor-level analyses have defined induced demand in terms of shares of traffic growth, some early studies did estimate elasticities. Much of this earlier work, summarized in Ruiter *et al*. (1979), estimated lane-mile elasticities of a much smaller magnitude than more recent work (reviewed later) carried out at an area-wide scale – generally in the range of 0.01 to 0.15.

Quasi-Experimental Comparisons

A criticism of many project-level comparisons, particularly early ones, is that little effort was made to introduce “controls”. Some studies used “quasi-controls” by comparing traffic trends between improved facilities and regions at-large. Holder and Stover (1972) employed such an approach in a study of eight urban highways in Texas, finding “apparent induced traffic” ranged from zero to 21 percent. Examining trends in pre- and post-construction average daily traffic (ADT) for 37 Texas urban corridors from 1955 to 1985, Henk (1993) obtained similar results.

A preferred approach to studying before-and-after traffic is matched-pair comparisons. This mainly involves comparing before-and-after screenline counts along an improved corridor versus a fairly comparable unimproved corridor. Induced traffic is measured as:

$$IT = [Q_{a(i)} - Q_{b(i)}] - [Q_{a(c)} - Q_{b(c)}] \quad (4)$$

where: IT = induced traffic; Q = quantity of traffic; b = before time point; a = after time point; i = improved corridor; c = control corridor

While matched-pair comparisons perform well in attributing traffic growth to road improvements, they say little about how much is diverted and how much is newly generated. Again, wide screenlines will partly solve this problem. Matched-pairs also assume controls are virtually identical in every respect save for the absence of the road improvement, which is of course never the case. Often efforts are made to choose corridors that are similar in terms of a few key factors like geographic setting, levels-of-service, and types of facilities.

Among the earliest matched-pair analyses of induced traffic in the United States were comparisons of traffic growth on Chicago's Dan Ryan and Eisenhower expressways with control corridors (Frye, 1964a, 1964b). Frye found between 7 and 11 percentage point differentials in corridor traffic growth rates, and concluded most of the difference was explained by route shifts not captured by screenline counts.

In a review of 20 matched-pair comparisons conducted for road projects in the United Kingdom, Goodwin (1996) calculated the average share of traffic growth attributed to induced traffic to be 25 percent, with a range of 7 percent to 66 percent. Moreover, the "unexplained" growth attributable to induced travel increased from an average of 10 percent for a very short time frame of less than one year to 33 percent over a 5-year period. Pells's (1989) review of 78 published and unpublished studies that used control corridors in the greater London area found considerable variation in traffic impacts, with induced demand effects (exclusive of redistributions) ranging from 0 percent to 80 percent.

Several recent matched-pair studies have found no measurable induced demand effects. A fairly rigorous matched-pair analysis in Melbourne, Australia recorded no induced travel over a 10-year period as a consequence of linking a major freeway to a major arterial (Luk and Chung, 1997). After netting out estimated traffic gains due to route and time-of-day shifts, the authors recorded an annual traffic-volume growth rate of 1.7 percent along the improved corridor. The average traffic growth rate of two control routes was actually more, 2.7 percent, suggesting no new travel was generated by the network completion.
A recent matched-pair comparison of 18 California state highway segments over 1976 to 1996 period also found little evidence of induced demand (Mokhtarian *et al*., 2000). The study found statistically and practically indistinguishable differences in ADT growth rates between improved and unimproved segments. The authors cautioned the inability to choose truly random and similar control sites could have meant matched-pair models understated induced demand effects (though one might expect any biasing effects to work in both directions).

Regression Models

An alternative to matched-pairs for controlling the influences of confounding factors that might explain traffic growth is multiple regression analysis. Because

of data limitations, this has rarely been done at the facility-specific level. Perhaps the most rigorous study to date to longitudinally study induced demand at the level of road segments is the work of Hansen *et al*. (1993). The authors probed the effects of adding highway capacity on VMT for a panel of 18 California highway segments from 1970 to 1990, all of which were expanded over this time period. The analysis employed a "counterfactual" approach. First, log-linear regressions were estimated that predicted traffic volumes as a function of capacities, controlling for secular growth in travel on all California state highways. The model was then applied under two scenarios. The first assumed the capacity increases occurred (which they had), while the second – the counterfactual – assumed there were no capacity expansions. The difference in predicted traffic under the two scenarios was assumed to be the traffic induced by expansion. For individual segments, the elasticities of VMT with respect to lane miles were 0.2 to 0.3 during the first four years, increasing to 0.3 to 0.4 after 10 years, and to 0.4 to 0.6 after 16 years.

4.2 Model Forecasts

Another approach to estimating induced demand invokes the use of large-scale travel-demand forecasting models to derive traffic estimates. Differences between forecasted and actual volumes are assumed to represent new "latent" trips. Implicitly, forecasting models are assumed to be valid except for their omissions of induced demand effects.

Relatively few travel-model-based estimates of induced demand have been carried out to date, at least in the United States. One example is the work of Addison (1990). The author compared actual and forecasted traffic on several expanded and enhanced facilities in northern California. While Addison used a conventional four-step model to forecast travel demand, he did not directly measure induced demand although he did find compelling evidence of its existence. In the case of a 12-mile arterial upgrade to a grade-separated facility, Addison found daily traffic on the improved section observed in 1985 exceeded 1995 forecasts by 21 percent while traffic in the peak was 25 to 30 percent greater.

The fact that relatively few studies have turned to four-step models to estimate induced demand effects of specific projects or corridor improvements is partly a commentary on the standing of today's forecasting tools. In many parts of the United States, travel-forecasting models are not up to the task of evaluating induced demand effects because they do no embody elasticities or feedback mechanisms that weigh, directly or indirectly, generative impacts. The relationship between induced demand and travel-forecasting models was the focus of a report produced by the Transportation Research Board (1995) of the National Research Council. The consensus view was that contemporary travel-demand forecasting models fail to adequately account for induced demand

effects. In a more recent appraisal, Heanue (1997) was more charitable, arguing that the vast majority of VMT growth due to induced travel is accounted by travel models. A study of transportation and land-use scenarios in Sacramento estimated that integrated transportation and land-use models account for 50 percent of the induced travel effect (Rodier, *et al*., 2001).

4.3 Simulations

Rather than modeling and estimating how road capacity shapes travel *ex post* (i.e., comparing actual and forecasted volumes), more recent large-scale modeling has focused on *ex ante* evaluations (i.e., simulations of future scenarios). This normally involves simulating future travel with versus without major road improvements, and measuring the resulting differences in regional traffic levels. An advantage of simulations is that, unlike the real world, one specific variable can be changed while holding others constant. Thus the impact of adding two lanes on VMT can be directly and unambiguously measured. This approach, of course, faithfully assumes the conventional four-step travel-demand forecasting model (and integrated land-use allocation model, if used) embodies induced demand effects – i.e., it is internally valid. As noted above, there is some disagreement on this question. While some metropolitan areas, like Portland and Sacramento, that are advancing the frontiers of travel-demand forecasting probably have models that significantly capture induced demand effects, many other metropolitan areas across the United States – big, medium, and small – probably do not.

One of the earliest and most systematic efforts to use transportation-planning models to simulate and predict the effects of road capacity expansion on vehicle travel is the work by Ruiter *et al.* (1979, 1980) (see Table 2). The authors estimated the effects on VMT of two highway improvements -- a new freeway and a freeway expansion -- in California. Their forecast models related trip generation rates to travel times, and were also able to account for impacts on modal splits as well as route and time-of-day distributions. For the new freeway, an elasticity of VMT with respect to vehicle miles of capacity of 0.38 was found. For the improved facility, a negative elasticity was actually produced (because added VMT was offset by reduced circuity for existing trips, and increased peak-period auto usage reduced off-peak travel).

Using the MEPLAN model and data from the Sacramento region, Rodier *et al*. (2001) employed a partial equilibrium approach to impute induced demand elasticities under a beltway improvement scenario. Arc elasticities of VMT as a function of beltway capacity (when accounting for trip generation, distribution, mode choice, and traffic assignment effects) were estimated to be 0.6 over a 15-year time horizon and 1.0 over a 40-year span.

Table 2. Summary of Area Studies and Simulations with Elasticity Estimates Based on Proxy Supply-Side Measures of Benefit

Study	Setting	Data	Method	Variables		Elasticity Estimates	
				Demand	Supply	Short-Term	Long-Term
Kassoff, Gendell (1972)	US urban areas	CS	GA	VMT/capita	Capacity Index	<0.58	--
Koppelman (1972)	20 U.S. cities	CS	Reg: OLS	VMT	Lane-miles	0.13	--
Ruiter et al. (1979)	CA corridors	TS	MS	VMT	New facility	--	0.38
Ruiter et al. (1980)	CA corridors	TS	MS	VMT	Widening	--	0
Payne-Maxie et al. (1980)	54 U.S. metro areas	CS	Reg: OLS	VMT/capita	Lane-miles	0.22	--
Hansen et al. (1993)	30 CA urban counties	TC/CS	Reg: OLS, DL, FE	VMT	Lane-miles	0.46-0.50	--
	CA metro areas	TC/CS	Reg: OLS, DL, FE	VMT	Lane-miles	0.54-0.61	--
Hansen, Huang (1997)	32 CA urban counties	TC/CS	Reg: AR/DL, FE	VMT	Lane-miles	0.30	0.68
	CA metro areas	TS/CS	Reg: AR/DL, FE	VMT	Lane-miles	0.50	0.94
Noland, Cowart (2000)	70 U.S. metro areas	TS/CS	Reg: IV, DL, FE	VMT/capita	Lane-miles/capita	0.66	0.81-1.00
Fulton et al. (2000)	220 counties: MD, NC, VA, DC	TS/CS	Reg: IV, DL, FE	VMT	Lane-miles	.3-.6 (OLS) .13-.43 (AR)	0.47-.89 --
Strathman et al. (2000)	48 U.S. urban areas	CS	Reg: IV	VMT/HH	Lane-miles/capita	0.29	--
Cervero, Hansen (2001)	34 CA counties	TS	Reg: 2SLS, DL, FE	VMT	Lane-miles	0.56	.78-.84
Rodier et al. (2001)	CA corridors	TS	MS	VMT	New facility	--	0.6-1.0

Key:

TS = Time Series

CS = Cross-section

MS = Model Simulation

GA = Graphic Analysis

Reg = Regression

OLS = Ordinary Least Squares

DL = Distributed Lag

FE = Fixed Effects

AR = Auto-Regressive OLS

IV = Instrument Variables

2SLS = Two-stage IV estimation

4.4 Area Studies: Models Using Proxy Measures

Area studies aggregate data, usually by pooling cross-sectional cases over multiple time points, to relate lane-mile additions (as a proxy of reduced travel costs) to VMT. Road capacity is usually measured on major facilities, like freeways and arterials, which are under state jurisdictions. As aggregate analyses, co-variation is captured by measuring differences in VMT across counties or metropolitan areas and over time points. Table 2 summarizes the research designs and core findings of key area studies reviewed in this paper.

What area studies of induced travel demand have most in common is the use of *elasticities* to gauge the relative sensitivity of VMT growth to lane-mile additions. This is partly because most regression analyses of induced travel demand to date have taken a log-linear form, yielding coefficient estimates that equal point elasticities.[5]

As noted earlier, some observers argue that capacity additions are a poor indicator of the benefits conferred by a road improvement (Cohen, 1995; DeCorla-Souza and Cohen, 1999). They note that capacity only releases suppressed demand in crowded traffic conditions. Only by lowering the travel-time "price" borne by motorists can traffic be induced.

In truth, accurately measuring travel times over numerous time points can be a daunting task. Travel times vary considerably by time-of-day, day-of-week, and season of year; in contrast, a fixed amount of road capacity does not vary. In the case of regional analyses, the scale that DeCorla-Souza (2000) and others maintain is most appropriate for capturing the spillover effects of road improvements, travel times also vary widely geographically and across facilities.

For pooled time series/cross-sectional studies, such as the work of Hansen and Huang (1997) and Noland and Cowart (2000), obtaining reliable annual travel-time data for dozens of counties and metropolitan areas over a several decade stretch would be a Herculean effort. The risk of measurement errors is extremely high. To cope with the fact that lane-mile additions is an imperfect proxy of "benefit" (e.g., in uncongested rural and exurban settings additional lanes yield little if any travel-time savings), many area analyses have used fixed-effect dummy variables. Fixed-effects variables absorb the unique nature of travel variation in certain places, like sparsely populated counties, that are not statistically captured by other variables (including proxies like lane miles) in an equation.

The first area studies that used road supply as a proxy for user benefit appeared in early 1970s. For example, Kassoff and Gendell (1972) studied the relationship between urban-area VMT per capita and road supply per capita for different size classes of U.S. urban areas. The study found that as a "system supply index" nearly doubled, VMT per capita rose roughly 50 percent. Hansen, *et al.* (1993) imputed an elasticity from this work with an upper bound of 0.58.[6] Other area studies from this period that regressed VMT on highway capacity across U.S. urban areas recorded lower elasticities, in the range of 0.13 to 0.22 (Koppelman, 1972; Payne-Maxie *et al*.,1980).[7]

Among the first area studies that gauged the effects of lane-miles of VMT in an econometric framework was the work by Mark Hansen and his colleagues from the University of California at Berkeley (Hansen, *et al*., 1993; Hansen and Huang, 1997). In both analyses, the authors used data on state-highway travel demand

and supply between 1970 and 1993 for 32 urban counties in California. Induced-demand elasticities were estimated using single-equation models of the form:

$$\log(VMT_{it}) = a_i + \beta_t + \sum_k ?^k \log (x^k_{it}) + e_{it} \qquad (4)$$

where:

VMT_{it} = vehicle-miles traveled in area i at time t;

a_i = fixed effect adjustment for area i

β_t = fixed effect adjustment for time t

x^k_{it} = value of explanatory variable k in area i and time t

$?^k$ = coefficient weight to capture distributed lag relationships

e_{it} = random disturbance term of area i and time t

The models estimated by Hansen and his associates used population, per capita income, population density, and average gasoline price as statistical controls and ordinary least squares (OLS) estimation. The inclusion of fixed-effect variables helped absorbed the influences of relevant but omitted variables, which Noland and Lem (2000) maintain is absolutely essential in induced demand studies since so many exogenous, difficult-to-measure factors have propelled VMT growth over the past several decades.

The initial (1993) study by Hansen and his associates found lane-mile elasticities in the range of 0.46 to 0.50. When county data were aggregated to the metropolitan level, elasticity estimates increased slightly, to a range of 0.54 to 0.61. The follow-up work introduced an auto-regressive (Prais-Winsten) estimation structure and focused more on the time-lag structure of induced demand effects. This analysis produced even higher elasticity estimates than the earlier one. At the county-level of analysis, VMT elasticities (with respect to lane miles) of between 0.3 (near term) and 0.7 (intermediate to long term) were found. Aggregating up to the metropolitan level, elasticity estimates increased to 0.5 in the short run and 0.9 over the long haul. The results of this study received wide circulation and were quickly embraced by highway critics who claimed they now had empirical proof that America will never be able to "build itself out of traffic congestion" (Dittmar, 1998).

Over the past five years, the work of Hansen and his associates has spawn numerous other studies, carried out using data from different areas of the country and different time periods, and usually with different model specifications (Noland and Cowart, 2000; Cervero and Hansen, 2001). Fulton, *et al*. (2000) pooled cross-sectional and time-series data to estimate VMT growth as a function of lane miles, population, and per capita income for counties in North Carolina, Virginia, and Maryland as well as the District of Columbia. Their base models

produced short-run estimates in the range of 0.33 (Washington, D.C.) to 0.51 (Virginia), with estimates for all areas combined of 0.52 to 0.57.

Distributed lag model structures have been used by a number of authors to estimate long-term induced demand effects (Hansen and Huang, 1997; Noland and Cowart, 2000; Fulton, *et al*., 2000; Cervero and Hansen, 2001). These models normally assume that lag effects taper according to an exponential function, with the strongest influences occurring immediately and impacts attenuating over longer lag periods. Long-run elasticities represent the cumulative sum of coefficients on log-transformed lagged variables. Fulton *et al*. (2000), for example, used a polynomial distributed lag model to estimate a long-run elasticity of 0.72 for three mid-Atlantic states and the Washington-Baltimore metropolitan area, ranging from a low of 0.488 for Maryland counties and a high of 0.81 for Virginia counties. As in all studies to date, these long-run elasticities exceeded those in the short run.

DeCorla-Souza (2000) contends studies that have estimated induced demand as a function of capacity expansion have overstated elasticities for two reasons. One, only higher-order (state) facilities were included in the analyses. Two, diversion from lower-order facilities to higher-order ones were counted as induced travel. To the degree higher-order facilities average the worst traffic conditions, and thus are most subject to the effects of induced demand, the focus on state highways may be less problematic than appears. And to the degree induced demand is measured at a regional scale, the commingling of diverted and induced trips is not a problem to the degree route diversions are internal to the region.

4.5 Area Studies: Models Using Partial Measures

Other aggregate models have sought to relate traffic increases directly to travel time savings. Accordingly, elasticities take on negative signs in contrast to the positive elasticities of aggregate models that predict travel demand as a function of lane-miles. As discussed earlier, these are considered to be partial estimates in that demand elasticities are imputed from estimated travel-time savings absent any effort to systematically express faster travel as a derivative of road improvements (vis-à-vis factors like mode shifts to upgraded transit services, economic downturns that reduce commuting volumes, etc.). Ideally, a path model is called for that measures travel-time savings as an intermediate step between initial road investments and consequent traffic increases. Nevertheless, a number of observers (Cohen, 1995; DeCorla-Souza, 2000) insist these studies provide the most accurate and valid basis for inferring induced travel impacts

The U.K.'s SACTRA report (1994), summarized by Goodwin (1996), is the most exhaustive review to date of how congestion relief stimulates travel. Culled from experiences documented in numerous unpublished and published studies across

the United Kingdom, the report found elasticities with respect to travel time ranged between –0.5 and nearly –1.0. DeCorla-Souza (2000) imputed elasticities of a similar magnitude using travel-demand forecasting models. Based on average regionwide travel speeds and VMT estimated for a beltway project in Memphis, Tennessee, DeCorla-Souza estimated short-run travel-time elasticities of –0.7 for models without feedback from traffic assignment to trip distribution and –1.1 when models included feedback. Because these estimates are at least as large as past estimates of travel-time elasticities, he contends travel forecasting models do adequately capture induced demand.

Several studies have measured elasticities of highway demand as a function of other price components, not all of which relate directly to road expansion. In a review of studies that measured the elasticity of VMT with respect to fuel prices, Goodwin (1992) found an average short-run elasticity of –0.16 and long-run elasticity of –0.30. Drawing from studies carried out on six U.K. highway corridors and pivoting off of fuel-price elasticities, Goodwin (1996) estimated an average travel-time elasticity of –0.28 in the short term and –0.57 in the long-term. In weighing the combined findings of several literature reviews on price elasticity of demand for car travel throughout the industrialized world, Goodwin (1996) concluded that travel-time elasticities appear to be quite varied, ranging from –0.1 to –1.0; most recent studies have produced estimates that approach the upper boundaries of this range. Travel-time elasticities imputed from exogenous price variables, however, are apt to be inferior to those calculated directly from travel-time data. As Cohen reviews in these proceedings, imputed estimates of travel-time elasticities are likely inflated.

Less empirical research has been carried out in the United States that relates highway VMT to changes in travel time in an econometric framework. One example is the work of Burright (1984) who estimated a simultaneous system of equations (using two-stage least squares) that predicted private vehicle miles per household as a function of three endogenous variables: travel time cost per household, bus trips per household, and urbanized land area. Using a panel data set consisting of observations from 1968 and 1970 for 27 urbanized areas, he estimated an elasticity of –0.51. Because standard errors were not reported, the precision of this estimate is unknown.

While travel-time elasticities more closely reflect the normative model of Figure 1 than do lane-mile elasticities, nevertheless they face potential problems of their own. As noted, travel-time savings conferred by a road expansion might vary considerably by corridor, time-of-day, day-of-week, or season. An assumed "typical" travel-time savings may be a poor proxy benefit to the majority of motorists. Also, if one believes in the principle of time-budget theory, a road improvement should have an imperceptible effect on collective travel times. As the theory holds, people could be expected to maintain total travel-time budgets, thus by definition elasticities should gravitate toward zero in the case of regional scale analyses. Also, it is unclear the degree to which past studies have

successfully netted out the effects of other factors (e.g., changing fuel prices) that might have influenced variable in travel times. This is especially so in the case of studies cited by Goodwin (1996). As shown in Figure 3, additions to road capacities can, *ceteris paribus*, be expected to increase travel speeds and thereby increase VMT. However, there might be one or more intervening factors, such as suburban location, that are explaining the co-movement in the capacity and speed variables. That is, road expansion might occur mainly in the suburbs (or sparsely populated areas more generally) where right-of-way is more easily acquired and where average travel speeds tend to be the highest. Unless the influences of such potential confounding factors are adequately controlled, the inferences drawn on the induced-demand effects of travel-time savings could be spurious. While many studies to date of induced-demand effects using lane-miles as predictors have sought to invoke an econometric framework to properly specify relationships, past studies using travel-time savings have generally paid less attention to specifying the complete chain of relationships. This could compromise the internal validity of the research findings.

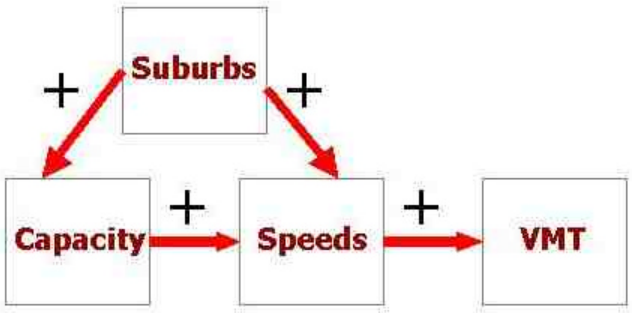


Figure 3. Possible Path Diagram of Factors Influencing Road Capacity, Travel Speeds, and VMT

4.6 Disaggregate Models

Disaggregate analyses enjoy inherent advantages over aggregate analyses in studying travel behavior, including that induced by road improvements (Marshall, 2000). By studying travel demand at the level of individual trip-makers, they are less vulnerable to the spurious inferences sometimes encountered with aggregate-scale data. Put simply, people travel, not TAZs.

Several recent studies have made headway in examining induced travel demand

at a disaggregate level using data from the Nationwide Personal Transportation Survey (NPTS). While data were drawn from across the United States, each observation represented the travel behavior of members of an individual household. Strathman *et al*. (2000) combined NPTS and Texas Transportation Institute (TTI) data on regionwide road capacities. Using different model specifications and data for 12,000 respondents from 48 urban areas, they estimated cross-sectional elasticities of VMT with respect to per capita road capacity of 0.29. Using the same data set, Barr (2000) imputed travel-time elasticities ranging between –0.35 and –0.58, with an average value of –0.44. How much of the travel time savings were attributable to road expansion, and thus were a measure of benefits conferred by road investments, was not specified in the analysis.

Both of these studies yielded lower elasticity estimates than those of most area studies, suggesting the possibility of ecological fallacies in inferring elasticities from aggregate data. However, cross-sectional studies have limitations as well. Studying variation in travel among people according to where they live and how well roads function in those areas might reveal the existence of a relationship, however it does not establish causality.[8] Causal inferences, many contend, require some time-ordering of events, something which only longitudinal data can provide (Asher, 1983). The limitations of cross-sectional data are revealed by poor model fits. Among the fifteen equations Barr (2000) produced to estimate travel-time elasticities, models explained less than 24 percent of the variation in household VMT. By comparison, pooled time-series/cross-sectional models of induced demand estimated by Hansen *et al*. (1993) and Cervero and Hansen (2001) explained over 99 percent of the variation in county-level VMT. Combining data from two disparate data bases is also fraught with difficulties. One, they face possible resolution problems since the numerator of the elasticity calculation (trips) is measured on a disaggregate scale whereas the denominator (lane miles) is aggregate in scale. Two, there is an assumption of concordance between the TTI and NPTS data bases. However, there is no way to know whether the locations where a region enjoys a generous supply of road capacity matched the locations where NPTS respondents traveled most of the time and reaped travel-time savings. This is similar to the discordance problem of using lane miles of highway to gauge induced-demand effects when it is not always clear whether capacity additions bring about travel-time savings. Lastly, disaggregate analyses that use household travel-diary data also totally ignore trips by commercial vehicles. This contrasts to aggregate-scale analyses that capture all forms of movement, including goods movements, on the facilities studied.

5. SORTING OUT THE CAUSAL CHAIN

To date, no metropolitan or sub-metropolitan scale study of induced travel demand has successfully used a normative model, such as depicted in Figure 1,

Table 3. Model Structures Used in Studies of Induced Demand Causal Relationships

Studies	Control Variables						Estimation	
	Population	Income per capita	Population Density	Employment Density	Gasoline Prices	Fixed Effects	Instrument Variables	Distributed Lags
Hansen *et al*. (1993)	✔	✔	✔		✔	✔		✔
Hansen & Huang (1997)	✔	✔	✔		✔	✔		✔
Fulton *et al*. (2000)	✔	✔				✔	✔	✔
Noland & Cowart (2000)	✔	✔	✔			✔		✔
Cervero & Hansen (2001)	✔	✔		✔	✔	✔	✔	✔

to measure induced travel demand in its many forms and shapes. Recently, however, research has probed the degree to which road improvements and travel demand are co-dependent – i.e., do road investments both induce and respond to travel demand? Studies that have sought to disentangle the two-way causality between road investments and travel demand have turned to econometric approaches in this pursuit. Table 3 summarizes the model structures employed by these studies.

To date, two approaches have been used to sort through the causal chain between road supply and demand: (1) Granger Causality Tests; and (2) Instrument-Variable Estimation. Both approaches are reviewed below.

5.1 Granger Causality Tests

Several studies have applied Granger Causality Tests to probe road supply-demand relationships (Granger, 1969). Fulton *et al*. (2000) applied GrangerTests to study the time-order of road improvements and VMT expansion. Using one and two year forward and backward lags to explain VMT growth as a function of lane-mile expansion, the authors found backward lags to be significant while forward lags were not. They inferred that in the mid-Atlantic states, lane-mile growth preceded growth in VMT, but not necessarily vice-versa. They cautioned that these findings do not imply lane miles caused increases in VMT.

Cervero and Hansen (2001) also used Granger Tests over two-year lags to examine road supply-demand relationships in California. Similar to Fulton *et al*. (2000) they found lane-mile expansions significantly accounted for VMT increases, however unlike the study of mid-Atlantic states, they found the relationship worked in both directions – past VMT increases also explained lane-

mile expansion. Their research suggested that, in California at least, causality works both ways – supply induces demand and likewise, demand induces supply.

5.2 Instrumental Variable Estimation

Instrumental-variable estimation, when applied in a simultaneous equation structure, is widely considered to be the most reliable and internally valid way to reducing estimation bias and capturing multivariate causal relationships (Pindyck and Rubinfeld, 1998). Several recent metropolitan-scale studies of induced demand have applied reduced-form instrument-variable models.

Noland and Cowart (2000) built models to estimate elasticities using instrument variables, though they did not simultaneously model supply-demand relationships.[9] To remove possible estimation biases, land area and population density were used as instruments to estimate lane-miles, and reduced-form estimates were then used to predict variation in VMT per capita. An ideal instrument is one highly correlated with one endogenous variable but not correlated with others. Conceptually, one could question the propriety of these instruments since both endogenous variables – VMT as well as lane miles – likely increase with increases in the area and use-intensity of land. This posed potential identification problems in specifying a simultaneous set of equations. The authors derived fairly high long-run elasticities in the range of 0.65 to 0.90.

A recent study by Cervero and Hansen (2001) also used instrument-variable estimation to resolve estimation bias problems, however unlike previous work this analysis introduced a simultaneous equation structure. Using data on 34 urban California counties from 1976 to 1997, VMT and lane-miles on state highways were jointly estimated employing various exogenous variables related to topographic, meteorological, air quality, and political variables as instruments. The simultaneously estimated models revealed an elasticity of VMT with respect to lane-miles of 0.56, controlling for fixed effects as well as the tendency for travel to increase with population and per capita income and decline with employment density and gasoline prices. (Using a distributed lag model structure, the research estimated a long-run elasticity of 0.78 to 0.84.) The research also showed evidence of "induced investments" – supply responding to demand. The analysis revealed an elasticity of freeway and highway capacity with respect to VMT of 0.33. Presumably, state highway investment in any year was based on levels of travel demand that were anticipated – suggesting, in California at least, road investments not only stimulated travel demand but responded to it as well. The analysis revealed that, also controlling for fixed effects, road investments rose with population size, carbon-monoxide emissions (lagged several years), temperature differentials, and democratic governorship, and declined with employment density. Prior-year slippages in air quality were interpreted to have added momentum to road investment under the premise that

congestion relief improves air quality. The influence of party affiliation reflected the time-lag structure in highway investments, with the impacts of a slowdown in highway construction engineered under Democratic leadership being felt by the time Republican governors were in office.

In general, models that have sought to account for two-way causality – with varying degrees of success -- in explaining induced demand effects have yielded somewhat lower elasticity estimates (in absolute terms) than those based on standard OLS estimation. This suggests some coefficient estimates from OLS models (e.g., Hansen and Huang, 1997) might be biased upwards. Still, econometric studies carried out in different parts of the country and that employ somewhat different model specifications have produced fairly consistent results (Noland and Cowart, 2000; Cervero and Hansen, 2001).

6. INTERACTION EFFECTS

Only recently have researchers sought to stratify their analyses of induced travel demand to account for interaction effects. Do road investments, for example, interact with levels of congestion to produce large induced demand outcomes? A Transportation Research Board (1996, p. 149) committee took a firm position on this: "The largest induced traffic effects are expected for the construction of a new freeway in a congested corridor that currently does not have a freeway because the new facility would provide significant travel time savings during both peak and off-peak periods". This section probes the degree to which empirical evidence bears this out. It should be noted that the findings presented are inter-related and therefore partly redundant – e.g., studies on how elasticities differ by population densities also generally reflect the influences of congestion levels since streets in dense areas tend to be more crowded.

6.1 Congestion Levels

Do induced demand effects vary according to congestion levels? It stands to reason that considerable pent-up demand will be unleashed by road expansion in a congested setting whereas the impacts of adding lanes in free-flowing conditions will be negligible. In truth, evidence is scant. The SACTRA (1994) report suggested stronger induced demand effects when a network is operating close to capacity, though offered no empirical evidence to substantiate this position. The study also skirted the question as to what are the primary sources of induced demand – whether new latent trips, or schedule, route, or modal shifts. Fulton *et al*. (2000) found some evidence that population densities and congested levels influenced the degree to which lane-mile expansions induced VMT increases, however the results were statistically insignificant. Henk (1993) uncovered evidence that traffic volumes increased with volume-to-capacity levels as well as population density following road improvements in Texas cities,

however his analysis did not separate out diverted from latent trips. Using a distributed lag model, Noland and Cowart (2000) found no difference in induced demand effects (i.e., VMT elasticities as a function of lane-miles) between highly congested and minimally congested metropolitan areas.

6.2 Urban Setting

Because urban areas are denser and more congested, they could be expected to experience greater induced demand effects than suburban, exurban, or rural settings. Again, the evidence is muddled. Using the 1995 U.S. Nationwide Personal Transportation Survey (NPTS), Barr (2000) found slightly higher travel-time demand elasticities in urbanized areas (-0.36) than non-urbanized ones (-0.32). However, two other analyses suggested the opposite. Fulton *et al*. (2000) found the relationship between lane miles and travel to be statistically weaker in the case of the Washington-Baltimore metropolitan area than the states of Maryland, Virginia, and North Carolina that contain many rural counties. In his review of British experiences, Goodwin (1996) found that urban roads averaged unpredicted traffic in the short term of 5.7 percent whereas the average under-prediction for rural roads was 13.3 percent. The inference was that induced demand accounted for more than twice the share of traffic growth in rural settings as in urban ones.

6.3 Metropolitan Size

Big metropolises could be expected to registered greater induced demand effects since they are known to suffer the nation's worst traffic congestion (Shrank and Lomax, 2000). The evidence is also weak on this front. Noland and Cowart (2000) found, surprisingly, that induced demand effects were highest for medium-sized metropolitan areas, followed by large and the small ones. Barr (2000) also found no clear relationship; when travel-time elasticities estimated from the NPTS data set were stratified by metropolitan size, values jumped around in a seemingly random fashion.

6.4 Type of Facility

A brand new highway can be expected to generate more new traffic than the expansion of an existing facility, all things being equal. This is because a new facility will draw traffic during all hours of the day whereas an improved one is likely to have little impact on off-peak conditions. This was supported by the findings of Ruiter *et al*. (1979, 1980) who, using simulation techniques, estimated substantially higher elasticities of VMT with respect to road capacity for the extension of a freeway linking Oakland, California to its eastern suburbs in comparison to the expansion of older segments of the same freeway.

How might induced demand vary by facility type – e.g., a beltway versus radial link? Luk and Chung (1997) postulate: "A radial route with added capacity could be less likely to generate demand than a circumferential route". Presumably this is because a circumferential faces less competition in the sense there are fewer parallel alternatives to cross-town facilities than radial ones. Of course, what matters is not the physical attributes of the facility but rather the amount of travel-time savings it confers. A new circumferential freeway might add more marginal capacity for tangential journeys in the outskirts however a new limited-access radial facility might add more travel-time savings along an urban corridor. In his study of 37 Texas highway project, Henk (1993) found a greater induced demand effect on circumferential than radial highways, and the latent trips added to orbital facilities increased in direct proportion to population densities. An earlier study of 54 U.S. metropolitan areas found slightly higher elasticities of VMT with respect to beltway mileage (0.12) versus non-beltway mileage (0.10) (Payne-Maxie, *et al*., 1980).

6.5 Summary

Overall, the few studies to date that have tried to statistically measure how road investments interact with other factors to induce travel demand have yielded inconclusive results. A literal interpretation of empirical findings would be that induced demand effects do not vary tremendously across settings – whether densely populated, highly congested urban areas or sparsely inhabited, less-congested exurbs. While common sense suggests this is not the case, so far the collective research community has been unable to jettison this "null hypothesis". This is probably more of an indictment of methodological tools and their inability to provide fine-grain insights into the induced demand phenomenon than an aspersion of the idea that induced demand impacts vary. Clearly, more and better research is needed on how induced demand effects vary across different settings and contexts.

7. META-ANALYSIS

As case-based analyses, most metropolitan-scale studies of induced travel demand have limited external validity. State-level and national analyses are more generalizable however the resolutions of these analyses raise questions of potential aggregation biases. One approach to generalizing research findings is a "meta-analysis" of elasticity estimates – i.e., essentially calculating an arithmetic average across many studies. Based on a meta-analysis of more than 100 road expansion projects in the United Kingdom, Goodwin (1996) estimated long-term elasticities (i.e., percent increases in traffic as a function of travel-time savings) of nearly |1.0|. More recent analyses suggest this number is on the high side.

Reviews of various empirical studies of induced demand by Ruiter *et al*. (1979), Pells (1989), Hansen *et al*. (1993), Cohen (1995), Goodwin (1996), and Noland and Lem (2000) found estimated elasticities with respect to road supply ranging from 0.1 to nearly 1.0. Studies reported by Goodwin (1996) and Noland and Lem (2000) were generally more recent than those of earlier reviews. Nevertheless, the reviews are essentially in agreement that road improvements induce demand; they disagree, however, with regards to the magnitude and sources of impacts. Empirical findings from studies cited in these reviews were dramatically affected by factors like the resolution and time expanse of analyses, the level of aggregation, measurement, and model specification. Why the magnitude of impacts varied so much across these studies was unanswered. While past reviews provide a good perspective into the evolution of induced demand studies, one must interpret summary findings with caution because they include studies of questionable reliability.

A simple unweighted arithmetic average of selected studies listed in Tables 1 and 2 reveals substantial variations based on the scale of analysis and methodological approach. In the case of facility-specific studies from the past 20 years that relied mainly upon matched-pair comparisons, the percent of traffic growth attributable to induced demand takes on the following mean values: short term = 0 percent; intermediate term = 26.5 percent (standard deviation = 35 percent); long term = 63 percent (standard deviation = 28 percent).[10] Not all of these studies successfully purged diverted trips from their calculations, thus these estimates could be on the high side. On the other hand, by not completely measuring impacts of road improvements on lower-order and connecting facilities, some of the estimates could very well be too low. Based on facility-specific analyses, perhaps all that can be said with a fair degree of confidence is that induced demand effects accumulate over time.

Area studies that have used lane-miles as a proxy of road-conferred benefits have generally produced results suggesting greater impacts, as revealed by elasticities. As noted earlier, the difficulty of reliably measuring travel time benefits for a large geographic area have prompted most analysts who studied induced demand at an area-wide scale to employ lane-miles as a metric of supply-side benefit. A meta-analysis calculation of post-1980 area studies that have presented elasticities based on proxy (lane-mile) estimates of benefits (drawn from Table 2, excluding simulation studies and disaggregate analyses) produced the following mean elasticities estimates: short term = 0.48 (standard deviation = 0.13); long term = 0.80 (standard deviation = 0.12).[11] In comparison to facility-specific studies, not only are impacts more significant at the area scale of analysis, results are also far more similar, with low standard deviations. It is important to note that area studies that have attempted to resolve the simultaneous-equation biases of past work by accounting for two-way causality – namely the work of Cervero and Hansen (2001) and Noland and Cowart (2000) – have produce similar and consistent results. Even when accounting for the fact that roads lag behind and respond to VMT growth, recorded induced demand

effects remain strong. Overall, area studies using lane-miles as a predictor and econometric estimation approaches have yielded surprisingly consistent results -- ones that gravitate toward a central tendency.

Two other types of elasticity estimates provide further insights – those based on travel-time measures of benefits, and those carried out at a disaggregate (household-level) scale. Goodwin (1996) provides the most authoritative summary of travel-time elasticities from area studies – i.e., travel consumption as a function of travel times (what have been called "partial" elasticities in this paper). Drawing from recent British experiences, he concluded elasticities ranged from –0.5 in the short term to nearly -1.0 in the long term. DeCorla-Souza (2000) obtained even higher estimates (in absolute terms) in his recent simulations of travel in Memphis. In general, area studies that have presented demand-elasticities in either form – whether with respect to travel times (partial estimates) or lane-miles (proxy estimates) – have yielded fairly similar estimates. If anything, evidence suggests that induced demand effects might be slightly greater when gauged in terms of travel time.

Disaggregate analyses of induced demand have generally yielded lower estimates. Both studies cited in this paper that used NPTS data to study variations in VMT per household produced, in absolute terms, elasticity estimates in the range of 0.29 to 0.58 – the lower value from Strathman, *et al*. (2000) based on lane-mile per capita as a predictor and the higher value from Barr (2000) based on travel-time as a predictor. These estimates could be on the low side because of the use of cross-sectional data for inferring causal relationships as well as the questionable compatibility of data from the NPTS and TTI sources. While disaggregate studies get high marks for using a more appropriate "ecological unit" for studying induced demand, they too raise questions of reliability in the use of aggregate (metropolitan-wide) data on road supplies and travel times that do not necessarily correspond to conditions experienced by the very small sample of regional travelers surveyed by NPTS.

If one believes the results of recently published studies on face value, the preponderance of research suggests that induced demand effects are significant, with most added capacity being absorbed by increases in traffic. The pattern appears to be that within a year or two of a road improvement, on average, nearly half of the capacity added is filled by new traffic. And five or more years downstream, upwards of three-quarters or more of the extra capacity gets absorbed. To the degree that the many specification, measurement, and resolution issues raised at the beginning of this paper have been problematic, these estimates have less credence. There remains some disagreement as to whether this is the case. As Pickrell and Cohen suggest in the proceedings, past elasticity estimates, based on lane-mile and travel-time inputs, have likely been inflated. All that can be said with certainty is that induced demand effects exist (i.e., elasticities vary from zero) and they accumulate over time. To the degree the normative framework presented earlier (Figure 1) can be invoked in

future research, hopefully a greater degree of consensus can be achieved on the scope and magnitude of induced demand effects in coming years. So far, there has been greater consistency in gauging the *size* of induced demand effects than in gauging their *scope*. Past efforts to explain variation by stratifying induced demand estimates according to factors like levels of congestion and urban-versus-rural setting have proven unsuccessful. This is an area worthy of more research attention.

8. CONCLUSION

Those who have probed the theory of induced travel demand point out that diverted trips should be excluded from the measurement of induced demand. They argue that, in the short term, induced trips are: latent trips (suppressed trips that are now made because travel costs are lower); modal shifts (such as from transit, meaning new cars are added to the highway network); and destination shifts (which might lengthen, or shorten, trips). While this technical definition provides a sound basis for gauging net increases in traffic within a region, in political terms, the traffic additions motorists complain about several years after a road is improved includes diverted trips. When critics contend "pave it and they will come", they are referring to the increased traffic and return to former speeds a year or so later after a road improvement. Increased traffic and a return to congested conditions reflect the impacts of diverted trips as well as truly induced demand.

In the U.K., the cumulative weight of evidence on induced demand effects has clearly affected public policy. In 1998, the U.K. Department of Environment, Transport and the Regions (DETR) published a White Paper, *A New Deal for Transport: Better for Everyone*, that jettisoned the previous policy trying to accommodate traffic growth through the strategy of "predict and provide". The amount of road infrastructure needed to meet unconstrained growth assumptions was deemed unsustainable – environmentally, financially, and socially (Noland and Lem, 2000). Goodwin (1999) noted this has elevated alternative transportation programs, like expanded transit services and demand-management, to a higher status. So far, claims of induced demand have failed to resonate as deeply in America's urban transportation policy circles.

At times, the transportation research community's near-obsession with measuring induced travel demand has perhaps caused us to loose sight of "the forest through the trees". Whether the elasticity of VMT with respect to road investments is 0.10, 0.50, or 0.90 is less important than understanding which transportation investment and management strategies provide the greatest social and economic payoff. All too often, urban transportation research takes a reductionist perspective. While the induced demand phenomenon is important and not to be trivialized, far more energies need to go toward studying how America can best invest and manage scarce urban transportation resources –

e.g., should we be building more bus rapid transit systems, expanding value-pricing on former carpool lanes, or more closely integrating transportation and land use, and if so, when, where, and under what conditions?

Upon immersing oneself in the considerable literature on induced travel demand, one might get the feeling that in building roads to fight traffic congestion, America has been taking a step backward for every step forward. Are we really making little headway in relieving traffic congestion through road expansion? Statistics cannot answer this question, however anecdotally, traffic congestion was a lot worse during the pre-freeway era in the early part of the 20th century than the past half-century of freeway expansion. And it is a lot worse in many mega-cities of the developing world with meager road systems in place (even given their much lower vehicle ownership rates).

The problems people associate with roads – congestion, air pollution, and the like -- are not the fault of road investments *per se*. These problems stem mainly from the unborne externalities from the *use* of roads, new and old alike. They also stem from the absence of thoughtful and integrated land-use planning around new interchanges and along new corridors. In opposing any and all highway investments, even those backed by careful benefit-cost analyses, critics are fighting the wrong battles. Energies should instead be directed at curbing mis-pricing in the highway sector and at better managing land-use changes spawn by road investments.

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NOTES

[1] From a transportation planning and policy perspective, metropolitan and regional scales ideally reflect “commutersheds” – the geographic extent in which labor is drawn by firms and businesses in urban areas. In truth, metropolitan areas, as defined as metropolitan planning organizations (MPOs), are often spatially smaller than commutersheds.

[2] The authors called changes in routes without changes in origins, destinations, or modes “diverted traffic”, changes in mode “converted traffic”, and changes in desire lines due to changes in origins or destinations “shifted traffic”.

[3] The ability to measure elasticities depends on the precision in which capacity expansions are measured. Many early studies expressed impacts in terms of percentage increases in traffic volumes over and beyond what was expected. Capacity expansion was not defined in percentage terms, thus elasticities could not be measured.

[4] Elasticities for new facilities can be imputed by gauging relative changes in traffic volumes to relative changes in total road capacity for a sub-area or corridor versus a specific facility.

[5] A point elasticity takes the form of ?log(Y)/?log(x) and has the advantage of yielding constant and symmetrical elasticity estimates of all points along a demand-curve surface. Arc elasticities are sometimes also presented, measured as (?Y/Y)/(?X/X), however they yield different and not always symmetrical results at different points along the surface.

[6] The “system supply index” equaled 100,000 * ((5* freeway miles) + (arterial miles))/population.

[7] Relationships were generally not models in log-linear, but rather linear, form. Midpoint elasticities were estimated by multiplying the estimated partial regression coefficient on the road-capacity variable by the ratio of mean values of travel demand and road capacity.

[8] While the use of NPTS might be viewed as a "national" glimpse of the induced demand phenomenon, because these studies used metropolitan-level data to gauge road capacity they are actually "inter-metropolitan" in scale.

[9] Rather, the analysis used instrument-variable estimation in an attempt to remove endogeneity biases in the estimation of VMT as a function of lane-miles, however it did not model the concomitant effects of VMT changes on lane-mile additions, presumably because limited numbers of exogenous variables posed identification problems.

[10] For studies that reported a range of estimates, the midpoint of the range was used in the calculation.

[11] Excluded from this calculation are the estimates by Strathman *et al*. (2000), a disaggregate study, and Rodier *et al*. (2001), a model simulation. For studies that reported a range of estimates, the midpoint of the range was used in the calculation.

Technical Article

Sustainability Analysis of the Proposed Elevated Road Corridors in Bengaluru City – A Comparative Scenario Analysis With Metro Rail System

by

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This paper is accepted for the International conference titled '***Transportation Infrastructure Projects – Concept to Execution (TIPCE)***' organized by Indian Institute of Technology, Roorkee from 7-10 January, 2019.

The article aims to give scientific outlook on the proposed elevated road corridor project in Bengaluru city, by Government of Karnataka (through KRDCL), from the point of view of Transportation Engineering and Planning. The Government of Karnataka has proposed to construct the elevated corridor for 92.2 km with 53 entry/exit ramps connecting North-South and East-West of the Bengaluru city. The article details the quantitative evaluation of travel behaviour in terms of trip length, mode share, Vehicle Kilometres Travelled (VKTs), Volume by Capacity ratio (V/C), exhaust emissions (CO, HC, NO_x and PM) and greenhouse gas emissions (CO_2). The technical analysis is carried out for Business as Usual (BAU) scenario and elevated corridor scenario for the base year (2017) and the future years 2020 and 2030. The study is executed with the assumption that the proposed elevated corridor project will be completed in 2020. The article highlights the demerits of the proposed elevated road corridor in respect of increased traffic congestion, VKTs and emissions. The evaluation also highlights the merits of the elevated Metro Rail corridor along the same corridor in terms of reduced traffic congestion, reduced emissions and also increase in modal shift to public transport. The detailed technical analysis of the various scenarios is explained in the following sections.

The above mentioned transportation system problems can be modelled using microscopic and macroscopic models. While the microscopic models analyse the transportation system at a very closer level macroscopic models analyse at a large scale considering the aggregated estimates. Various types of scenarios which can be potential transportation problem solving methods can be modelled using these methods. Figure 1 shows a flow chart about the transportation sector mitigation to reduce GHG emissions, local pollutants and traffic congestion for the Bangalore Metropolitan Region. The flow chart focuses on evaluating various alternative transport mitigation scenarios and compare the results with the Business As usual Scenario (BAU) to come up with a best policy scenario to reduce the transportation problems. A detailed explanation of the flow chart is out of scope for this article but the full details about the flow chart are available in the report by Verma A., Harsha V., Hemanthini AR. (2018), "Sustainable Transport Measures for Liveable Bengaluru", Project Sub Report, IISc Bangalore, India.

The technical details of the proposed elevated corridor are obtained from the '*Detailed Feasibility Report (DFR) for the Construction of Proposed Elevated Corridors within Bengaluru Metropolitan Region, Bengaluru by Karnataka Road Development Corporation Limited*' which is then digitised and added to the existing road network for further analysis. It is also mentioned in the DFR that only two-wheelers, cars and buses are allowed to ply on the elevated corridor and the same had been incorporated in this study. The Bangalore Metropolitan Region (BMR) covering an area about 8005 sq. km. is considered for the current study. The conventional macro-simulation framework in terms of four-stage Travel Demand Modelling (TDM) is adopted for the transportation forecasts and scenario evaluation. The trip end equation utilized for forecasting is obtained from the report '*Sustainable Transport Measures for Liveable Bengaluru by Verma et. al. Indian Institute of Science, Bangalore*'.

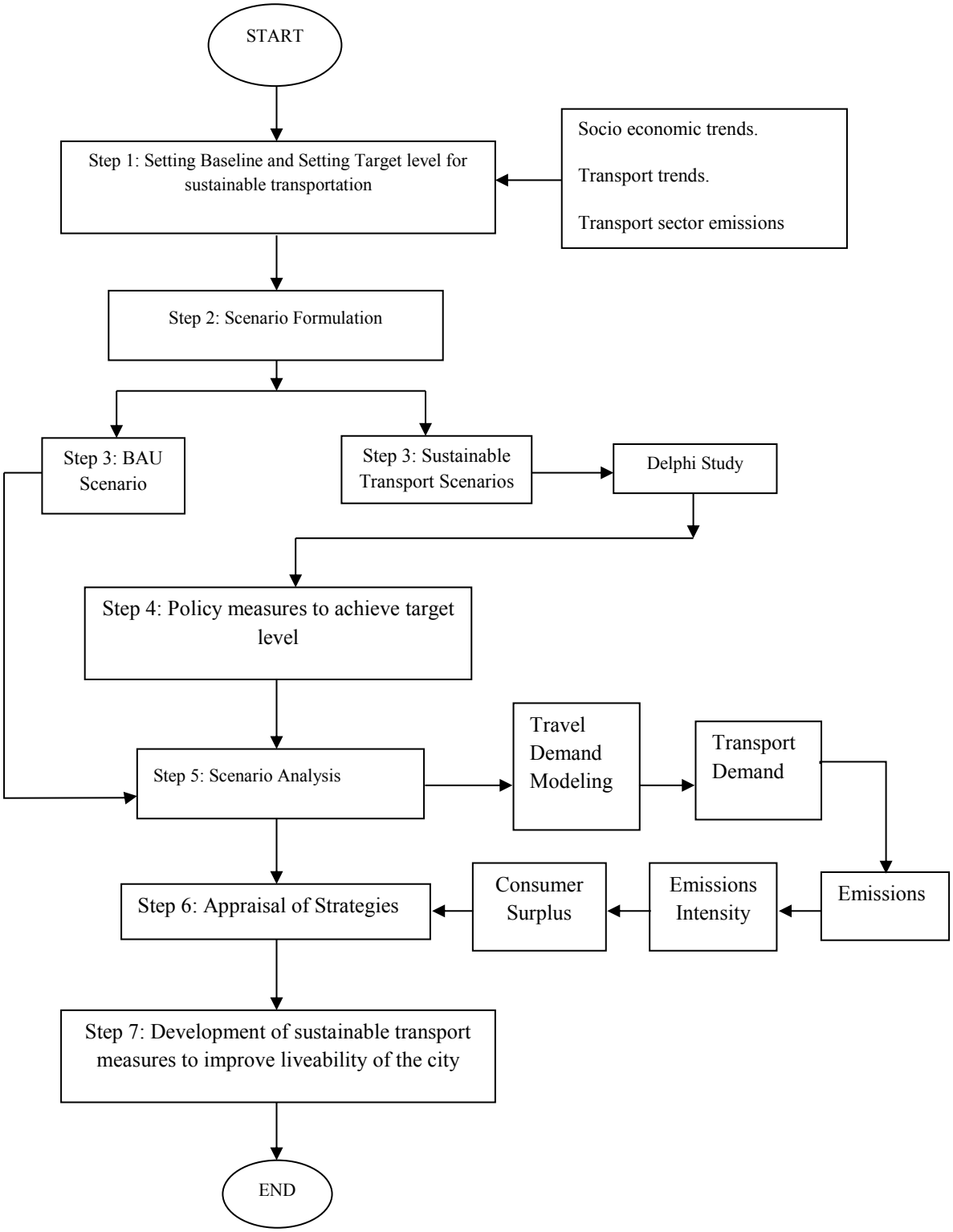


Fig.1: Macro-Simulation based CLIMATRANS methodology for scenario evaluation of different transport policies

The trip end equations used for forecasting the future year trip productions and attractions separately for private and public transport were taken from the CLIMATRANS study of authors.

Population from Base Year (Verma et. al. 2018) is projected to 2017, 2020 and 2030 using the trip end equations. The base year model is used to forecast the travel demand for 2020 and 2030 respectively. The three scenarios considered for the analysis are described below:

- **Business as Usual Scenario (BAU)** – Scenario without Elevated Corridor construction.
- **Scenario 1 (S1)** – Scenario where Elevated Corridor is constructed.
- **Scenario 2 (S2)** – Scenario where Metro Rail is constructed instead of Elevated Corridor along the same proposed corridor.

The impact in the travel behaviour with reference to the above mentioned scenarios is explained in the following sections. The trip length distribution for private and public transport for the scenarios is presented in Figure 2.

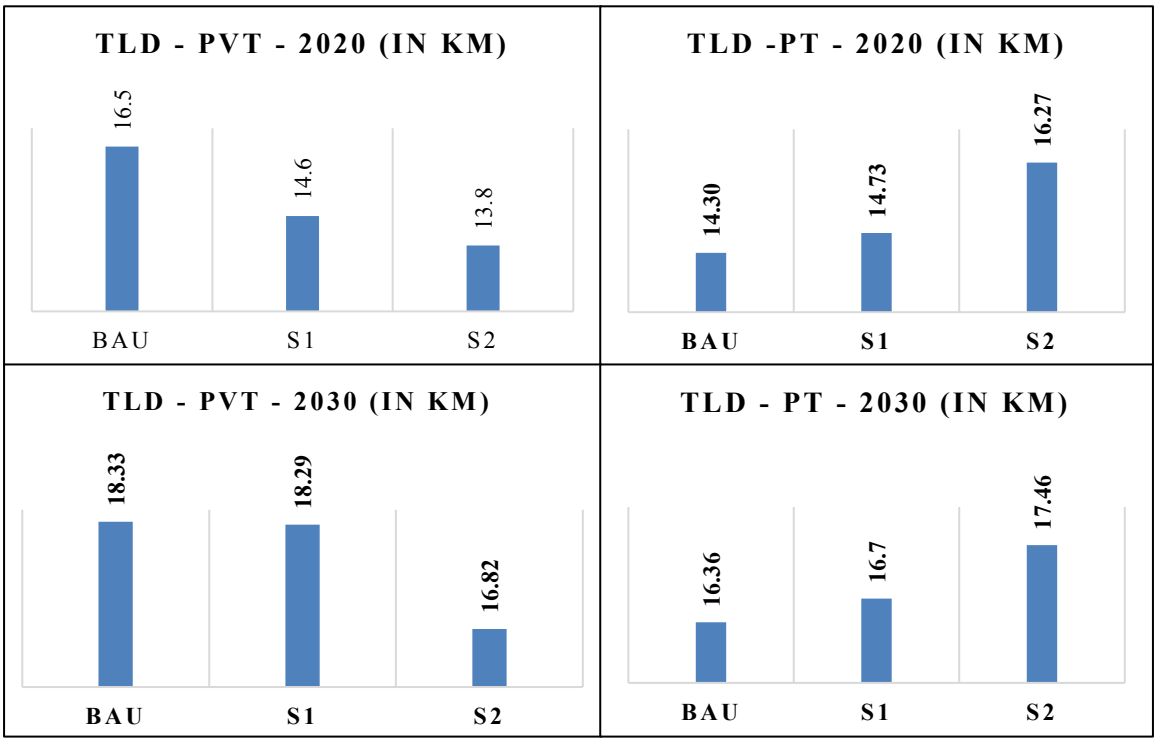


Figure 2. Estimated Trip Length Distribution for Private and Public Transport for the years 2020 and 2030

The average trip length for private transport is decreasing with the construction of elevated road corridor or Metro Rail corridor whereas in case of public transport the average trip length increases with the construction of elevated road corridor or Metro Rail corridor due to completion of remaining phase 2 work of Metro Rail. The modal share estimation for the years 2020 and 2030 for the given scenarios is represented in Figure 2.

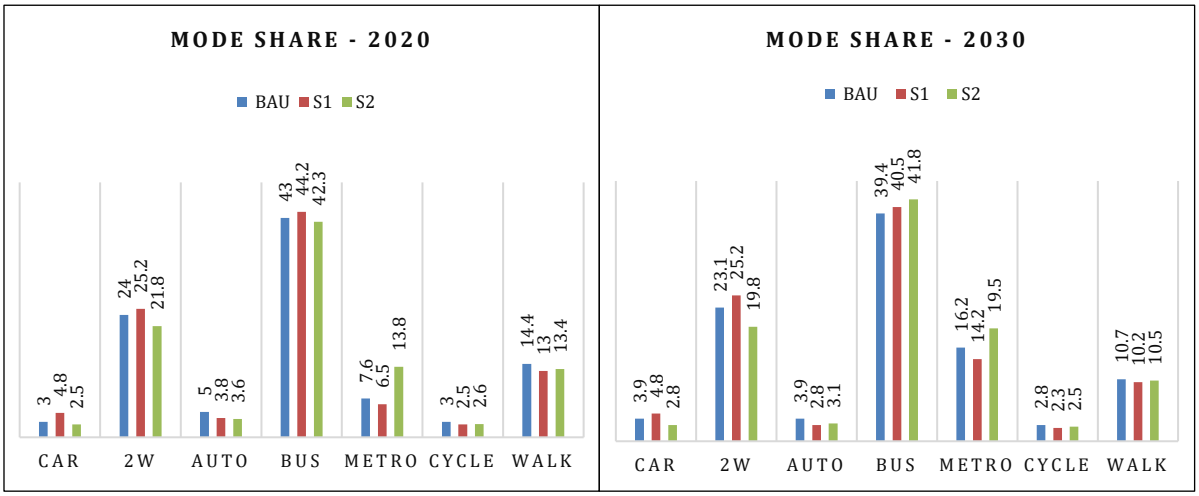


Figure 3. Comparison of the Modal Share for the years 2020 and 2030

It is observed from the figure 3 that the construction of Elevated Corridor will only encourage the usage of private vehicles such as cars and two wheelers in the future years which will eventually lead to traffic congestion. The share of non-motorised transport is also reducing with the Elevated Corridor scenario. The modal share of public transport accounts for about 56.1% and 61.3% in the Metro Rail corridor scenario.

The trips are assigned to the road network using User Equilibrium Trip Assignment method and Vehicles kilometres travelled, Volume on link and volume/capacity ratio (V/C) are estimated. The Vehicle Kilometres travelled for the future years is estimated by updating the road network for the three scenarios and is given in Figure 4. It is observed from the figure 4 that for 2020, there is 2.7 % increase for in VKT for Scenario 1 (Elevated Corridor) and 5.3 % reduction in VKT for Scenario 2 (Metro Rail corridor) from BAU 2020 whereas, for 2030, there is 4 %

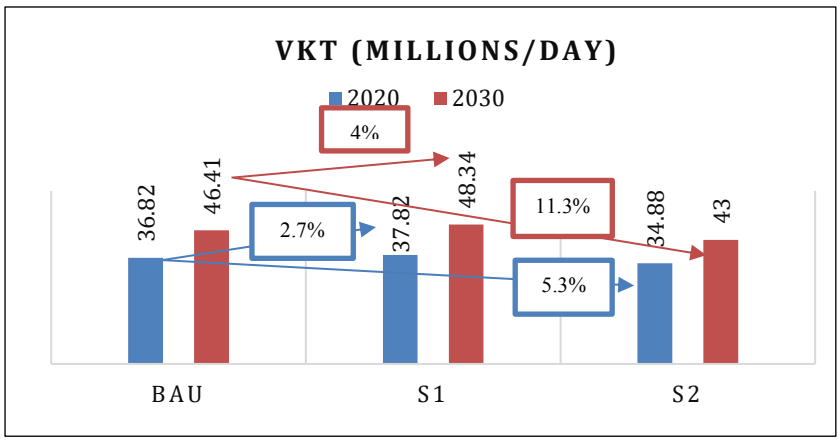
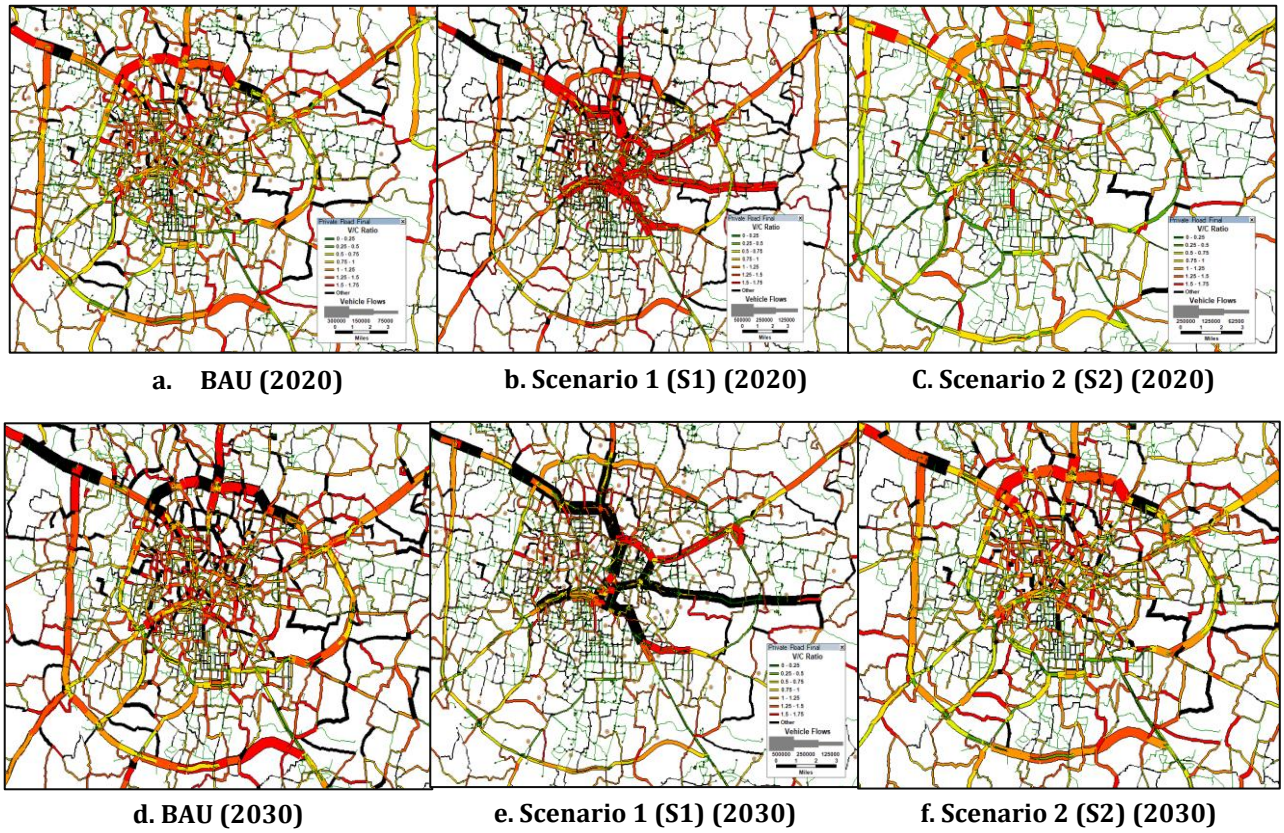


Figure 4. Total Vehicle Kilometres Travelled in 2020 and 2030

increase in VKT for Scenario 1 (Elevated Corridor) & 11.3 % reduction in VKT for Scenario 2 (Metro Rail bridge) from BAU 2030. The increase in VKT for scenario 1 is due to additional network being added to the road network. It is observed that people try to reach the Elevated Corridor to travel at faster speed eventually leading to congestion.



a. BAU (2020) b. Scenario 1 (S1) (2020) C. Scenario 2 (S2) (2020)

d. BAU (2030) e. Scenario 1 (S1) (2030) f. Scenario 2 (S2) (2030)

Figure 5. Trip Assignment of Vehicles in 2020 and 2030

Figure 5 shows the close up flows on the road network for the 3 scenarios. It is to be noted that the green colour links shows low congestion levels and the black coloured links have extreme congestion. It is observed that the Elevated Corridor grabs the attention of the private vehicle users (Fig 5b and 5c) thereby reducing the congestion on the neighbouring roads to the Elevated Corridor and increasing congestion on Elevated Corridor. Figures 4c and 4f shows the v/c maps under the Metro Rail scenario with less congested network due to availability of Metro Rail. A critical link like K R Puram Junction has been chosen to check the change in V/C for the 3 scenarios and it is shown in table 1.

Table 1: V/C estimates at KR Puram road junction

V/C					
Location	**BAU**	**S1**	**S2**	**Section**	**Year**
K R Puram JN	-	2.23	0.08	On bridge	2020
	1.9	0.61	0.45	Below Bridge	
	-	3.18	0.09	On bridge	2030
	2.7	0.81	0.58	Below Bridge	

The V/C has been calculated on the Elevated Corridor and the road adjacent to the Elevated Corridor to observe the change and it is found that the Elevated Corridor gets congested while the adjacent road gets decongested which does not serve the purpose of an Elevated Corridor construction. The V/C of Metro Rail as seen in the table 2 are 0.08 and 0.09 for the years 2020 and 2030 respectively for Scenario 2. The adjacent roads to the Metro Rail corridor will have a V/C of 0.45 and 0.58 for the years 2020 and 2030 respectively. This clearly shows how the transportation system benefits by providing a Metro Rail corridor as it reduces the burden on the roads and they will operate a Level of Service less than C (LOS 'C').

Further this article tries to estimate the emissions that are emitted from each of the scenarios. The emission factors are estimated by Munish et.al. 2018 from IIT Bombay based on World

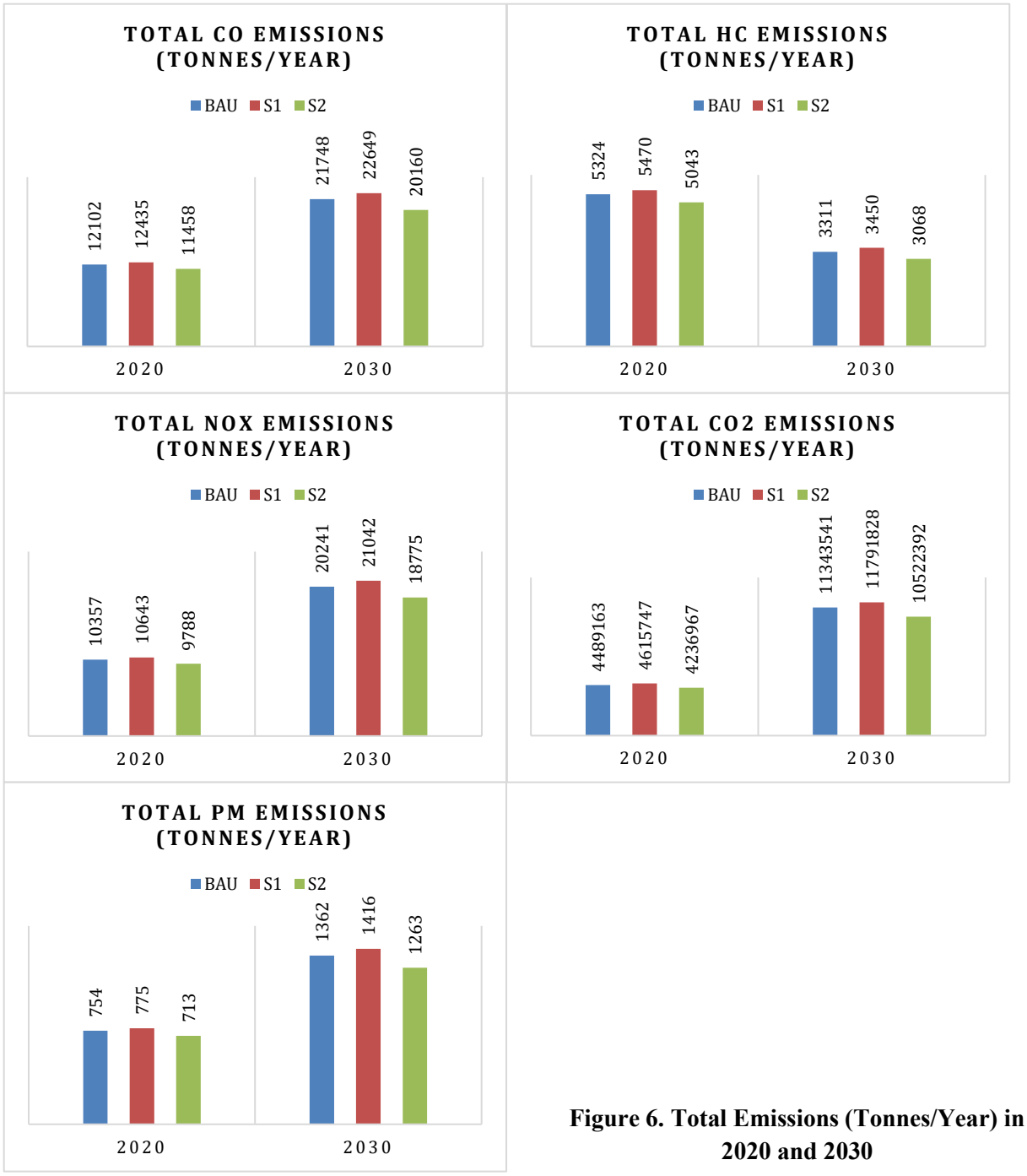


Figure 6. Total Emissions (Tonnes/Year) in 2020 and 2030

Energy Outlook report by IEA, 2015. Although the report consists of four scenarios with various energy mixes this report highlights the emissions for the BAU emission factor scenario. The pollutants considered are CO, HC, NOx, CO_2, PM.

From figure 6 it is observed that there is an increase in emissions for the S1 scenario (With Elevated Corridor) and reduction in emissions for S2 scenario (With Metro Rail) for 2020 and 2030. The construction of Elevated Corridor has increased the vehicle kilometres travelled because of the commuters trying to reach it from every direction thereby increasing the emissions. On the other hand, construction of Metro Rail has led to a shift towards Metro Rail reducing VKT from all private modes of transport there by reducing emissions. For the year 2020 emissions of the pollutants CO, HC, NOx, CO_2 have increased by 3% for S1 scenario and reduces by 5% for S2 scenario when compared with BAU. For PM pollutant there is an increase of 3% for S1 scenario and reduction of 6% for S2 scenario as compared with BAU scenario. In the year 2030, it is observed that the emissions of all pollutants increase by 4% for S1 scenario and decrease by 7% for S2 scenario when compared with BAU scenario

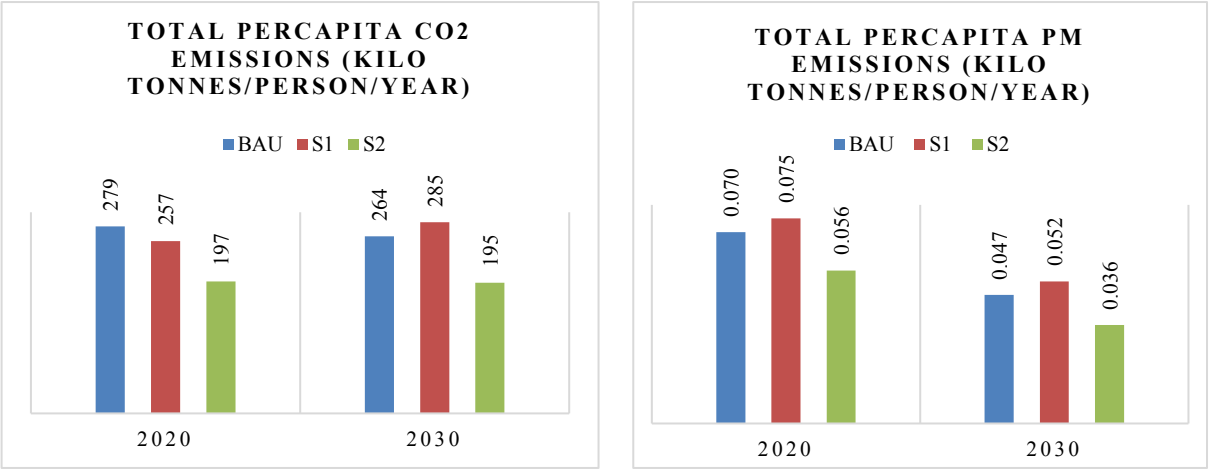


Figure 7. Total Percapita CO_2 Emissions in 2020 and 2030

The emissions percapita is an important factored to be determined as it shows the share a person contributes to the emissions for a particular mode. Figure 7 shows the total percapita emissions for CO_2 and PM from all the modes for the years 2020 and 2030. It is seen that the emissions percapita are much lower in S2 for the year 2020 compared to S1 scenario. In other scenarios the percapita emissions are increasing for S1 scenario and reducing for S2 scenario. For the year 2020 the percapita emissions for CO_2 reduce by 8% and 29% for S1 and S2 scenarios respectively. In the year 2030 the percapita emissions for CO_2 increased by 8% for S1 scenario and reduced by 26% respectively as compared to BAU scenario. For PM pollutant, in 2020 there is an increase of 7% in S1 scenario and a reduction of 20% in S2 scenario from BAU. In the year 2030 there is an increase of 11% for S1 scenario and a reduction of 23% for S2 scenario as compared to BAU.

Summary and Conclusions:

- It is observed that the construction of Elevated Corridor is attracting the traffic from all directions reducing the level of congestion on connecting roads and increasing congestion Elevated Corridor.
- Providing a Metro Rail corridor on the proposed Elevated Corridor reduces congestions more with lower V/C ratios.
- Since the project is connecting the main trip production centres, providing Metro Rail corridor seems to have resulted in mode shift towards Metro Rail and reduction in private vehicle trips.
- Due to high speeds on the elevated corridor and less congestion due to Metro Rail there is a 8 % reduction in total system travel time for scenario 1 & 40% reduction in travel time for scenario 2 when compared with BAU 2020.
- Similarly, there is a 5.3 % reduction in total system travel time for scenario 1 & 53.4% reduction in total system travel time for scenario 2 when compared with BAU 2030.
- From the emissions plots it is seen that the least amount of emissions are from the Scenario 2
- Although Bus and Metro Rail emit high amount of CO_2 their high occupancy levels leads to less percapita emissions (Less contribution to emission by Public Transport users).
- The percapita emissions for CO_2 reduced by 8% and 29% for S1 and S2 scenarios respectively in the year 2020. In the year 2030 the percapita emissions for CO_2 increased by 8% for S1 scenario and reduced by 26% respectively as compared to BAU scenario
- For PM pollutant, in 2020 there is an increase of 7% in S1 scenario and a reduction of 20% in S2 scenario from BAU. In the year 2030 there is an increase of 11% for S1 scenario and a reduction of 23% for S2 scenario as compared to BAU.
- Since, VKT is higher for S1 scenario with respect to BAU, the total energy (fossil fuel) consumption will also be higher for S1 as compared to BAU and S2 scenario.
- From the above results it is clearly evident that the Elevated Corridor construction will not yield any improvement to the city's traffic condition and is therefore not a sustainable solution and will also make Bengaluru city less liveable.
- Policies and infrastructure to encourage public transport system like bus and Metro Rail have shown better results in terms of congestions and sustainability.

For more comprehensive and specific solutions for BMR on the above lines, please refer to the project report of IISc Bengaluru titled "Sustainable Transport Measures for Liveable Bengaluru". The same can be downloaded from the link: -

http://civil.iisc.ernet.in/~ashishv/bengaluru/CLIMATRANS_Report_BENGALURU_P_April_2018.pdf

Jump to Grey Slender Loris: In detail

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Grey Slender Loris

Loris lydekkerianus

ABSTRACT

Grey Slender Loris *Loris lydekkerianus* has most recently been assessed for *The IUCN Red List of Threatened Species* in 2020. *Loris lydekkerianus* is listed as Near Threatened under criteria A2cd.

feedback

Download Text Overview

THE RED LIST ASSESSMENT

Dittus, W., Singh, M., Gamage, S.N., Kumara, H.N., Kumar, A. & Nekaris, K.A.I. . 2020. *Loris lyd...*

LAST ASSESSED

14 October 2020

SCOPE OF ASSESSMENT

Global

Assessment in detail

POPULATION TREND

Decreasing

NUMBER OF MATURE INDIVIDUALS

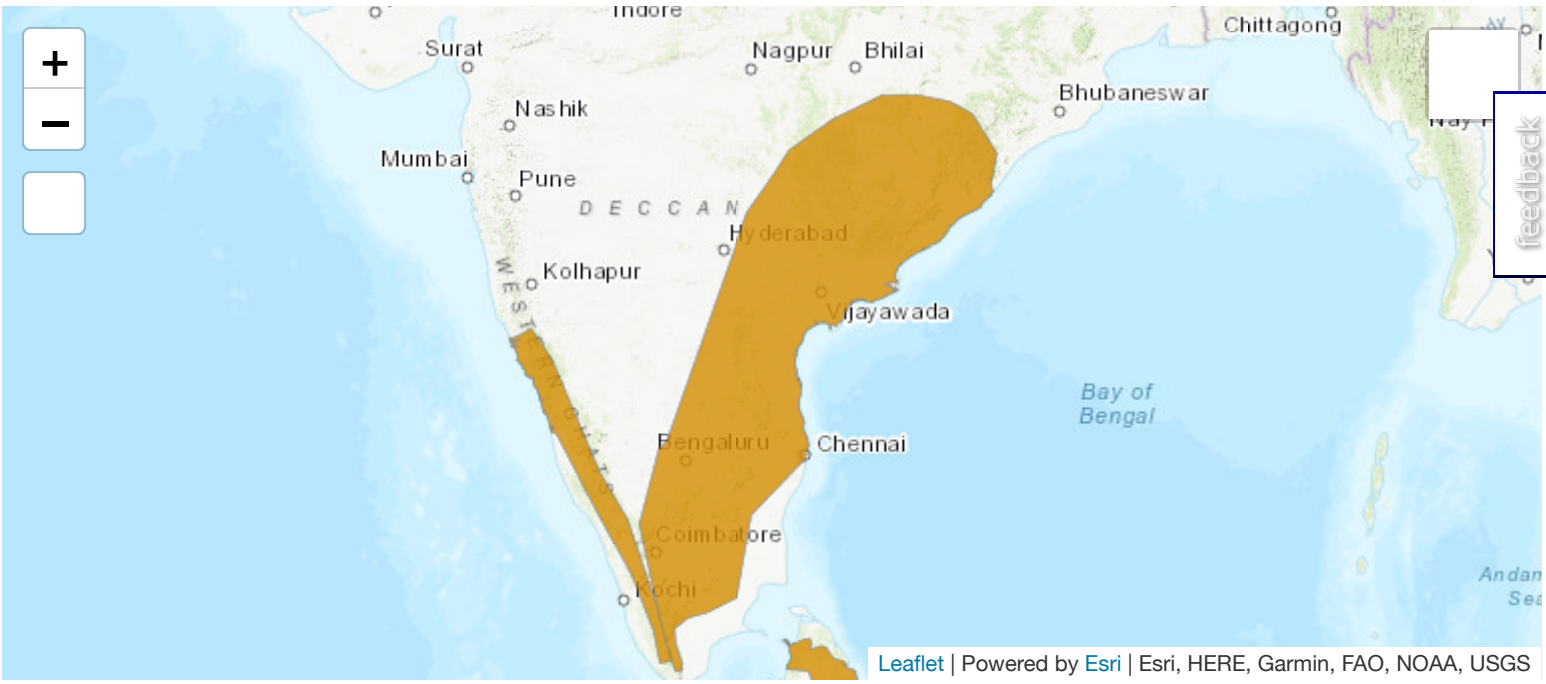
Population in detail

HABITAT AND ECOLOGY

Forest, Artificial/Terrestrial

Habitat and ecology in detail

GEOGRAPHIC RANGE



EXTANT (RESIDENT)

IUCN (International Union for Conservation of Nature) 2020. Loris lydekkerianus. The IUCN Red List of Threatened Species. Version 2021-3

Geographic range in detail

Taxonomy

Assessment Information

Taxonomy

KINGDOM
Animalia

PHYLUM
Chordata

CLASS
Mammalia

ORDER
Primates

FAMILY
Lorisidae

GENUS
Loris

Taxonomy in detail

Assessment Information

IUCN RED LIST CATEGORY AND CRITERIA
Near Threatened A2cd

ver 3.1

DATE ASSESSED
14 October 2020

feedback

YEAR PUBLISHED

2020

Assessment Information in detail

Geographic Range

NATIVE

Extant (resident)

India; Sri Lanka

NUMBER OF LOCATIONS

150-175

UPPER ELEVATION LIMIT

2,000 metres

LOWER ELEVATION LIMIT

50 metres

Geographic Range in detail

feedback

Population

CURRENT POPULATION TREND

Decreasing

NUMBER OF MATURE INDIVIDUALS

POPULATION SEVERELY FRAGMENTED

Yes

CONTINUING DECLINE OF MATURE INDIVIDUALS

Yes

Population in detail

Habitat and Ecology

SYSTEM

SYSTEM

Terrestrial

584

HABITAT TYPE

Forest, Artificial/Terrestrial

GENERATION LENGTH (YEARS)

8-9 years

CONGREGATORY

MOVEMENT PATTERNS

CONTINUING DECLINE IN AREA, EXTENT AND/OR QUALITY OF HABITAT

Yes

Habitat and Ecology in detail

Threats

Agriculture & aquaculture

- Annual & perennial non-timber crops

Transportation & service corridors

- Roads & railroads
- Utility & service lines

Biological resource use

- Hunting & trapping terrestrial animals
- Logging & wood harvesting

Natural system modifications

- Fire & fire suppression

Threats in detail

Use and Trade

Pets/display animals, horticulture

feedback

Pets/ display animals/ horticulture

Local: ✔

National: ✔

International: ✘

Medicine - human & veterinary

Local: ✔

National: ✘

International: ✘

Other (free text)

Local: ✔

National: ✘

International: ✘

Use and Trade in detail

Conservation Actions

In-place research and monitoring

- Action Recovery Plan : No
- Systematic monitoring scheme : No

In-place land/water protection

- Conservation sites identified : No
- Area based regional management plan : No
- Occurs in at least one protected area : Yes
- Invasive species control or prevention : No

In-place species management

- Harvest management plan : No
- Successfully reintroduced or introduced benignly : No
- Subject to ex-situ conservation : No

In-place education

- Subject to recent education and awareness programmes : No

feedback

- Included in international legislation : Yes
- Subject to any international management / trade controls : Yes

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Conservation Actions in detail

Bibliography

Red List Bibliography

EXTERNAL DATA

Images and External Links

Images and External Links in detail

CITES Legislation from Species+

DATA SOURCE

The information below is from the Species+ website.

CITES Legislation from Species+ in detail

Studies and Actions from Conservation Evidence

DATA SOURCE

The information below is from the Conservation Evidence website.

Studies and Actions from Conservation Evidence in detail

feedback

THE RED LIST PARTNERSHIP

IUCN

SSC Species Survival Commission

ABQ BIOPARK

ASU Center for Biodiversity Outcomes

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Sponsors
Red List Committee
Frequently Asked Questions
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Red List Partnership
IUCN–Toyota Partnership
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Citing The IUCN Red List

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Spatial Data & Mapping Resources

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IUCN 2022. The IUCN Red List of Threatened Species. Version 2021-3.
<https://www.iucnredlist.org>
ISSN 2307-8235

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Cities

The night-time hunt for the secretive urban slender loris of Bangalore

Implausibly, this elusive nocturnal animal has somehow survived in Bangalore, a mushrooming megacity of 10 million people. But a catastrophic loss of trees in what was formerly known as India's 'garden city' threatens their future

Elizabeth Soumya

Fri 31 Jul 2015 06.00 BST

It's 7pm on a Saturday night and a park in the heart of the city is teeming with people. The pathways are crammed with jostling walkers, park benches are spilling over with couples and senior citizens. In all the bustle, a group of people carefully trail the walkway armed with torches that they shine across the park's treetops. They're looking for something. They find ant nests, a spotted owlet and bats hanging upside down - but they keep moving. They reach the end of the park's walkway and a swathe of light from a torch hits a tall tree outside the

park boundary. A pair of eyes glowing in the dark stare back and begin floating in the dark. They've found what they're looking for - a small and extremely elusive furry creature - a slender loris. With wide, unblinking eyes and long, skinny limbs, these peculiar squirrel-sized primates live on trees in the forests of southern India and Sri Lanka.

But the park where the group spots the loris is far from a pristine forest. The roundabout next to it is clogged with traffic, drowned in a cacophony of horns and city noises. Bangalore, known as India's Silicon Valley, is one of the world's fastest-growing cities with a population of 10 million.

And yet, somehow, the lorises have survived, hidden in the heart of the city despite its relentless urbanisation. Until a few decades ago, the lorises - called *Kaddu paapa* (forest baby) in the local language of Kannada - were found in parts of the city, including MG Road in Bangalore's central business district. Snake charmers with lorises in their pockets were a common sight and the lorises were sometimes sold as pets. But lorises were thought to have disappeared from the inner city as jackals and mongooses had. Today, few know what a slender loris is, let alone that the peculiar looking animal could be sharing their neighbourhood.



Volunteers from the Urban Slender Loris Project on a night survey. Photograph: Ashok Hallur

But a citizen science mission has brought the spotlight on these hidden lorises for the first time. The Urban Slender Loris Project (USLP), with its local volunteers, has been surveying the city for the last six months investigating urban lorises. With absolutely no data to fall back on, they had to begin from scratch. Their first goal was to assess where the lorises had survived. They divided the city into 5 sq km grids and acquired the necessary permissions to

scrutinise after dark public green spaces (such as parks, lakes, institution campuses), as well as residential areas and other possible loris habitats. One hundred and fifty Bangaloreans have volunteered in 26 night trails. There have been 61 loris sightings.

Kaberi Kar Gupta, the principal scientist behind USLP has studied slender lorises in the wild for a decade. In 2013, Gupta and some wildlife experts looked for lorises in a city university campus and were rather surprised. “They were everywhere. Their density was much higher than what I saw when I did my PhD,” she recalls. The reason slender lorises are here is because the city falls in the natural distribution zone of the animal. “You would expect them here, but we didn’t expect they could be living inside the city, especially with the way Bangalore has been growing in the past 20 years,” she adds.

The lives of Bangalore’s lorises are shrouded in mystery. Even in the wild, these curious primates have not been studied much. Gupta’s research in the forests of Tamil Nadu is the only radio-collared study of slender lorises. Weighing around 200g or less, these small creatures are hard to spot. They are arboreal and nocturnal, foraging for tiny fruits and insects. It is perhaps these characteristics that have helped the loris stay out of sight even in a big city.

“ Snake charmers with lorises in their pockets were once a common sight in Bangalore



A slender loris spotted in Bangalore. Video by Adarsh Raju

The USLP team have encountered odd behaviour in the urban loris. While slender lorises are usually found perched at an average height of 5 metres, the city lorises were seen a greater

height. “They’re probably avoiding disturbance from human activities and using Bangalore’s availability of large trees,” explains Padma Ashok, a core volunteer in the project. Lorises have also been spotted on unusual plants such as bougainvillea and two rare sightings on a coconut tree and a Christmas tree were reported. These shy mammals have even been spotted near lamp-posts catching moths that were attracted by the light.

The presence of lorises, as an indicator species, suggests the presence of other creatures in the ecosystem - and, accordingly, the USLP has also recorded frogs, snakes, birds, insects and other mammals on its walks. But the lorises have very specific ecological requirements and are therefore picky about their homes. “They need continuous horizontal tree canopy to move along treetops, and they prefer small branches that they can hold with their slender limbs,” explains Gupta. They don’t sleep in nests or tree holes and, because of the way they sleep - they roll up, tuck in their heads and sleep in the canopy thickets - they need very specific sleeping sites. “Given these very particular needs,” Gupta adds, “how is it they survive in a city?”

Without connected tree canopy, slender lorises can’t move from one green patch to another. “Bangalore, like many large cities, has patchy green cover, but continuous canopy is particularly important for mobile species such as lorises, bats and butterflies. It’s also critical for their genetic viability in the long term,” says urban ecologist Harini Nagendra.



Lorises need continuous horizontal tree canopy to move along treetops. Photograph: Angad Achappa

Until a decade ago, many city roads were buried under the cooling shade of avenue trees that overlapped and kept treetops connected. These not only provided food and shelter, but were

midway points for species moving between habitats in the city - especially crucial for canopy creatures such as lorises.

In the past decade, Bangalore - once famous as India's "garden city" for its green spaces - has lost most of its trees. According to an estimate by the Environmental Support Group (ESG), a Bangalore based NGO, 50,000 trees were felled to widen a series of streets in the late 2000s. Between 2011 and 2014, 9,281 trees were felled for the city's metro and other road-widening projects. The city's peri-urban outskirts - once full of orchards - have also lost hundreds of thousands of trees to allow for the expansion of a city whose 47% growth rate between 2001 and 2011 was the highest in India.

"The orchards were connected to inner-city parks and open spaces through avenue trees, and served as wildlife corridors," explains Leo Saldana of ESG. "This isn't merely an aesthetic or environmental loss, but has been ecologically disastrous with an irreplaceable loss of biodiversity," he says.

In April, citizens from the USLP spotted five slender lorises in a small city forest adjoining one of Bangalore's busiest roads. The green patch is being developed as a city park and the felling of trees for a walkway has begun.

While development is essential for a city, Gupta recommends that developers and city authorities work with environmental experts for solutions. "Urban areas are not sterile; they can create refuge for wildlife. But, unlike protected areas, in cities the pressures are too many," she says.

Slender lorises are an endangered species accorded the highest protection under Indian law. While they continue to be threatened by poaching for superstition and the illegal pet trade, the gravest danger they face in a city is habitat destruction. For how much longer can Bangalore have these rare creatures? "That really depends on whether we can co-exist," says Gupta. "I believe we can."

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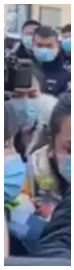
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The slender loris struggles to find canopy in Bengaluru

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by Mohit M. Rao on 24 September 2020
Mongabay Series: Almost Famous Species

- *The grey slender loris, which spends most of its time in canopies, is found across peninsular India and parts of Sri Lanka. Bengaluru comes in the northern end of the range, and before it became the country's third most populous city, it was also home to a significant number of lorises.*
- *The species has somehow clung to life in Bengaluru's remnant green spaces, even as the city is getting concretised at a frenzied pace.*
- *When continuous patches of green become isolated patches, it can have catastrophic effects on loris populations, who, unlike monkeys, do not jump between branches nor are seen descending on the ground to cross wide open spaces.*

Flanked by the Outer Ring Road, where unceasing traffic spews noxious fumes, and a concreted canal where heaps of plastics float amid sewage, the Hennur Lake biodiversity park in Bengaluru is an incongruous speck of green in a wide swath of concrete. And for a few slender loris individuals, it is an unlikely home.

As implausible as it may seem, grey slender lorises (*Loris lydekkerianus*) have clung to life while the city's concrete-scape has corned them into this 34-acre park.

At least 4-5 individuals of the beady-eyed, small, elusive primate have been spotted in the park's canopies. Surveys conducted between 2015 and 2017 had spotted two infants, signifying a breeding population.

"We can't say for sure how they came about here," said Vidhisha Kulkarni, from the Urban Slender Loris Project (USLP), a citizen science project that surveyed and studied the primates in Bengaluru between 2014 and 2017. "Perhaps, they ended up being isolated here due to the loss of greenery around them. Or, perhaps, they had been left here by animal rescuers in the city."

As recent as 20 years ago, the park was connected through canopies to the wetlands of the Hebbal-Nagawara valley. The shrubs and trees that lined the Rajakaluves (Storm Water Drains) provided a corridor for lorises to travel to the Indian Institute of Science Campus, about 11 km in the west, or to the verdant green campus of University of Agricultural Sciences' GKVK campus – 13 km to the North.

First came the broad Outer Ring Road, which sliced through the canopy. Then, the wetlands of the valley itself became residential areas and towering IT complexes. The woodlands in Hennur provided a sanctuary.

“But, as we surveyed the place, we could see the threats playing out in real-time. Trees were being cut and piles of garbage were being burnt around the park. This is such a small, isolated patch of land – we don’t know what will happen to this population in a few years,” said Kulkarni.



The grey slender loris, which spends most of its time in canopies, is found across peninsular India and parts of Sri Lanka. The animal is also found in a busy city such as Bengaluru. Photo by Angad Achappa/Urban Slender Loris Project.

Shrinking space, thinning canopies, vanishing lorises

The grey slender loris, which spends most of its time in canopies, has a range from southern Andhra till the southern tip of India and into large parts of Sri Lanka. Bengaluru comes in the northern end of the range, and before it became the country’s third most populous city, it was also home to a significant number of lorises.

This is reflected in the interviews of old-time residents conducted by USLP. Lorises have been sighted all across Bengaluru, even in the congested heart of the city, till a few decades ago. The timeline varies from area to area. Lorises disappeared from the city’s centre about four decades ago, while they have been spotted in other areas as recently as ten or 20 years ago.

This information is from interviews and needs to be taken with a pinch of salt. “Lorises are elusive creatures and people’s memories can be dodgy with dates,” said Kulkarni.

And then, Bengaluru exploded, leaving slender lorises to scamper towards remaining green spaces or perish. Researchers from the Indian Institute of Science (IISc) tabulate, through satellite imagery, that between 1973 and 2017, Bengaluru’s urban built-up area

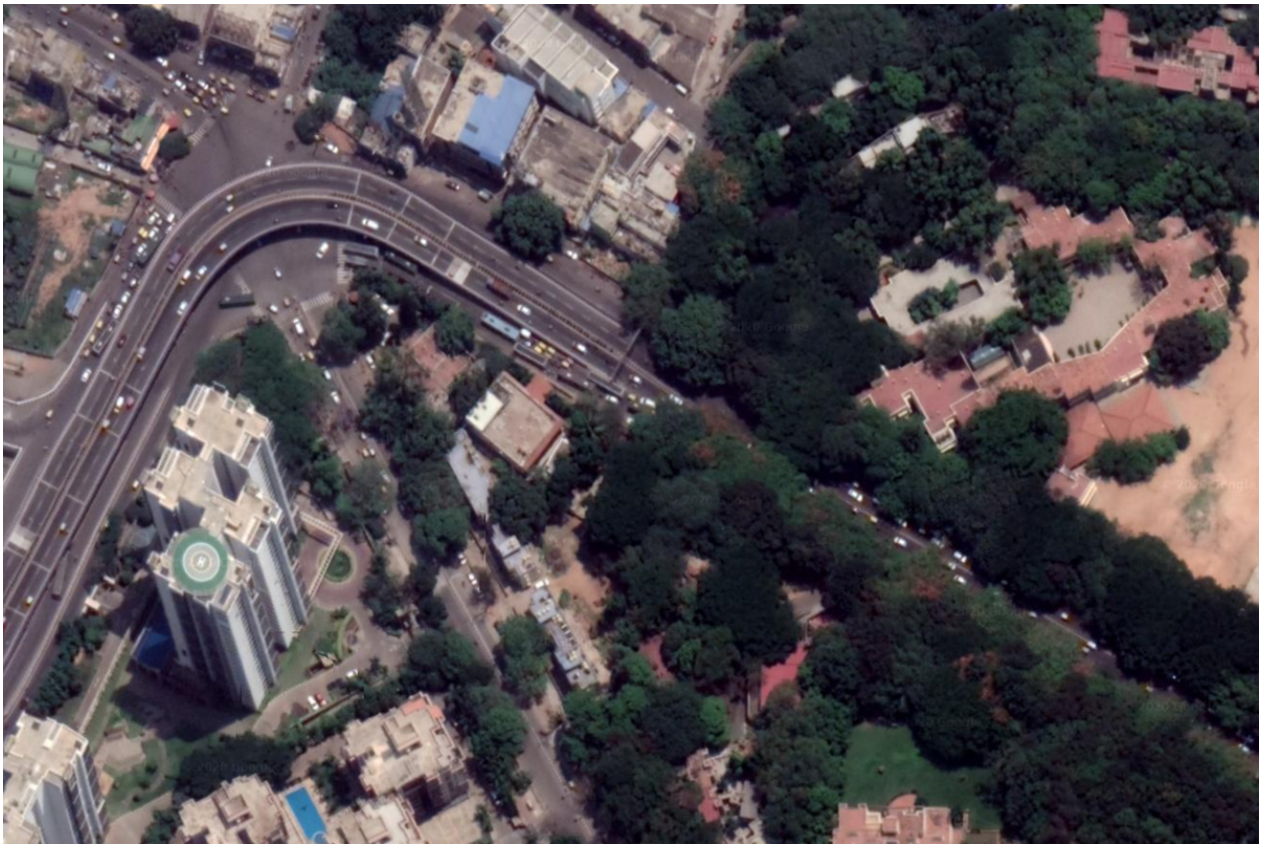
rose by 1028 percent, while its vegetation declined by 88 percent.

What were continuous patches of woodlands, scrub forests or trees in valleys became isolated patches of green. This is most stark in southern Bengaluru's Turahalli forest, which has been split into two.

This can have catastrophic effects on loris populations, who, unlike monkeys, do not jump between branches nor are seen descending on the ground to cross wide open spaces.

A connected canopy is key to their survival, and this is seen in ULSP surveys conducted in 2015 on the current distributions of the nocturnal primate. The surveys showed established populations in eight patches – a majority of them in north Bengaluru, which is home to remnants of a contiguous canopy cover spanning research institutes and public sector enterprises.

North Bengaluru has not been spared from Bengaluru's urbanisation, but it is home to some of the last remaining large contiguous patches of greenery. The best among these as a loris habitat is the leafy campuses of the Indian Institute of Science that connects with Central Power Research Institute, University of Agricultural Sciences, Raman Research Institute, upmarket Sadashivanagar residential area and Sankey Tank. This spans an area of 6.58 square km, with canopies enabling movement of slender lorises.



Satellite view of tree canopies in concretised Bengaluru. Tree canopies act like highways for arboreal animals such as the slender loris to move between areas. Vanishing green cover poses threat to the animal. Photo from Google Earth Pro.



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"Our campus has four families of slender loris as we have appropriate and secured habitat. The animal also gets adequate food here," said T.V. Ramachandra, from the Centre for Ecological Sciences at Indian Institute of Science.

Apart from the canopy cover, which has defined the campus since it started more than a century ago, IISc also enhanced its ecological richness by creating a mini-forest, which houses over 49 indigenous tree species of the Western Ghats. The 1.74-hectare forest planted a little more than 25 years ago has provided a sanctuary for slender loris and even the jungle cat.

ULSP's surveys within the campus have indicated that lorises tend to favour native trees, which attract more insect populations than non-native species such as acacia, copper pod or gulmohar. There is some sort of adaptation of lorises to urban life, with ULSP researchers and volunteers observing the use of lampposts where the lights attract a veritable buffet of insects.

However, even the IISc campus has seen its fair change of changes: older, smaller labs have given way to multi-storied blocks. A concrete building has replaced a clump of trees where lorises were spotted in the 2015 survey. Meanwhile, canopies across the main roads that connect IISC to neighbouring campuses are thinning out.

"Creation of mini forests in each ward [of the city] would act as islands of biodiversity. Apart from creating mini forests, we need to have canopy connectivity. Otherwise, with the chances of inbreeding, population become non-viable," said Ramachandra, who

emphasises the need to revive the traditions of planting species such as figs, mango, tamarind, among others along roads which acted as canopy bridges.

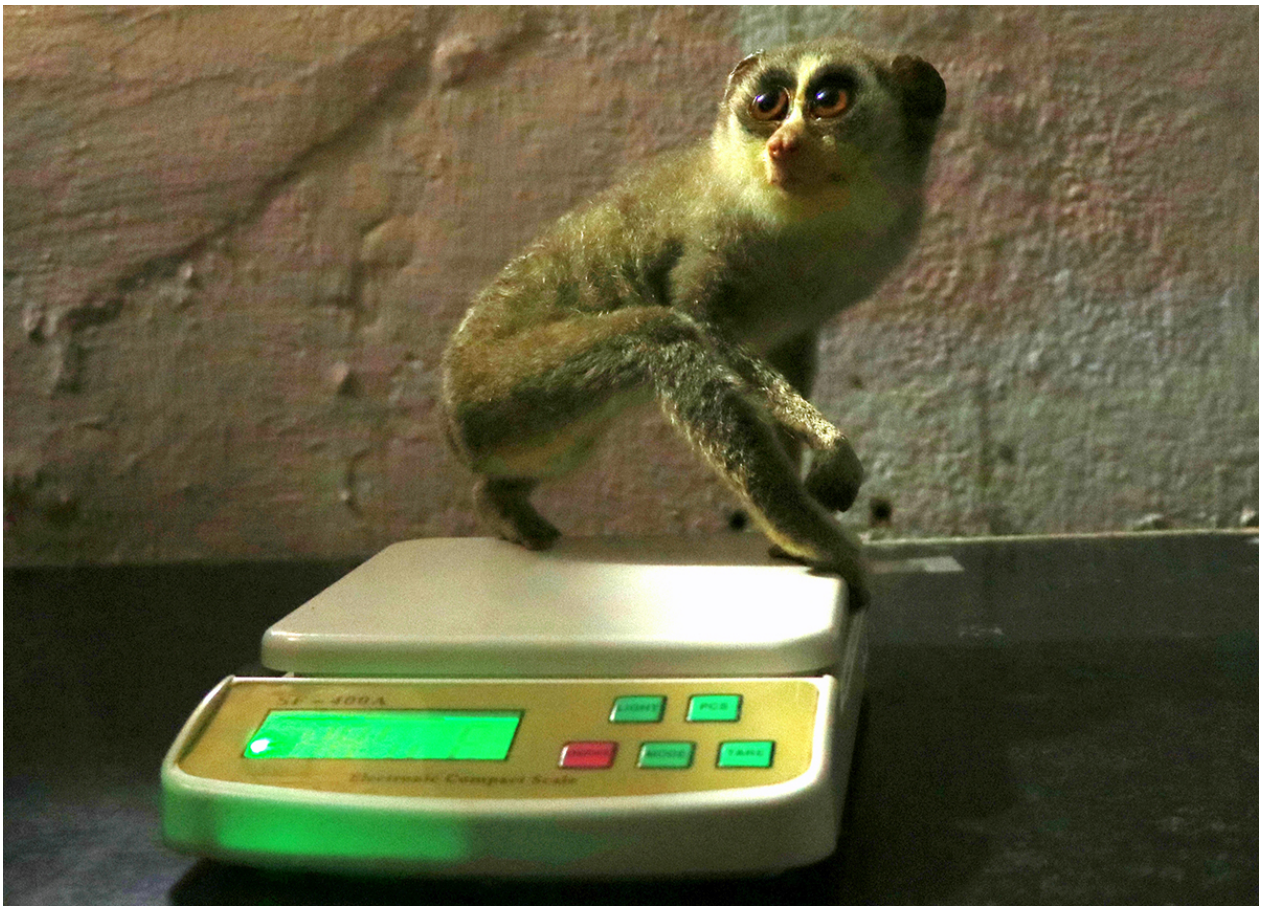
Studying lorises in a stressed habitat

The shy slender loris, which scuttles away in the presence of humans, occupies a strange space in local beliefs. Kaadu Papa (literally translated to “forest baby” in Kannada) is believed to have medicinal properties, while others believe these stealthy creatures to possess black magic. In some extreme beliefs, blinding the bulbous eyes of the loris is believed to cure cataracts.

However, contrary to popular perception, the threat of poaching or its capture for black magic practices is not a threat in Bengaluru. Anthropogenic disturbance and landscape change are the big killers.

People for Animals (PfA) has rescued 67 lorises in the past 12 years. A majority are from North Bengaluru, particularly in and around IISc — another sign that this could be the last viable habitat in the city. Of 19 cases where causes of injuries were studied, just two cases of starvation and stress were linked to the use of lorises for black magic rituals. The rest were due to electrocution, dehydration, injuries to the body, perhaps due to a fall, and displacement in dense residential areas.

“The only way to save them from extinction is through habitat conservation and awareness creation. We have come across so many people who do not even know the existence of a slender loris, and then we have those who traffic them, abuse them for black magic,” said Colonel Navaz Shariff, Chief Veterinarian and General Manager of PfA Wildlife Rescue & Conservation Centre, Bengaluru.



A rescued slender loris being weighed. Photo from People for Animals, Bengaluru.

Elusiveness characterises lorises. They hunt insects primarily at night and hide in canopies during the day. In Hennur Biodiversity Park, for instance, even regular walkers seemed blissfully unaware of the primates; while, a forest department guard says he knows of their existence only through rare, sudden movement in the canopy, but has yet to see one in person.

It was to create awareness and get citizens involved in protecting the animals that the Urban Slender Loris Project was started sometime in 2014. Largely volunteer-driven, the project would conduct regular walks. These walks/surveys would see an eclectic collection of people spanning the spectrum of professions point their torchlight on canopies. Occasionally, a pair of glowing back would stare back.

“We did see a lot of interest from people and the media. We were trying to show people that urban spaces are not dead spaces, and people could co-exist with animals here,” said Kaberi Kar Gupta, Founder of ULSP whose doctoral research gave crucial insight into behaviour of lorises in the Western Ghats.

By 2017, grants were drying up, and it became difficult to continue the project regularly. Currently, the project is on a hiatus. ULSP had sought to bridge some of the gaps in understanding behaviours of lorises. How does genetic inbreeding affect the lorises? What is the average territory for lorises in cities? How far do they travel in their nocturnal hunts or for mating?

“There is so much to study about lorises and urban spaces. But, urban ecology is not a big thing in India. Lorises are not considered endangered and do not attract grants,” said Gupta.

But considering the rapid rate of construction in Bengaluru, time may not an ally of the lorises or for researchers interested in understanding their behaviours in the city. Multiple roads are slated to be widened at the cost of trees; while canopy cover in residential areas and research institutions have been on a decline.

Even areas surveyed in 2015 have become concretised. Hennur biodiversity park, for instance, has transformed since the survey: around Rs. 5 crores (50 million) has been spent on beautifying and adding visitor amenities – often at the cost of trees or canopies.

“Lorises will not survive if you have small, isolated patches of manicured city parks. We still borrow ideas of urban green spaces from the west. We need to decolonise this aspect of city planning,” said Gupta. And lorises can be the driving force for a more holistic version of planning that recognises co-existence with urban fauna.

“Slender lorises can be an icon of Bengaluru city. If you could save lorises, you could save green spaces, mitigate urban heat effect, create a healthy ecosystem for other primates and birds,” she said.

> Read more: Hunted and traded for body parts, the Bengal slow loris needs a conservation strategy

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This article is part of a series on Bengaluru’s Ecosystems and Biodiversity, a joint project between Mongabay-India and Citizen Matters, supported by the Bengaluru Sustainability Forum (BSF).

Banner image: A slender loris coexists in India’s third most populated city, Bengaluru. Photo by Angad Achappa/Urban Slender Loris Project.

Article published by Sandhya Sekar

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Zoology and Ecology

ISSN: 2165-8005 (Print) 2165-8013 (Online) Journal homepage: http://www.tandfonline.com/loi/tzec20

Impact of threats on avifaunal communities in diversely urbanized landscapes of the Bengaluru city, south India

S. Rajashekara & M. G. Venkatesha

To cite this article: S. Rajashekara & M. G. Venkatesha (2017): Impact of threats on avifaunal communities in diversely urbanized landscapes of the Bengaluru city, south India, Zoology and Ecology

To link to this article: http://dx.doi.org/10.1080/21658005.2017.1380366

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Impact of threats on avifaunal communities in diversely urbanized landscapes of the Bengaluru city, south India

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ABSTRACT

Identification of threats contributing to occurrence and range distribution of avifaunal communities is poorly known in diversely urbanized landscapes of the Bengaluru city, south India. For the first time, we investigated the disturbance scores along the low (LDS) to high disturbance sites (HDS) with respect to various parameters, i.e. canopy cover, vegetation structure and its composition. We examined their habitat associations and the potential effects on them corresponding to various threats including human development pressure and other habitat suitability indices in urban landscapes of the Bengaluru region. HDS with a lower number of bird species harbour more threat scores than the LDS with the highest number of bird species. Habitat alteration, practice of monoculture plantations, improper waste management and grass cutting were more commonly observed threats in landscapes of the Bengaluru region. The maximum number of perching plant species was characteristic of low disturbance sites with a greater fraction of moist deciduous species. Canopy coverage of plants/trees and the structure of canopy cover were the highest in LDS with the highest strata of the vegetation cover. Human development pressure was the highest in HDS. Management further includes several approaches for the maintenance of urban landscapes for avian communities to minimize bird problems and promote management options that favour bird diversity.

ARTICLE HISTORY
Received 8 August 2016
Accepted 12 September 2017

KEYWORDS
Canopy cover; diversity indices; habitat suitability index; species diversity and richness; threat index; vegetation structure

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Introduction

The greediness of humankind provides footprints for industrialization and modernized agricultural farming in the present urban landscapes of the world. Adaptation and modification in the wildlife habitat within urban areas via replacement of forest area and native vegetation with lawns, constructions, roads, and other impermeable surfaces postures one of the extreme threats to avian populations on a global scale (Czech, Krausman, and Devers 2000). Avian communities are the potential contestant species for the study of biodiversity and conservation to identify the health of the urban ecosystem by documenting their occurrence, abundance and frequencies for all species (Lerman et al. 2014; Rajashekara and Venkatesha 2015).

Analysis of threats for any biological organisms is also known as a gap analysis extended by including different environmental variables that are quantified based on each variable's possible impact on conservation. It is designed for the assessment of the present and future of any taxa/species responses to human developmental pressure on organisms (Theobald 2003). Therefore, threat ranking is a method for unambiguously considering the degree to which each direct threat affects biodiversity of species or targets at a particular study site. Further it involves in identifying systematically a set of criteria to the direct threats so that conservation activities can be engaged if they are maximum needed (IUCN Redlist of Threatened Species 2009). The ability of citywide surveys to rapidly prioritize species has to be tested according to their sensitivity to development and the impact of humans on bird diversity in urban areas (Turner2003).

Our understanding of habitat and bird relationships forms a traffic lane for both of them in urban landscapes, hence unbearable effective conservation plans aimed at improving habitat within the city regions (Margoluis and Salafsky 1998). Birds are highly perceptible and fairly sensitive to changes in habitat structure and composition. Therefore, they are excellent indicators of modifications and pressures in the urban ecosystem (Savard and Falls 1982; Clergeau et al. 1998). Bird species richness in urban ecosystems is influenced both by local and landscape-level characteristics, and a multi-scale approach is critical to their proper management (Savard, Clergeau, and Mennechez 2000). Understanding and forecasting the temporal and spatial dynamics and composition of avian populations remains a central goal in avian biology

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of different landscapes of the urban Bengaluru region (Rajashekara and Venkatesha 2015).

This provides a detailed understanding of how demographic rates vary through space and time as well as the underlying causes. This affords the answer to the particular question: How does spatial and temporal environmental heterogeneity influence avian diversity at different scales? (Sutherland et al. 2013).

Urban bird communities and their underlying processes is the major concern of current avian ecology, but we made an attempt at reviewing the present background and limited its conservation implication and readership to a single city. Although natural and man-made threats in some locations of oriental India have been simply mentioned (Karr 1976; Gaston 1986; Sridhar and Karanth 1993; Lalitha et al. 1999; Mahabal and Vasanth 2001; Arunchalam et al. 2004; Awan et al. 2004; Das, Saikia, and Bhagawati 2005; Rajkumar 2005; Narang, Akhtar, and Kumar 2008; Ramesh and Sathyanarayana 2009; Acharya and Vijayan 2010; Bharali and Khan 2011; Jan, Uniyal, and Chauhan 2011; Menon and Mohanraj 2016), their quantification and their effect on the composition, abundance and diversity of birds have not been thoroughly studied in major landscapes of the urban region. The need for scientific information related to several threats on urban bird communities in the Bengaluru region has engaged us to start the present study. Since few studies on avian diversity, interaction with perching plants, role of threats have been conducted, it is important to emphasize the impacts of perceptible threats.

For the present study, precisely we have (1) identified the vegetation composition (perching plants/trees for birds), structure, and landscape features associated with the presence of a complement of representative bird species based on an extensive literature review in Indian context, (2) quantified the characteristics of landscapes in nineteen study sites across the disturbance gradients using a collection of primary datasets and assessment for the urban planning program, (3) exhibited the habitat suitability indices for representative bird species in urban forest monitoring plots, validated the habitats, and compared habitat suitability indices among study landscapes, and (4) tested whether the ranking of threats changed over time for low to high disturbance sites.

Finally, our study objective was answered through (1) investigation of the response of avian communities to human-induced activities and impact of threats on the activities and patterns of avian composition of differently urbanized landscapes in the metropolitan Bengaluru city, south India. Furthermore, this study aimed (2) to describe and validate threats in diverse landscapes along disturbance gradients of the urban region, and (3) to demonstrate their applicability for improving the urban bird diversity of the Bengaluru city, India.

Materials and methods

Study area

Bengaluru is located in the South Deccan plateau of the Peninsular region of India (Figure 1), occupying an area of 2191 km^2 of metropolitan area inhabiting 9 million population (Census of India 2011) and set in the midst of valleys with the rivers of Arkavathi, Kumadavathi and Vrishabhavathi flowing from the Nandi Hills (Devanahalli) to Kengeri (Mysuru Road) (Figure 1). This city is composed

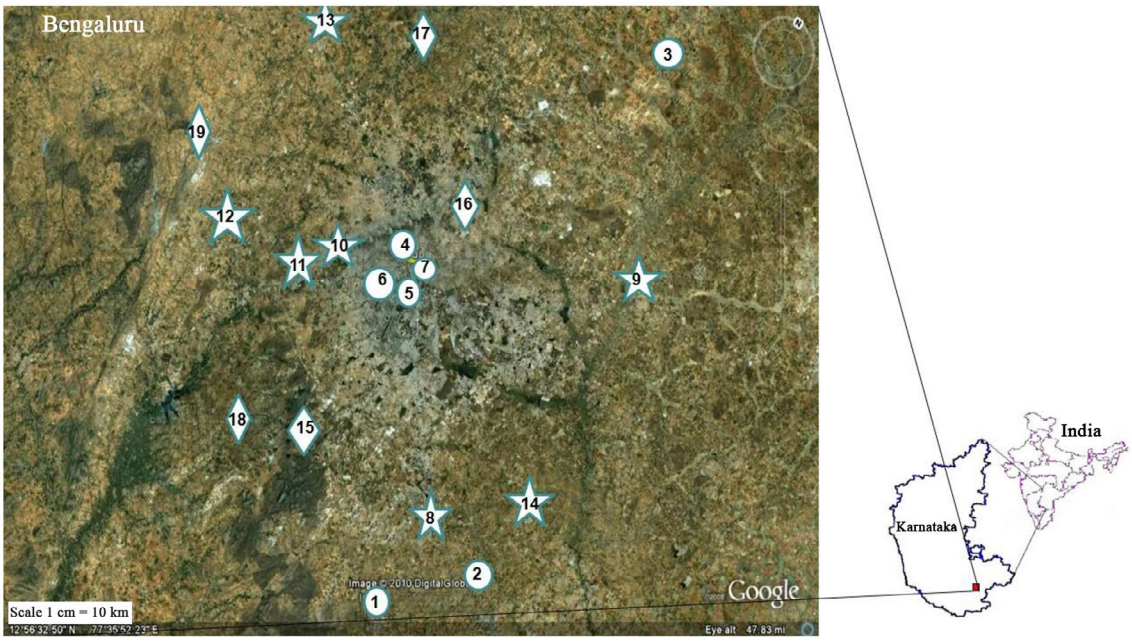


Figure 1. Map showing the study sites with reference to threats across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, south India. [Map data: Google, DigitalGlobe].

Note: Circles represent high disturbance sites (HDS: 1-AK, 2-AB, 3-DH, 4-KBS, 5-KRM, 6-LBG, 7-LCP), stars represent medium disturbance sites (MDS: 8-CP, 9-HK, 10-JBC, 11-KG, 12-KH, 13-NM, 14-SJP), and rhombi represent low disturbance sites (LDS: 15-BNP, 16-HB, 17-HG, 18-SM, 19-TGH).

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of urban landscapes from dry deciduous forests scrub with open to closed canopy evergreen forests along the streams, urban to semi-urban regions. Winter (December to February), summer (March to May) and monsoon (June to November) are three main seasons occurring in this region. An average maximum and minimum temperature is 36º and 14º C, respectively. Rainfall of the Bengaluru region has an average of 800 mm and humidity range is 35–80% in this region.

The floral species play a major role in maintaining the carbon sink in terms of plant biomass (density or area) with various kinds of trees distributed in various urban landscapes of the Bengaluru region. This city has a lush green vegetation cover with numerous species comprising bushes, shrubs and trees. The flora has generated a successful local amalgamated symbiotic relationship with associated fauna of this region including mammals, birds, reptiles, amphibians and several species of invertebrate fauna.

Usage of indices for assessing threat ranking in urban landscapes

A preliminary observation was made to document the category of threats, including anthropogenic activities and disturbance score obtained for each site/landscape in the urban region of Bengaluru, Karnataka, south India, following methods of Shenoy, Varma, and Prasad (2006) and Rajashekara and Venkatesha (2013). Surveys of threats and other scores for the assessment of several indices were conducted once a month from February 2008 to January 2010. All the study sites experienced various categories of anthropogenic activities affecting the avian distribution of different landscapes of the urban zone. Although several study landscapes are located in the protected areas such as national parks and botanical gardens, etc., the intensity of anthropogenic activities in those regions is found to be higher due to the presence of tourism centres. Hence, anthropogenic activities were given scores based on the impact of disturbance on avian communities. Various types of disturbances were categorized into ranks: 1 for light disturbance, 2 for moderate where a few reiterations were found, and 3 for severe replications of threats. The disturbance level for each study site was calculated using the following relation:

Disturbance level= $\sum_{i=1}^{3} \text{score}_i$ * total number of incidents of activity *i* /observer effort (Rajashekara and Venkatesha 2013), where *i* = various types of disturbances in each site, score *i* = sum of the score given to each site based on intensity of disturbances.

Disturbance scores given to each site/landscape by qualitatively assessing various disturbances (encroachment of landscapes, gaming and other recreational activities (including photography), grass cutting, livestock grazing, monoculture plantations, open and wood-log fire occurrence, over-extraction of resources, tourists and settlements (anthropogenic activities), and bridle pathways) were ranked into rare (1), occasional (2), and frequent (3) levels of disturbances. Study landscapes were classified into different anthropological disturbance categories: high disturbance sites (HDS) for scoring high ranks, moderate disturbance sites (MDS) for middle ranks, and low disturbance sites (LDS) for low ranks with the help of the disturbance index which was based on the minimum and maximum values of observed disturbance parameters.

The index of decline was based on the local-scale reduction in an area of occupancy of bird species in face of human-induced habitat loss as followed by earlier works (Martof et al. 1980; Conant and Collins 1991; Mitchell 1991; Brown and Dickson 1994; Greenlaw 1996; Petranka1998; Blackburn, Nanjappa, and Lannoos 2001; IUCN Redlist of Threatened Species 2009). The index of decline was calculated and the values were expressed in units of 0.1, range from 0.1–1.0, and represented the probability an individual bird would be excluded from a habitat as a result of human development based on expert opinion. This index was used to derive a projected percentage habitat reduction using the formula: Development Pressure = %ΔHousing units.

%ΔHousing Units = (No. of housing units in 2008 – No. of housing units in 2000)/(No. of housing units in 2000)*100 (Surasinghe et al. 2012).

Percentage Range Unprotected = Species distribution within study area that is protected/Total distribution within study area. Percentage Habitat Reduction = Development Pressure * Percentage Range Unprotected * Index of Decline.

Models for threat analysis were based on the development rate of housing units in the study area, the habitat suitability index for each species, and protection rank in the study area distribution of each species (Baldwin and deMaynadier 2009). A similar approach was used for the habitat reduction model to calculate development pressure for these models, but there was used a county-specific growth rate of housing units (Surasinghe et al. 2012). We generated Habitat Suitability Indices based on habitat suitability for bird species as determined by the earlier works (Blackburn, Nanjappa, and Lannoos 2001; IUCN Redlist of Threatened Species 2009). We ranked the suitability of each major habitat type on an ordinal suitability ranging from very high to low suitability, and assigned a fixed value for each habitat that happened within the distribution range of each species. Habitat suitability values were assigned as follows: 1 – very high, 0.75 – high, 0.50 – moderate, and 0.25 – low suitability.

We reconsidered the study region into five groups based on management authority: centrally owned, state owned, protected private lands, protected lands with unknown ownership, and unprotected areas to govern the distribution of bird species. Based on land use practices allowed by different management authorities (e.g. recreational use, hunting, harvesting), we derived values

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from 1 to 5 to indicate the likelihood that selected species would be safeguarded from future anthropogenic disturbance.

Thus, Threat Index = (Growth Rate of Housing Units*Habitat Suitability Index)/Protection Status. There are some standards for threat ranking using the absolute system using scope, severity, and irreversibility with the following definitions and scoring methods as follows:

(a) **Scope:** The proportion of the target that can reasonably be expected to be affected by threats within ten years, given the continuation of current situations and trends. The proportion of the target's occurrence/population for bird species was measured for different landscapes in the Bengaluru region.

(b) **Severity:** Within the scope, the level of damage to the target from threats that can reasonably be expected given the continuation of current circumstances and trends. The degree of destruction/degradation of the target for bird species within the scope was typically measured for different landscapes in the urban region.

(c) **Irreversibility (Permanence):** The degree to which the effects of a threat can be reversed and the target affected by the threat restored for a particular landscape. Effects of threats cannot be reversed, it is very doubtful the target can be restored, and/or it would take more than 100, 21–100, 6–20, or 0–5 years to achieve this, e.g. wetlands converted to a shopping centre or playgrounds, wetlands converted to agriculture, draining of wetland, or off-road vehicles trespassing in wetland, respectively.

For the above three scoring methods, we used the four-scale measurements as given below: 4 = very high, 3 = high, 2 = medium, and 1 = low, for which the threat is likely to be pervasive in its scope, affecting the target across all or most (71–100%, 31–70%, 11–30%, and 1–10%, respectively) of its occurrence.

Finally, we compared all the direct threats using scope, severity, and irreversibility in a given site to one another across each measure adapted by the method of Margoluis and Salafsky (1998). This method involves a detailed ranking of each threat, using a four-point absolute scale and applying a series of algorithms to convert the ratings into an overall threat rating. The method used by Microsoft Excel software is a simplified version of this threat rating method using the following formula: Tota l = 2*(Scope + Severity) + Irreversibility. Based on this formula, the classification of threats into categories is as: 4 = very high, 3 = high, 2 = medium, and 1 = low.

Field sampling for avian communities

Furthermore, low to high disturbance sites were subjected to avian survey in order to assess dynamics in different landscapes of the urban region with respect to disturbance sites (Figure 1). Four stripe transects are laid for the study of avifaunal species documentation in diversely urbanized landscapes. Each stripe transect was trailed of one km^2 (20 m wide on either side of the prefixed transect) arrayed in low, moderate and high disturbance sites. Prefaced transects were marched at an even speed of about 1–1.5 km h^{-1} in the before-noon (08.00–11.00 h) and in the afternoon (15.00–18.00 h) as followed by Verner (1985). Bird surveys were conducted once a fortnight from February 2008 to January 2010. Standardized sampling methods were used for survey methods in fixed time-spans (30–40 min transect count) with sampler's effort transversely in all the study sites (Watson 2003). Call notes of bird species were also used for locating them (Ali 2012). Nomenclature and taxonomy of birds was assigned according to BirdLife International (2014).

Further, mosaic diversity as a measure of landscape complexity can be assessed as a compositional diversity pattern using affinity analysis (Scheiner 1992). This measures compositional pattern diversity in which the arrangements of subunits in the mathematical space are defined by the site-species composition matrix. Species richness (S) is the total number of bird species recorded in a particular study landscape. In the same site, the number of endangered bird species (including critically endangered, threatened, and vulnerable according to IUCN Redlist of Threatened Species 2009) is noted down. The ratio of endangered and normal number of bird species is calculated. Consecutively, the number of families, genera and species, proportions of genus and species, family and species, and family and genus are calculated. Data on bird species were analyzed for relative frequency, abundance, and species distribution ratio, as well as the species importance value index (SIVI) (relative frequency + relative abundance + relative species distribution ratio) was calculated (Curtis and McIntosh 1951). Similarly, the collected data on birds were transferred for calculation of the family importance value index (FIVI) (relative family abundance + relative family richness) to understand the community organization in relation to competitive ability using a method of Curtis and McIntosh (1951).

Diversity can be measured by grouping species into several subunits in an ecological unit also known as differentiation diversity (Whittaker 1960). Beta diversity quantifies how many subunits there would be if the total species diversity and mean species diversity per subunit remained the same, but the subunits shared no species or turnover (Tuomisto 2010). Fisher's alpha diversity of bird populations was calculated at each site, using the formula $S = a*\ln(1 + n/a)$, where S is the number of taxa, n is the number of individuals, and a is the Fisher's alpha (Fisher, Corbet, and Williams 1943; Magurran 2004), using PAST version 1.60 software (Hammer, Harper, and Ryan2001).

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Vegetation sampling

Flowering plants (>10 cm in diameter at breast height (DBH) at 1.37 m above the ground level) were sampled precisely at the locations where bird surveys were conducted in each sampling site excluding grasses, epiphytes, seedlings and herbs (Nagendra and Gopal 2010). Canopy cover is one of important parameters in the measurement of disturbance (Fiala, Garman, and Gray 2006) and quantified by digital canopy photography (Engelbrecht and Herz 2001). Canopy coverage (in %) for each site was calculated by averaging ten values of ten images taken within a particular site and was expressed in range and mean ± standard error. Vegetation cover (%) was measured after Lynch, Morton, and Van der Voort (1985) at different strata (St1: 0–0.4, St2: 0.4–0.8, St3: 0.8–1.2, St4: 1.2–1.6, St5: 1.6–2.0, St6:>2.0 m). Six strata of vegetation were classified into two variables of lower vegetation (%) at 0–1.2 m high (VgL: St1–3) and higher vegetation (%) at >1.2 m high (VgH: St4–6) for simplicity (Kurosawa 2007). The number of perching plant species per site and the number of plant species dependent on birds for dispersal of fruits and seeds were estimated.

Statistical analyses

The difference in the values of species diversity and richness, canopy structure, development pressure, percentage range unprotected, habitat suitability index, and disturbance scores (levels) (as a categorical variable) of avifaunal communities among diversely urbanized landscapes (response variable) along the various disturbance gradients was statistically analyzed using one-way analysis of variance (ANOVA) – Tukey's Honestly Significant Difference (HSD) test (SPSS Inc. 2008). We evaluated the influence of various environmental variables such as the number of buildings (n), human population density (n), total number of bird species (n), protected birds (%), number of endangered species (n), protected area (%), site disturbance score (%), tree density (%) (No./ha), index of decline (%), species diversity of birds, threat index (%), scores for degree of suitability, area (in km^2), endemicity value (%), number of bird families, number of genera in a particular bird family were subjected to the Pearson correlation coefficient to understand the relationship between them (SPSS Inc. 2008). All these data were logarithm 10 base transformed prior to analyses to better approach a normal distribution, then the correlation of various parameters with the bird populations was analyzed (SPSS Inc. 2008). Ward's method of Bray-Curtis Cluster Analysis was carried out to create a dendrogram to assess the similarity within various threats faced by the density of birds among study landscapes of the Bengaluru region using PAST version 1.60 software (Hammer, Harper, and Ryan 2001).

The relationships between attributes of bird community composition (as response variables) and environmental/disturbance parameters (as explanatory variables) such as protected area (%), log10 tree density (%)(No./ha), log10 disturbance score (%), log10 index of decline (%), log10 threat index (%), log10 scores for degree of suitability, log10 area (in km^2), log10 endemicity value (%), log10 number of buildings (n), log10 human population density (n) were assessed using Multiple Linear Regression Models (MLRM) (Lehmann, Overton, and Austin 2002; Lehmann, Overton, and Leathwick 2003). This Multiple Linear Regression Model is explained as given below:

Suppose we have a sample consisting of n pairs of observations

$$(x_1, y_1), (x_2, y_2), \ldots \ldots, (x_n, y_n).$$

We propose the model that each y_i is an observation from a random variable

$$Y_i = \beta_0 + \beta_1 x_i + E_i,$$

where the E_i's are independent normally distributed random variables with expected value 0 and common variance σ2. Thus we can express each y_i as

$$y_i = \beta_0 + \beta_1 x_i + e_i,$$

where e_i is an observation from E_i. We call y_i the response variable, x_i the declaring variable, and e_i the remainder term.

Thus, the fitted multiple linear regression line is $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_{10} x_{10}$. The goodness-of-fit and statistical significance of best models were assessed using the relevant statistics (R^2 test) (SPSS Inc. 2008).

This type of linear regression models (McCullagh and Nelder 1989) can be used to determine the relationship between the response variables and explanatory variables (Jachmann 2008) in order to extrapolate levels of site-wise disturbance gradients over time. Regression methods can be effective in estimating group size, and the slope of the regression of group size (or log group size) on distance tends to have a positive slope (as group size increases with distance), and on detection probability a negative slope. Sometimes the sign of the slope is reversed. This happens when observers underestimate the size of groups and the degree of underestimation increases with distance. Even in this case, however, using regression should give a valid estimate of mean group size (Jachmann 2008).

Results

Usage of indices for assessing threat ranking in urban landscapes

A proportional analysis between the disturbance scores notching for threats in different landscapes of the Bengaluru region, south India reveals that high disturbance sites (HDS) (five out of seven sites) harbour more threat scores (20 to 24) than the other disturbance sites

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Table 1. Disturbance scores (1 = low; 2 = moderate; 3 = high) for 19 study landscapes in the Bengaluru region, Karnataka, south India.

Disturbance sites	Study landscapes	Acronyms	Landscape encroachment	Gaming and other recreational activity (including photography)	Grass cutting	Livestock grazing	Monoculture populations	Open fire	Resource over-extraction	Tourists/pilgrims and settlements (anthropogenic activities	Use of bridle pathways	Wood-log fire	Total scores*
	Anekal	AK	3	3	0	3	3	2	3	3	3	0	23
	Attibele	AB	3	2	0	3	3	2	3	3	3	0	22
	Devanahalli	DH	3	3	0	3	3	2	3	3	3	0	23
High disturbance sites (HDS)	Kempegowda Bus Station	KBS	3	3	3	1	3	1	3	3	3	3	24
	Krishna Rajendra Market	KRM	3	3	2	2	0	2	3	3	3	2	23
	Lalbabh Botanical Garden	LBG	1	3	3	1	0	0	1	1	3	2	15
	Lord Cubbon Park	LCP	1	3	3	1	0	0	2	1	3	3	17
	Chandapura	CP	2	2	0	3	3	2	3	3	2	0	20
	Hoskote	HK	1	3	0	3	3	0	3	3	2	2	20
Moderate disturbance sites (MDS)	Jnana Bharathi Campus	JBC	2	2	3	3	0	3	2	3	2	0	20
	Kengeri	KG	2	2	2	2	2	0	3	3	2	1	19
	Kethohalli	KH	2	2	1	2	3	0	3	3	2	1	19
	Nelamangala	NM	3	3	0	3	3	3	3	3	3	0	23
	Sarjapura	SJP	3	3	0	3	3	3	3	3	2	0	23
Low disturbance sites (LDS)	Banneraghatta National Park	BNP	2	3	0	2	0	2	3	2	1	0	15
	Hebbala	HB	2	3	1	3	2	2	3	3	1	0	20
	Hesaraghatta	HG	1	3	2	3	3	0	3	2	1	1	19
	Somanahalli	SM	2	3	0	3	3	3	3	3	2	0	22
	Thippagondanahalli	TGH	1	3	3	3	3	2	3	1	1	0	20

*Results in a column under various disturbance scores indicate not significantly different among diversely urbanized landscapes at $p > 0.05$ (one-way ANOVA, $F_{2,16} = 0.669$, $p > 0.05$).

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(15 to 20) (Table 1). Of which, resource over-extraction (collection of food sources, fibre, firewood, fuel wood, and fodder extraction), unrestricted livestock grazing, human activities including developmental activities (roads and fly-overs) and recreational activities, and landscape encroachment (habitat loss, fragmentation, degradation and adaptation) were recorded as common threats in all the landscapes. Both open landscape fire (highest in three sites of MDS) and wood-logging fire (highest in one study site from HDS) were found in the Bengaluru region. Furthermore, the occurrence of disturbance scores was not significantly different for 19 study landscapes of the Bengaluru region (one-way ANOVA, $F_{2, 16} = 0.669$, $p > 0.05$).

A dendrogram showing similarity in the disturbance scores for threats faced by the birds of different landscapes with three major clusters showed significant negative affinities. Grass cutting and wood-log fire accounted for low disturbance scoring belonging to the first cluster; landscape encroachment, use of bridle pathways and open fire accounted for moderate scoring in the second cluster, whereas human interferences such as monoculture practices, gaming and other recreational activities, handling livestock grazing and tourists and other settlements accounted alone for the third cluster with a high disturbance scoring (Figure 2). Furthermore, principal threats to terrestrial bird fauna, i.e. habitat alteration, crop cultivation, monoculture plantations (except BNP, HG and TGH), improper waste management and grass cutting were more common in almost all the urban landscapes (16 sites) of the study region. Other threats, i.e. building construction and firewood collection affected bird population in the urban region.

Population variations in urban bird species

During the study period, different landscapes of the Bengaluru region, Karnataka, south India had 118 bird species belonging to 78 genera and 43 families distributed in various disturbance sites (Appendix 1). A comparative analysis between the disturbance sites reveals that LDS harboured more species of birds (115) than the HDS (33 spp.) did (Table 2). Out of recorded bird species, 115 (97.46%) were found exclusively in LDS with a greater fraction of moist deciduous species (Table 2). Species richness of avifaunal communities among 19 study landscapes along the various disturbance gradients was significantly different (Tukey HSD, $F_{2, 16} = 3.817$, $p < 0.05$). Correspondingly, the highest diversity of birds (Fisher's Alpha and Beta diversity – 16.20 and 1.95) was recorded in the LDS (BNP) with the highest genus (76) and species (115) richness compared to the other MDS and HDS. Moreover, species diversity of bird species among 19 study landscapes along the various disturbance gradients was significantly different (Fisher's alpha diversity – Tukey HSD, $F_{2, 16} = 4.360$, $p < 0.05$ and Whittaker's Index – Tukey HSD, $F_{2, 16} = 3.766$, $p < 0.05$). Beyond 68 tree species, the maximum number of perching plant species was characteristic of LDS with a greater fraction of moist deciduous species and native plant/tree species (Table 2). The canopy coverage of plants/trees and the structure of canopy cover were the highest in LDS (TGH – 78.49 to 99.99 and 91.05 ± 1.80, respectively) with the maximum strata of the vegetation cover (>2.0 m). In addition, the canopy coverage of vegetation structure was not significantly different for 19 study landscapes of the Bengaluru region (one-way ANOVA, $F_{2, 16} = 0.7353$, $p > 0.05$).

Columba livia (12.03), *Acridotheres tristis* (10.41), and *Corvus splendens* (10.27) showed the highest species importance value index (SIVI), whereas *Gyps indicus* (0.01) showed the lowest value (Appendix 1). On the contrary, 33 species of birds (27.96%) were confined to HDS with the presence of generalist number of pioneer species, while 32 (27.19%) bird species were common to both areas (Appendix 1). Furthermore, Accipitridae had the highest family importance value index (FIVI) (13.95) and relative species richness (9.45) with the highest number of bird genera and species (9 and 10, respectively) (Appendix 2). However, Muscicapidae had the highest relative abundance (5.59%) than the other families. And

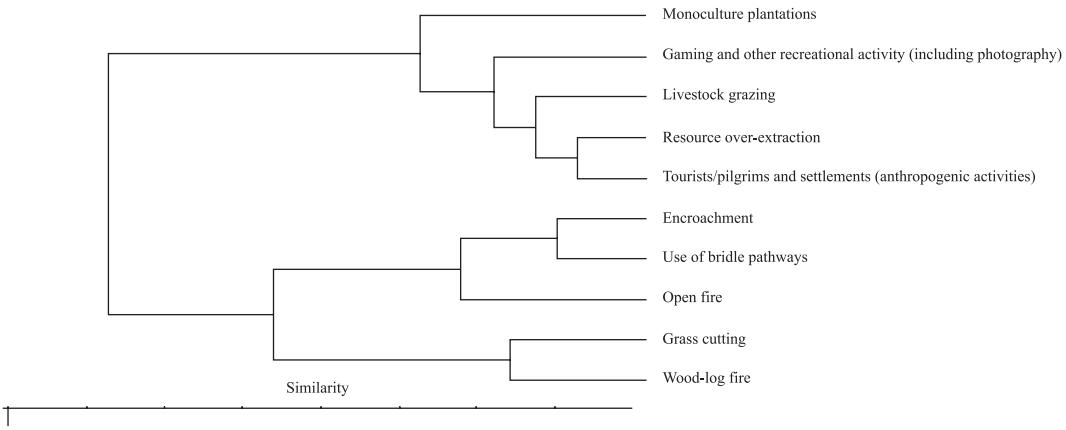


Figure 2. Dendrogram showing the contribution of threats across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, southern India.

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Table 2. Survey sites and composition patterns of avifauna and vegetation across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, south India.

	High disturbance sites (HDS)							Medium disturbance sites (MDS)							Low disturbance sites (LDS)				
Avian composition	AK	AB	DH	KBS	KRM	LBG	LCP	CP	HK	JBC	KG	KH	NM	SJP	BNP	HB	HG	SM	TGH
Study landscapes																			
Species richness[a]	107	96	96	33	35	80	81	99	103	106	97	86	100	96	115	93	106	97	105
Number of endangered species	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0
Number of genera	43	42	42	21	21	37	38	42	43	42	40	39	42	42	43	40	42	43	42
Number of families	71	65	65	28	30	55	55	66	69	71	65	57	67	64	76	60	71	65	70
Genus: species	0.66	0.68	0.68	0.85	0.86	0.69	0.68	0.67	0.67	0.67	0.67	0.66	0.67	0.67	0.66	0.65	0.67	0.67	0.67
Family: species	0.40	0.44	0.44	0.64	0.60	0.46	0.47	0.42	0.42	0.40	0.41	0.45	0.42	0.44	0.37	0.43	0.40	0.44	0.40
Family: genus	0.61	0.65	0.65	0.75	0.70	0.67	0.69	0.64	0.62	0.59	0.62	0.68	0.63	0.66	0.57	0.67	0.59	0.66	0.60
Endangered species: number of bird species	0.009	0.000	0.000	0.000	0.000	0.013	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.010	0.000
Fisher's alpha diversity[b]	15.67	15.32	14.60	4.23	4.09	11.96	11.70	15.65	15.61	15.81	14.87	13.87	15.34	15.21	16.20	15.13	15.88	15.27	15.85
Whittaker's Index[c]	1.81	1.63	1.63	0.56	0.51	1.36	1.37	1.68	1.75	1.80	1.64	1.46	1.69	1.63	1.95	1.58	1.80	1.64	1.78
Vegetation composition																			
Number of perching plant species	63	63	65	24	26	68	65	61	61	63	57	42	63	63	68	60	63	58	65
Number of plant species dependent on birds for dispersal of fruits and seeds	41	41	41	35	36	41	40	41	41	41	41	37	41	41	41	41	41	41	41
Canopy cover (range = minimum to maximum)	78.59–97.26	81.67–97.52	81.67–99.30	81.67–97.14	79.53–97.14	78.52–97.14	71.83–100.00	81.67–97.52	75.14–100.00	65.74–99.63	81.00–99.73	79.42–97.14	76.12–97.26	72.08–97.52	70.68–100.00	81.67–97.26	74.04–100.00	78.52–97.52	78.49–99.99
Canopy cover[d] (mean ± standard error)	88.45 ± 1.35	89.06 ± 1.35	89.71± 1.48	88.53 ± 1.77	87.99 ± 1.74	87.34 ± 1.14	86.86 ± 1.92	89.47 ± 1.39	87.14 ± 1.53	87.39 ± 1.35	89.65 ± 1.79	87.97 ± 1.74	86.47 ± 1.79	87.32 ± 1.72	88.00 ± 1.59	89.26 ± 1.29	88.12 ± 1.16	87.39 ± 1.40	91.05 ± 1.80
Vegetation strata (meter)	1.6–2.0	1.6–2.0	1.2–1.6	0.0–0.4	0.0–0.4	0.4–0.8	0.4–0.8	0.8–1.2	1.2–1.6	1.2–1.6	1.2–1.6	1.2–1.6	0.8–1.2	0.8–1.2	>2.0	>2.0	>2.0	>2.0	>2.0
Classification of stratum	St 5	St 5	St 4	St 1	St 1	St 2	St 2	St 3	St 4	St 4	St 4	St 4	St 3	St 3	St 6	St 6	St 6	St 6	St 6

[a]Results in a column under species richness indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 3.817$, $p < 0.05$);
[b]Results in a column under Fisher's alpha diversity of birds indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 4.360$, $p < 0.05$);
[c]Results in a column under Whittaker's Index indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 3.766$, $p < 0.05$);
[d]Results in a column under canopy coverage of vegetation indicate not significantly different among diversely urbanized landscapes at $p > 0.05$ (one way ANOVA, $F_{2, 16} = 0.7353$, $p > 0.05$).

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20 families of birds (1.00 each) showed the highest ratio of genus and species (Appendix 2).

Moreover, the development pressure (%ΔHousing Units) was the highest in HDS (KBS and KRM – 21.82 each) (Table 3). Furthermore, the development pressure among 19 study landscapes along the various disturbance gradients was significantly different (Tukey HSD, $F_{2, 16} = 4.252$, $p < 0.05$). Also, the habitat suitability index was the highest in four study sites from HDS (three) and in one LDS (1.00 each). Moreover, the habitat suitability index was not significantly different for 19 study landscapes of the Bengaluru region (one-way ANOVA, $F_{2, 16} = 0.354$, $p > 0.05$). Similarly, habitat reduction is totally absent in four study sites (0%). In addition to this, the index of decline was higher in seven disturbance sites (7.19% each). On the contrary, the percentage of unprotected range was the highest in one LDS with '5' (BNP –91.30%). Also, the value of '5' indicates the highest protection level in LDS (Table 3). Besides this, the percentage of range protection among 19 study landscapes along the various disturbance gradients was significantly different (Tukey HSD, $F_{2, 16} = 2.499$, $p < 0.05$). Besides, the ranking of threat indices scored for maximum in all HDS (16–20), and in these sites it was categorized as very high (Table 4). After subjecting to the threat index and ranking scores, still LDS come under the medium category (6–9).

Influence of environmental variables on bird species richness and diversity

Besides this, the total number of bird species showed a significant positive correlation with the protected area, tree density, degree of habitat suitability, study area and species endemicity values, and a significant negative correlation with the threat index and the number of buildings in urban landscapes of the Bengaluru region (Table 5). Species diversity of birds showed a significant positive correlation with the total number of bird species, number of bird species, number of genera in a particular bird family, protected birds and area, tree density, degree of habitat suitability and species endemicity values, and a significant negative correlation with the number of buildings. The number of bird families and the number of genera in a particular bird family showed a significant negative correlation with the number of buildings and threat index (Table 5). Protected birds showed a significant negative correlation with the threat index and the number of buildings. Also, protected area of landscapes showed a significant negative correlation with the index of decline and threat index. Tree density showed a significant negative correlation with the number of buildings. The index of decline showed a significant negative correlation with the protected birds, protected area and endemicity values. The threat index showed a significant negative correlation with six parameters such as total number of bird species, number of bird families and genera in a particular bird family, protected birds and area, species endemicity values, and a significant positive correlation with the human population density. The study area showed a significant negative correlation with the index of decline. The endemicity values of birds showed a significant negative correlation with the index of decline and threat index. In contrast, the number of buildings showed a significant positive correlation with increase in the human population density. Human population density showed a significant negative correlation with the protected area and species endemicity values, and a significant positive correlation with the threat index and tree density (see Table 5).

Many big metropolitan cities including Bengaluru city of India are relatively known as heterogeneous in terms of environmental awareness and change in the land use patterns for needs of human population. There was a significant positive correlation between the number of buildings and houses and increasing local human population density in Bengaluru city ($n = 19$, $r^2 = 0.4416$, $y = 0.4784\times + 2.6951$, $p < 0.000$) (Figure 3(a)).

There was no significant association between human population density and total number of bird species (Figure 3(b)). Human population density did not vary significantly with variations in patches of urban greenery areas in the urban region. The total number of bird species was significantly correlated with the study area (Figure 3(c)). As well as there was a significant association of the study area with the total avian species richness, but the proportion of protected areas was not correlated with the total avian species richness (here, only four sites – BNP, HG, LLBG, and TGH are protected areas). However, there was no significant negative correlation between the human population density and tree density (Figure 3(d)) showing that increase in urbanization correlated with increase of deforestation. Tree density was in a significant positive correlation with the total number of bird nests in the urban region (Figure 3(e)) and the number of bird species (Figure 3(f)). There was no significant association between canopy coverage and tree density in the urban region (Figure 3(g)). Other correlations between bird population indices and environmental factors are presented in the Figure 3(h–s).

Existence of avian communities across the disturbance gradients of different landscapes was explained with three major clusters. The number of genera, species and families forming the first sub-cluster mainly dependent on the threat index, index of decline and endemicity value form the important factors for diversity of bird species; protected birds and area in the other first sub-cluster showed negative relationship with the second cluster comprising the scores for the degree of suitability, tree density, number of endangered species and study area, and the third cluster alone with human population density and the number of buildings (Figure 4).

For the first attribute (e.g. bird species richness), the variation explained by the fitted multiple linear regression line is 99.90% (Table 6). For all the cases, R^2

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Table 3. Assessment of the study landscapes for calculation of the habitat suitability indices.

Habitat type	Study landscapes	Development Pressure (%ΔHousing Units)[a]	Percentage Range Unprotected[b]	Index of Decline (Percentage)	Percentage Habitat Reduction	Habitat Suitability Values[c]	Protection Status (Values on Conservation Potential)[d]	Protected lands with unknown ownership
Dry scrub/shrub thicket	AK	18.12	85.98	5.40	21.82	1.00	2	Protected lands with unknown ownership
Dry scrub/shrub thicket	AB	1.11	88.54	3.96	1.42	1.00	2	Protected lands with unknown ownership
Dry scrub/shrub thicket	BNP	0.00	91.30	3.60	0.00	1.00	5	Federal lands
Closed canopy evergreen forest/woodland	CP	1.11	80.81	6.83	1.18	0.50	3	Private conservation lands
Open canopy/recently cleared forest	DH	14.42	89.58	3.60	18.85	0.75	4	State lands
Urban residential	HB	2.59	89.25	3.60	3.36	0.25	3	Private conservation lands
Closed canopy evergreen forest/woodland	HG	1.48	90.57	3.60	1.98	0.50	4	State lands
Closed canopy evergreen forest/woodland	HK	7.03	90.29	3.60	9.33	0.50	3	Private conservation lands
Closed canopy evergreen forest/woodland	JBC	–0.07	90.57	3.60	–0.10	0.50	4	State lands
Urban residential	KBS	21.82	60.61	4.68	13.05	0.25	1	Unprotected lands
Closed canopy evergreen forest/woodland	KG	1.48	79.38	7.19	1.52	0.50	2	Protected lands with unknown ownership
Closed canopy evergreen forest/woodland	KH	0.00	76.74	7.19	0.00	0.50	3	Private conservation lands
Urban residential	KRM	21.82	71.43	3.60	18.13	0.25	1	Unprotected lands
Closed canopy evergreen forest/woodland	LBG	–0.15	75.00	7.19	–0.14	0.50	4	State lands
Closed canopy evergreen forest/woodland	LCP	0.00	75.31	7.19	0.00	0.50	4	State lands
Open canopy/recently cleared forest	NM	7.03	80.00	7.19	7.32	0.75	3	Private conservation lands
Open canopy/recently cleared forest	SJP	1.11	79.17	7.19	1.13	0.75	3	Private conservation lands
Open canopy/recently cleared forest	SM	1.11	79.38	7.19	1.14	0.75	3	Private conservation lands
Dry scrub/shrub thicket	TGH	0.00	90.48	3.60	0.00	1.00	4	State lands

[a]Results in a column under development pressure indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 4.252$, $p < 0.05$).
[b]Results in a column under percentage range protection indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 2.499$, $p < 0.05$).
[c]Each habitat occupied by the selected species was assigned a numerical value reflecting the degree of suitability of that habitat as following: 1 – very high suitability, 0.75 – high suitability, 0.50 – moderate suitability and 0.25 – low suitability; Results in a column under various habitat suitability index indicate not significantly different among diversely urbanized landscapes at $p > 0.05$ (one way ANOVA, $F_{2, 16} = 0.354$, $p > 0.05$).
[d]Protection levels based on the management authorities of lands (see text reference).

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Table 4. Assessment of the study landscapes using threat indices.

Study Landscapes	High disturbance sites (HDS)							Medium disturbance sites (MDS)							Low disturbance sites (LDS)				
	AK	AB	DH	KBS	KRM	LBG	LCP	CP	HK	JBC	KG	KH	NM	SJP	BNP	HB	HG	SM	TGH
Scope	4	3	4	4	4	4	4	2	2	2	3	3	3	3	1	1	1	1	1
Severity	4	3	4	4	4	4	4	3	3	2	3	3	4	4	1	2	2	2	2
Irreversibility	4	4	4	4	4	4	4	3	3	2	3	3	4	4	2	3	2	2	2
Total[†]	20	16	20	20	20	20	20	13	13	10	15	15	18	18	6	9	8	8	8
Classification of threats	Very high	Very high	Very high	Very high	Very high	Very high	Very high	High	High	Medium	High	High	Very high	Very high	Medium	Medium	Medium	Medium	Medium

[†]Total = 2 * (scope + severity) + irreversibility.

Table 5. Pearson's Correlation Coefficient analysis for the interaction of avian community composition and habitat suitability indices.

	log10 total bird species (n)	log10 species diversity of birds	log10 number of bird families	log10 number of genera in a particular bird family	log10 protected birds (%)	log 10 number of endangered species (n)	log10 protected area (%)	log10 tree density (%) (No./ha)	log10 site disturbance score (%)	log10 index of decline (%)	log10 threat index (%)	log10 scores for degree of suitability	log10 study area (in km^2)	log10 endemicity value (%)	log10 number of buildings (n)	log10 human population density (n)
log10 total bird species (n)	1	0.993**	0.991**	0.997**	0.991**	0.153	0.807**	0.813**	−0.064	0.053	−0.471*	0.696**	0.486*	0.830**	−0.596**	−0.427
log10 species diversity of birds	0.993**	1	0.995**	0.984**	0.977**	0.112	0.773**	0.764**	−0.097	0.104	−0.444	0.666**	0.411	0.797**	−0.608**	−0.423
log10 number of bird families	0.991**	0.995**	1	0.983**	0.973**	0.163	0.761**	0.796**	−0.075	0.123	−0.407	0.698**	0.413	0.788**	−0.600**	−0.378
log10 number of genera in a particular bird family	0.997**	0.984**	0.983**	1	0.992**	0.148	0.824**	0.833**	−0.023	0.019	−0.482*	0.719**	0.511*	0.846**	−0.570*	−0.421
log10 protected birds (%)	0.991**	0.977**	0.973**	0.992**	1	0.107	0.880**	0.809**	−0.055	−0.077	−0.511*	0.681**	0.525*	0.899**	−0.556*	−0.455
log 10 number of endangered species (n)	0.153	0.112	0.163	0.148	0.107	1	−0.069	0.394	0.159	0.312	−0.060	0.319	0.332	−0.053	−0.317	0.108
log 10 protected area (%)	0.807**	0.773**	0.761**	0.824**	0.880**	−0.069	1	0.666**	−0.021	−0.531*	−0.589**	0.525*	0.597**	0.998**	−0.330	−0.493*
log10 tree density (%) (No./ha)	0.813**	0.764**	0.796**	0.833**	0.809**	0.394	0.666**	1	0.148	0.029	−0.369	0.703**	0.552*	0.690**	−0.563*	−0.274
log10 site disturbance score (%)	−0.064	−0.097	−0.075	−0.023	−0.055	0.159	−0.021	0.148	1	−0.024	0.127	0.364	0.130	−0.019	0.262	0.293
log10 index of decline (%)	0.053	0.104	0.123	0.019	−0.077	0.312	−0.531*	0.029	−0.024	1	0.392	0.091	−0.398	−0.483*	−0.257	0.283
log10 threat index (%)	−0.471*	−0.444	−0.407	−0.482*	−0.511*	−0.060	−0.589**	−0.369	0.127	0.392	1	−0.194	−0.559*	−0.574*	0.427	0.788**
log10 scores for degree of suitability	0.696**	0.666**	0.698**	0.719**	0.681**	0.319	0.525*	0.703**	0.364	0.091	−0.194	1	0.501*	0.541*	−0.329	−0.190
log10 study area (in km^2)	0.486*	0.411	0.413	0.511*	0.525*	0.332	0.597**	0.552*	0.130	−0.398	−0.559*	0.501*	1	0.580**	−0.231	−0.386
log10 endemicity value (%)	0.830**	0.797**	0.788**	0.846**	0.899**	−0.053	0.998**	0.690**	−0.019	−0.483*	−0.574*	0.541*	0.580**	1	−0.355	−0.485*
log10 number of buildings (n)	−0.596**	−0.608**	−0.600**	−0.570*	−0.556*	−0.317	−0.330	−0.563*	0.262	−0.257	0.427	−0.329	−0.231	−0.355	1	0.665**
log10 human population density (n)	−0.427	−0.423	−0.378	−0.421	−0.455	0.108	−0.493*	−0.274	0.293	0.283	0.788**	−0.190	−0.386	−0.485*	0.665**	1

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level.

values are highly significant. Therefore, our model of fitness holds good for all the analyzed data. These patterns are consistent with analyses of attributes of bird community composition (as response variables) and environmental/disturbance parameters (as explanatory variables).

Discussion

Usage of indices for assessing threat ranking in urban landscapes

The patterns of avian species richness in different landscapes of the Bengaluru region, south India were examined using anthropogenic and ecological covariates. The

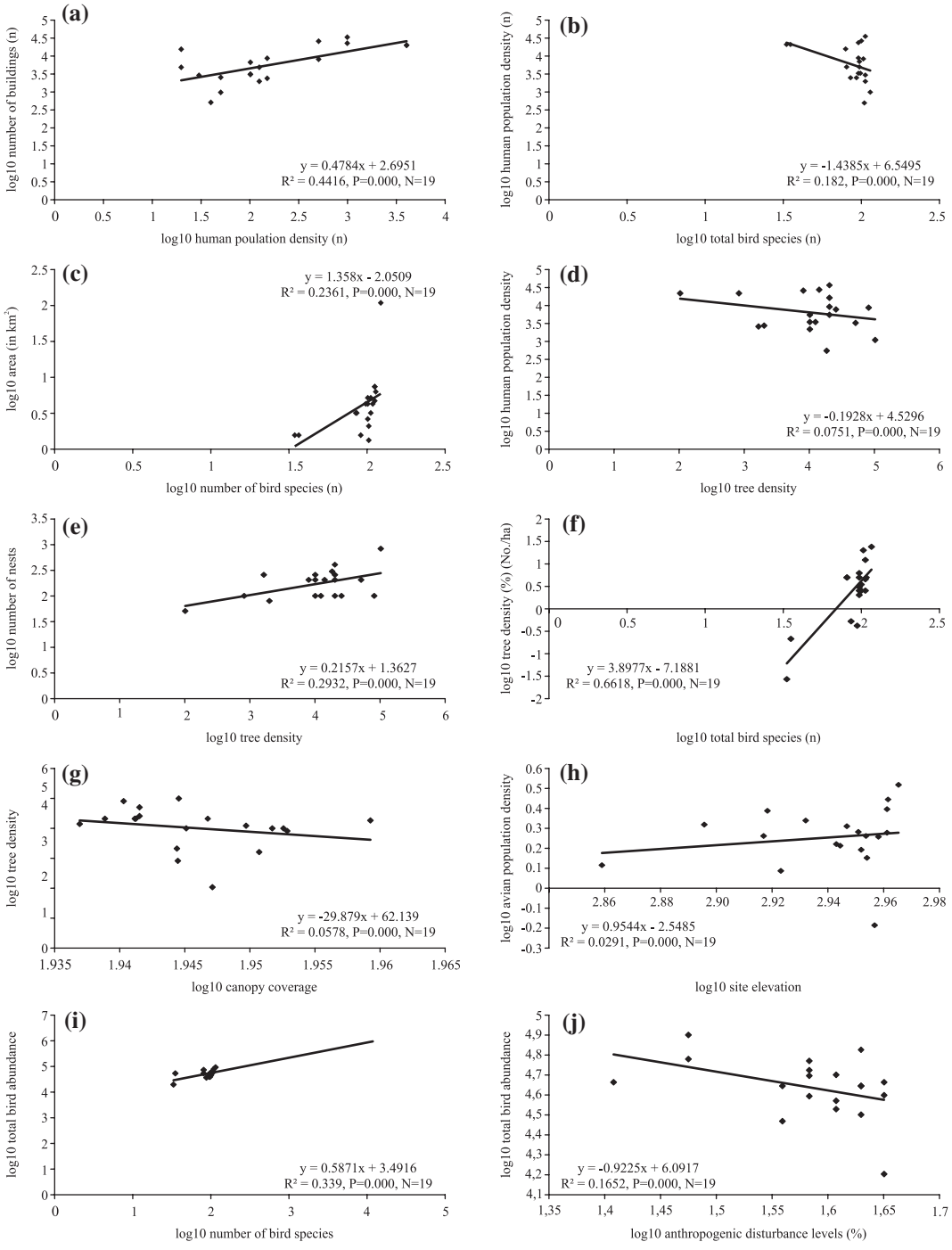


Figure 3. Correlations between: the number of buildings and human population density for Bengaluru region (a); the number of bird species and human population density for Bengaluru region (b); the number of bird species and study site area (c); the human population density and tree density (d); the number of nests and tree density (e); the number of bird species and tree density (f); tree density and canopy coverage (g); avian population density and study site elevation (h); total bird abundance and the number of bird species (i); total bird abundance and anthropogenic disturbance scores (j); total bird species and protected bird species (k); the number of endangered bird species and protected area (l); total bird species and disturbance scores (m); total bird species and the index of decline (n); the diversity of bird species and the index of decline (o); threat index for bird species and scores for degree of suitability (p); total bird species and endemicity value of birds (q); the number of genera in a particular site and the number of bird families (r); mean number of bird species per family and species richness of birds in a particular family (s).

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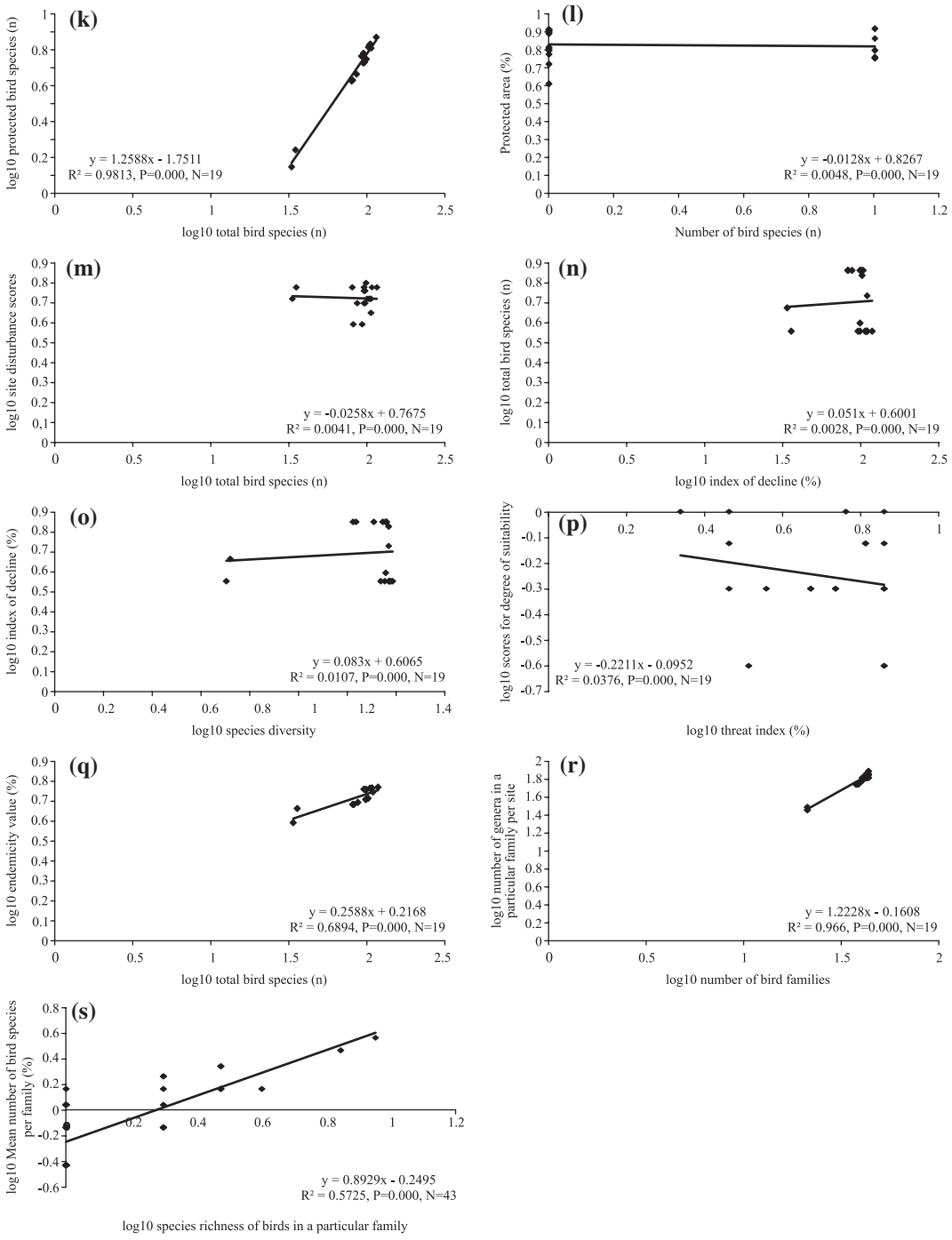


Figure 3 . (*Continued*).

main threats to avian fauna of urban landscapes such as habitat alteration, resource over-extraction including collection of timber, firewood, cultivation, fodder extraction, monoculture plantations, fuel wood collection, improper waste management, grass cutting, fire, and unrestricted livestock grazing, and other human activities including developmental activities (roads and fly-overs) and recreational activities, and landscape encroachment (habitat loss, fragmentation, degradation and adaptation) in the urban region were recorded as common in all landscapes and were also reported earlier in other regions of India (Mahabal and Vasanth 2001; Narang, Akhtar, and Kumar 2008; Ramesh and Sathyanarayana 2009; Acharya and Vijayan 2010; Bharali and Khan 2011; Jan, Uniyal, and Chauhan 2011; Rajashekara and Venkatesha 2013; Menon and Mohanraj 2016). Further, HDS harboured more threat scores than the other disturbance sites. Improved road communications and vehicles closeness to the breeding and roosting areas of birds have increased and they disturbed often as reported by Sridhar and Karanth (1993) in open woodlands and scrublands of the Bangalore region.

Habitat fragmentation is a principal threat used as a model for any species that share distributional, ecological or life-history features and may enable more effective conservation of bird species (Tworek 2002). The major cause of endangerment for many of the world's threatened species is habitat destruction and fragmentation due to encroachment and mining activities (stone

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quarry) (Losos et al. 1995; Fahrig 1997). This in turn can benefit in the indirect conservation of these bird species which are endemic (any of these endangered/near threatened/vulnerable ones) in different landscapes of the Bengaluru region.

The habitat of a species can be defined as that portion of a multi-aspects apprehensive location that is occupied by a given species (Whittaker, Levin, and Root 1973). Species richness is an important and widely used indicator of where conservation initiatives and funding need to be directed (Rosenzweig 1995). Further, expansion of agricultural lands including monoculture or mixed agriculture practices, expansion of real estate for houses/buildings, exploitation of landscapes for the construction of roads through Reserve Forests to improve the urban landscape and greenery lead to the dwindling of bird species (Rajashekara 2006, 2011; Rajashekara and Venkatesha 2008, 2011, 2013; Menon and Mohanraj 2016).

Man-made fires, lopping of trees, non-timber forest produce collection practices and frequency of human intrusions into the forests and management of habitats for a specific species are contributing to change in the quality of habitats. Combined factors, *viz*. habitat loss, development, fragmentation and restricted distribution pose considerable threats to avian fauna in the urban landscapes of the Bengaluru region as reported earlier by Mahabal and Vasanth (2001) in Nilgiri Biosphere Reserve of south India. The loss of greenery in urban areas was known to affect the composition, abundance and distribution of birds (Narang, Akhtar, and Kumar 2008). Habitat fragmentation and the changing heterogeneity of landscape would have synergistic effects on the physical, chemical and biotic factors that affect the distributions of birds in complex ways (Boulinier et al. 1998).

Population variations in urban bird species

Low disturbance sites (BNP, HB, HG, SM and TGH) harboured more species of birds than the HDS. Also, the highest diversity of birds was recorded in LDS with the highest number of genera and species compared to MDS and HDS. Bird communities in different landscapes are most conspicuously different in the LDS and most similar in the most urbanized sites (Blair 1996, 2001). From the earlier studies we confirmed that the maximum bird density was observed in sites with a lesser anthropogenic factor and greater tree density (Rajashekara and Venkatesha 2015). On the contrary, a greater percentage of anthropogenic disturbances was interrelated to lower vegetation density, which in turn affected the avian density (Shochat, Lerman, and Fernández-Juricic 2010; Rajashekara and Venkatesha 2014, 2015). The total population of bird species richness decreases with increasing human population size as reported by McKinney (2008). The number of globally threatened bird species richness is positively associated with human population size, but this correlation is not significant when controlling the overall region bird species richness (Pautasso and Dinetti 2009). Human population density is negatively correlated with species richness in avian studies at fine spatial scales, but plant richness is positively correlated with species richness of birds when analyzing at coarse spatial scales (Pautasso 2007; Rajashekara and Venkatesha 2015; Menon and Mohanraj 2016).

Influence of environmental variables on bird species richness and diversity

A wide range of human activities forms the strong distribution of avian fauna in the urban landscapes (Marin et al. 2007). A high positive correlation between plant and bird species diversity and linear deterioration was obtained (Venkataraman and Ramaswamy 1993). Structural and floristic characteristics were more closely correlated with the diversity and species richness of birds (Harvey, Gonzalez, and Jorge 2007). Similarly, an increase in the area of canopy openings positively correlated with the abundance and diversity of birds (Daniel and Fleet 1999). Species richness of birds increases with structural complexity of the habitat and influenced by plant species richness (O'Reilly et al. 2006; Rompré et al. 2007). Further, bird species richness increases with structural complexity of habitat diversity (Rajashekara and Venkatesha 2011, 2016). Canopy patterns can influence the communities of bird composition, abundance or distribution at the landscape scale (Lundquist and Reich2006). The population density of birds was positively correlated with tree density and negatively correlated with canopy coverage, human population density, and buildings (Rajashekara and Venkatesha 2015).

Ehrlich and Pringle (2008) found out threats to the future of biodiversity which included habitat conversion, environmental toxification, climate change, and direct exploitation of wildlife, etc. The surrounding habitat type, fruiting phenology and the level of human disturbance also influenced the presence and abundance of individual species and accounted for differences in the composition of bird communities among habitats (Trager and Mistry 2003). The threshold effects of landscape change on relative influences of habitat loss and habitat configuration on species conservation in forest dominated landscapes are reported by Boutin and Hebert (2002).

Species richness, density and diversity of bird communities were influenced more strongly by mature forest area than by fragmentation, although both the area and fragmentation of mature forest at the landscape level are strongly related to the diversity of bird communities (Cushman and McGarigal 2003). Birds mainly respond to vegetation structure and composition, and urban areas that retain native vegetative characteristics preserve

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more native species than those that are overgrown with exotic vegetation (Mills, Dunning, and Bates 1989). A uniform diversity between urban landscapes occurs due to overlapping of habitats, less remoteness, altitudinal similarity and majority vegetation composition and its structure as in the reserve of Nanda Devi Biosphere, Uttarakhand (Jan, Uniyal, and Chauhan2011).

Bird species richness and diversity was unimodal in an urban region implying that birds increase to their maximum richness/diversity at a moderate urbanization level and then decrease with further increasing urbanization (Blair 2004; McKinney 2008). The nature of vegetation, canopy cover, tree density, availability of food and water sources are factors that determine the survival of terrestrial bird communities in a particular habitat (Verghese and Chakravarthy 1978). Also, species richness of birds is positively correlated to the canopy coverage, canopy depth, and composition of tree density (Van Bael et al. 2007). Our study revealed that the local variation of bird richness and diversity in microhabitats among the urban landscapes showed significant differences with various disturbance sites. It is similar to that of abundances of bird species, and mainly residents with large canopy nesters increased with increasing amounts of disturbance within forested landscapes (Rodewald and Yahner2001). The processes contributing to urbanization mainly included changes in the vegetation pattern, habitat fragmentation, exotic plants, nest predation, visitation disturbances, changes in food supply abundance, changes in predator assemblage, human activities and other factors that lead to decline in avian communities (Chace and Walsh2006).

The sum of all scores that depicted the highest ranks in HDS exposes the high level of anthropogenic disturbance, and low ranks in LDS express low disturbance. LDS bear similarity to the surrounding forests, both in terms of vegetation composition as well as species composition and diversity. There is habitually a strong positive correlation between the structure of native vegetation and native bird diversity and species richness (Mills, Dunning, and Bates 1989). A lower diversity and a lower number of bird species in HDS was probably due to a lower niche diversity with more human disturbances. Also, habitat suitability for bird species is potentially exaggerated by human recreational activities in the various disturbance gradients. Patten, Silva, and Smith-Patten (2009) described that ongoing deforestation is the cause for species turnover. Human impacts on different landscapes include direct impacts on habitats such as land conversion and fire use, habitat modification, changes in habitat fragmentation as well as changes in species composition of vegetation structure (Sutherland et al. 2013). Small sized bird species which depend on grasses may face threats when grasses are heavily grazed (Vickery et al. 1999). Human activities and road constructions were additional threats for terrestrial birds in the urban environment as reported by Forrest and St Clair (2006).

Table 6. Goodness of fit of multiple linear regression model analysis for the bird community attributes (as response variables) against environmental/disturbance parameters (as explanatory variables): protected area (%), log10 tree density (No./ha), log10 disturbance score (%), log10 index of decline (%), log10 threat index (%), log10 scores for degree of suitability, log10 area (in km^2), log10 endemicity value (%), log10 number of buildings (n), log10 human population density (n).

Bird community attributes	R^2 value	Percentage	Model for goodness-of-fit
log10 total bird species (n)	0.999	99.90%	Good
log10 species diversity	0.996	99.60%	Good
log10 number of bird families	0.991	99.10%	Good
log10 number of genera in a particular family	0.998	99.80%	Good
log10 protected birds (%)	0.999	99.90%	Good
log10 number of endangered species	0.661	66.10%	Moderate

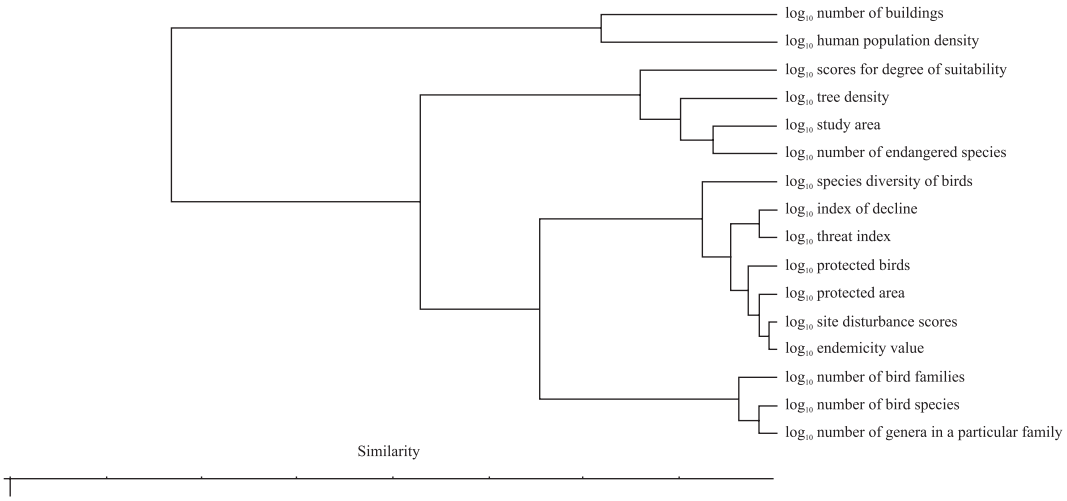


Figure 4. Dendrogram showing the contribution of various parameters to the existence of avian communities across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, south India.

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Species-specific studies focusing on population status, habitat requirements and assessment of threats are necessary for the execution of conservation measures (Acharya and Vijayan2010). Both local and landscape-level resources remained important in shaping the distribution of birds in urban areas (McKinney 2008). Parks, reserves and the adjacent inhabited areas should be combined into urban planning and development designs to maintain resident avian fauna and overall species diversity in city environments (Melles, Glenn, and Martin 2003). Thus, the assessment of anthropogenic scoring (threat) index forms an important factor in correlating the diversity of avian fauna in an urban ecosystem indicating that threats tend to be focused on the region's most important areas for biodiversity conservation (Rajashekara and Venkatesha 2013). In spite of threats posed by urbanization, major cities across the world still harbour a good percentage of native bird species, thus providing opportunities for regional and global biodiversity conservation, restoration and education (Aronson et al. 2014).

Conclusions

Our method helps in evaluation and ranking of the study sites in terms of their conservation values and in identifying priority areas. Hence, habitat conservation plans (HCPs) afford one response to the conflict between conservation and development plans to protect scrub habitats, and a greater focus is given to a few endangered species and their habitat requirements. HCPs provide a regional landscape plan for protecting essential habitats (Root, Akçakaya, and Ginzburg 2006). Also, enhancement of biodiversity in urban ecosystems has a positive influence on the quality of life and education of city inhabitants, and thus facilitates the preservation of biodiversity in natural ecosystems (Savard, Clergeau, and Mennechez 2000).

With increasing focus on biodiversity conservation and setting priority areas, a site-wise comparison along with repeated studies of the same area over a longer time period will help in defining the status of the site in terms of diversity and in identifying priority sites for conservation (Rosenzweig 1995). Long-term planning for threat management is essential for operative conservation of avian biodiversity and biological resources through environmental education. Hence, there is a requirement to take compulsory steps to save them from all possible threats, primarily by ensuring safe and sufficient food, rehabilitating habitats and protecting the environment.

This paper answers some of the questions related to ecosystem impacts on species decline; interspecific interactions between composition of vegetation and avian fauna, and the impact of major threats between them (Sutherland et al. 2008). Conserving biodiversity over a long term means we should take into account future value while deciding whether to exploit a particular biological resource irreversibly (Faith 2013; Geeta et al. 2014).

This paper also summarizes the impacts of human activities within urban landscapes as indicated by the level of threats faced by avian communities including endangered species. The present study helps in designing the shape, structure and size of corridors to optimize bird use, planning of residential parks to increase bird diversity, policy for building to reduce bird collisions, strategies for the type, structure and distribution of vegetation to favour birds, and insuring building architecture harmonious with birds (Savard, Clergeau, and Mennechez2000). Management suggestions mainly involve encouragement of long-term conservation education among local people. The main attributes of local people that influence the option value for attitudes, habitat management and resource harvest should be identified in conservation strategies. Management further includes several approaches for the maintenance of urban landscapes for avian communities, *viz*. reduce lighting of buildings at night during migration periods, manage waste to reduce bird problems, plant vegetation in urban parks, green corridors and along streets, and promote other management options that favour bird diversity (Savard, Clergeau, and Mennechez 2000).

Author declaration

SR and MGV conceived and designed the experiments. SR performed the experiments. SR analyzed the data. SR wrote the manuscript and other author provide editorial advice.

Acknowledgements

We thank Mr. Sadiq Pasha, Research Scholar, Department of Statistics, Bangalore University for analysis of data and the anonymous referees for critical comments on the manuscript.

Disclosure statement

The authors declare that they have no conflict of interests.

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Appendix 1. Species Importance Value Index (SIVI) for the urban birds in the landscapes of the Bengaluru region

Bird species	Species Important Value	Bird species	Species Important Value
Accipiter badius	0.97	*Merops orientalis*	2.20
Accipiter nisus	0.42	*Milvus migrans*	8.03
Acridotheres fuscus	6.10	*Mirafra erythroptera*	0.32
Acridotheres tristis	10.41	*Motacilla alba*	2.53
Acrocephalus aedon	1.24	*Motacilla cinerea*	2.29
Acrocephalus agricola	3.13	*Motacilla madaraspatensis*	2.51
Acrocephalus stentoreus	0.03	*Muscicapa dauurica*	2.73
Aegithina tiphia	1.69	*Nectarinia asiatica*	4.51
Alcedo atthis	2.00	*Nectarinia lotenia*	2.14
Anthus cervinus	1.27	*Nectarinia zeylonica*	4.37
Anthus rufulus	1.74	*Neophron percnopterus*	0.05
Apus affinis	4.90	*Oriolus oriolus*	1.70
Athene brama	2.16	*Orthotomus sutorius*	3.84
Bubulcus ibis	5.80	*Parus major*	2.76
Buteo rufinus	0.25	*Parus nuchalis*	0.93
Carpodacus erythrinus	2.96	*Passer domesticus*	8.11
Celeus brachyurus	2.88	*Pavo cristatus*	0.39
Centropus sinensis	2.44	*Pelargopsis capensis*	1.38
Chloropsis aurifrons	1.34	*Perdicula asiatica*	1.10
Chloropsis cochinchinensis	1.04	*Perdix perdix*	0.63
Circus aeruginosus	0.47	*Pericrocotus cinnamomeus*	1.53
Columba livia	12.03	*Pericrocotus erythropygius*	2.04
Copsychus saularis	2.79	*Pericrocotus flammeus*	0.26
Coracias benghalensis	0.60	*Pernis ptilorhyncus*	0.39
Corvus macrorhynchos	8.23	*Phylloscopus magnirostris*	3.20
Corvus splendens	10.27	*Phylloscopus trochiloides*	4.45
Cuculus canorus	2.40	*Ploceus philippinus*	2.38
Cuculus micropterus	2.66	*Prinia socialis*	4.18
Cyornis rubeculoides	2.25	*Prinia subflava*	4.25
Cyornis tickelliae	2.79	*Prinia sylvatica*	3.51
Cypsiurus parvus	0.70	*Psittacula alexandri*	0.92
Dendrocitta vagabunda	2.17	*Psittacula cyanocephala*	0.82
Dendronanthus indicus	0.48	*Psittacula krameri*	9.46
Dicaeum agile	2.88	*Pycnonotus cafer*	2.52
Dicaeum erythrorhynchos	3.45	*Pycnonotus jocosus*	3.04
Dicrurus adsimilis	2.83	*Pycnonotus leucogenys*	2.36
Dicrurus leucophaeus	2.75	*Pycnonotus luteolus*	0.66
Dinopium benghalense	1.89	*Rhipidura albicollis*	3.53
Dumetia hyperythra	2.17	*Rhipidura aureola*	3.17
Elanus caeruleus	0.60	*Rhipidura euryura*	2.66
Eremopterix griseus	0.39	*Saxicola caprata*	3.50
Eudynamys scolopaceus	2.84	*Saxicoloides fulicatus*	3.73
Eumyias thalassinus	1.01	*Stigmatopelia chinensis*	2.79
Ficedula parva	0.21	*Stigmatopelia senegalensis*	1.73
Gallus sonneratii	2.34	*Streptopelia tranquebarica*	1.04
Glaucidium radiatum	0.38	*Sturnus malabaricus*	1.11
Gyps indicus	0.01	*Sturnus pagodarum*	0.16
Halcyon pileata	0.48	*Sturnus roseus*	2.36
Halcyon smyrnensis	2.27	*Tephrodornis pondicerianus*	0.89
Haliastur indus	2.20	*Terpsiphone paradisi*	1.51
Hirundo daurica	3.13	*Turdoides affinis*	3.75
Hirundo rustica	3.14	*Turdoides caudata*	3.32
Hirundo smithii	1.59	*Turdoides malcolmi*	3.19
Lanius cristatus	2.50	*Turdoides striata*	3.25
Lanius excubitor	0.95	*Turdus merula*	2.13
Lonchura punctulata	1.75	*Turnix suscitator*	0.73
Megalaima haemacephala	1.94	*Tyto alba*	2.89
Megalaima viridis	5.19	*Upupa epops*	1.64
Megalaima zeylanica	1.56	*Zosterops palpebrosus*	1.38

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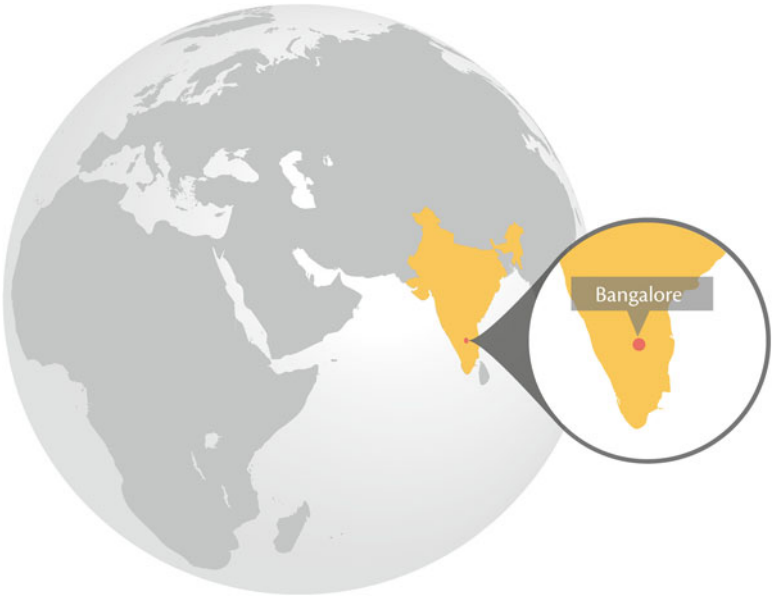
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Appendix 2. Family Importance Value Index (FIVI) for the urban bird populations in the landscapes of the Bengaluru region

Bird family	Number of genera	Number of species belonged to genera (S)	Relative % abundance (RA)	Relative species richness (RSR)	Family Importance Value (FIV = RA + RSR)	Genus: species
Accipitridae	9	10	4.50	9.45	13.95	0.90
Aegithinidae	1	1	0.39	0.00	0.39	1.00
Alaudidae	2	2	0.20	1.49	1.69	1.00
Alcedinidae	3	4	1.47	3.52	4.99	0.75
Apodidae	2	2	2.12	1.13	3.25	1.00
Ardeidae	1	1	2.47	0.00	2.47	1.00
Campephagidae	2	4	1.04	3.66	4.70	0.50
Chloropseidae	1	2	0.49	1.33	1.82	0.50
Cisticolidae	1	3	4.19	2.11	6.30	0.33
Columbidae	3	4	7.23	3.01	10.25	0.75
Coraciidae	1	1	0.09	0.00	0.09	1.00
Corvidae	2	3	8.59	1.98	10.57	0.67
Cuculidae	3	4	2.71	3.31	6.02	0.75
Dicaeidae	1	2	2.01	1.14	3.14	0.50
Dicruridae	1	2	1.51	1.17	2.68	0.50
Estrildidae	1	1	0.43	0.00	0.43	1.00
Fringillidae	1	1	0.98	0.00	0.98	1.00
Hirundinidae	1	3	2.57	2.22	4.78	0.33
Laniidae	1	2	0.94	1.23	2.17	0.50
Meropidae	1	1	0.60	0.00	0.60	1.00
Monarchidae	1	1	0.30	0.00	0.30	1.00
Motacillidae	3	6	2.91	5.47	8.39	0.50
Muscicapidae	7	8	5.59	7.20	12.79	0.88
Nectariniidae	1	3	3.72	2.14	5.86	0.33
Oriolidae	1	1	0.38	0.00	0.38	1.00
Paridae	1	2	1.73	1.15	2.89	0.50
Passeridae	1	1	3.45	0.00	3.45	1.00
Phasianidae	4	4	1.16	3.61	4.77	1.00
Picidae	2	2	1.26	1.19	2.45	1.00
Ploceidae	1	1	0.73	0.00	0.73	1.00
Psittacidae	1	3	4.64	2.09	6.73	0.33
Pycnonotidae	1	4	2.50	3.33	5.84	0.25
Ramphastidae	1	3	2.82	2.20	5.01	0.33
Rhipiduridae	1	3	3.17	2.17	5.34	0.33
Strigidae	2	2	0.62	1.29	1.91	1.00
Sturnidae	2	5	7.70	4.00	11.70	0.40
Sylviidae	3	6	5.32	5.17	10.49	0.50
Timaliidae	2	5	5.38	4.13	9.51	0.40
Turdidae	1	1	0.61	0.00	0.61	1.00
Turnicidae	1	1	0.15	0.00	0.15	1.00
Tytonidae	1	1	0.75	0.00	0.75	1.00
Upupidae	1	1	0.31	0.00	0.31	1.00
Zosteropidae	1	1	0.30	0.00	0.30	1.00
Total	78	118	100.00	100.00		

Chapter 7
Local Assessment of Bangalore: Graying and Greening in Bangalore – Impacts of Urbanization on Ecosystems, Ecosystem Services and Biodiversity

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T. Elmqvist et al. (eds.), *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment*, DOI 10.1007/978-94-007-7088-1_7,
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Abstract Bangalore is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka, with a population approaching nine million. Economic growth has had a major impact on ecosystems and biodiversity, leading to the encroachment and pollution of water bodies, the felling of thousands of trees, and urbanization of green spaces. The city periphery experiences accelerated growth, with changes in ecosystems, land use and governance leading to impacts on ecosystems and biodiversity. Vegetation in the city core is species rich but less dense compared to other cities, with a high proportion of exotic plant species, and high faunal and insect diversity, although shaped by social preferences that vary across location and time. Bangalore's green spaces and lakes are embedded within multiple land use categories, and governed by a multiplicity of institutions with overlapping, often uncoordinated jurisdictional responsibilities. Civil society also significantly shapes the environmental agenda in Bangalore, taking an active and vibrant role in respect of environmental issues. In the coming decades, climate change and scarcity of access to clean water are likely to pose significant challenges for the city, exacerbated by the loss of lakes, wetlands and green spaces. Socio-economically vulnerable populations will be especially susceptible to these changes. In this context, Bangalore's cultural character, as a location of significant civic and collective action, will play a very important role in shaping urban environmental protection and conservation efforts, with collaborations between citizens of different economic strata and government agencies playing an increasingly critical role.

Keywords Economic growth • Urban sprawl • Traditional knowledge • Keystone species • Lakes

Key Findings

- Bangalore is simultaneously sprawling and growing rapidly in population
- The official governance structure is heavily compartmentalized and fragmented
- The lakes and green spaces in the city are rapidly transforming or disappearing
- Civic initiatives play an important role in providing protection for the urban ecosystems
- The city's poor often play a direct role in maintaining the biodiversity, while also being the most vulnerable to environmental hazards.

7.1 Introduction

Bangalore is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka. The city is geographically located at 12.95° N latitude and 77.57° E longitude and situated on the Deccan plateau, at an altitude of 920 m above msl. Bangalore is a fast growing incipient megapolis, with

an increase in population from 163,091 during 1901 to 8,499,399 as per the 2011 Census (Census of India 2011). With the advantages of booming economic activity, availability of land for expansion, and the city's year-round favorable climate due to its location at a higher elevation; population growth, migration and expansion has been extensive, leading to urban sprawl and landscape fragmentation in and around Bangalore (Sudhira et al. 2007; Nagendra et al. 2012).

Bangalore was known as a tiny village in the twelfth century and has grown through the intervening centuries, to emerge as the fifth largest city in India today. Popular belief associates this with an agricultural ecosystem service, considering the name "Bengaluru" (the city's name in the local language Kannada, from which "Bangalore" has been anglicised) to be derived from "*benda kaalu ooru*" – town of boiled beans. Tradition associates the twelfth century Hoysala King Vira Ballala with the origin of this name. The tale states that Vira Ballala once lost his way during a hunting expedition in this region and reached the hut of an old woman, who offered him cooked beans that were locally grown. In memory of her hospitality, the king is believed to have named the place as '*benda kaala ooru*' (town of boiled beans) (Rice 1897a). While this is an interesting story, it is unlikely to be true as there are references to the name seen much prior to the supposed date of this incident, in a nineth century war memorial stone inscription (Annaswamy 2003; Sudhira et al. 2007). Kamath (1990) offers an alternative explanation also linked to the local ecology, stating that Bangalore is said to have got its name from *benga*, the local Kannada language term for *Pterocarpus marsupium*, a species of dry and moist deciduous tree, and *ooru*, meaning town. Thus, the ecological character of the surrounding landscape appears to be closely linked with the very name of the city.

The founding of modern Bangalore is attributed to Kempe Gowda, a scion of the Yelahanka line of chiefs, in 1537 (Kamath 1990). Kempe Gowda is also credited with construction of four towers along four directions from the Petta, the central part of the city, to demarcate the boundaries of anticipated growth. The city has substantially surpassed these boundaries envisaged in the sixteenth century, with particularly rapid growth in the past half century. Since 1949, Bangalore has grown spatially more than ten times (see Fig. 7.1) (Sudhira et al. 2007).

Bangalore's prominence as a center of trade and commerce was established during the early nineteenth century, when the city supported a flourishing trade and commerce (Buchanan 1870). In the past two decades, Bangalore's economic growth, due to information and communication technology (ICT) industrial expansion, has placed the city on the global map (Friedman 2005). Bangalore's economic growth is powered by the presence of numerous higher education institutions, public sector companies and knowledge based industries (Glaeser 2011).

Despite the popular perception of the economic dominance of the ICT-based industries, the city's economy is highly diversified, being also characterised by textile, automobile, machine tool, aviation, space, defence, and biotechnology based industries, as well as numerous services, trade and banking activities. An important feature of the economic activities of Bangalore is the huge concentration of small and medium enterprises (SMEs) in diversified sectors across the city, with more than 20 industrial estates/areas comprising large, medium and small enterprises (Sudhira et al. 2007). The city is a source of wealth for many, with a net district

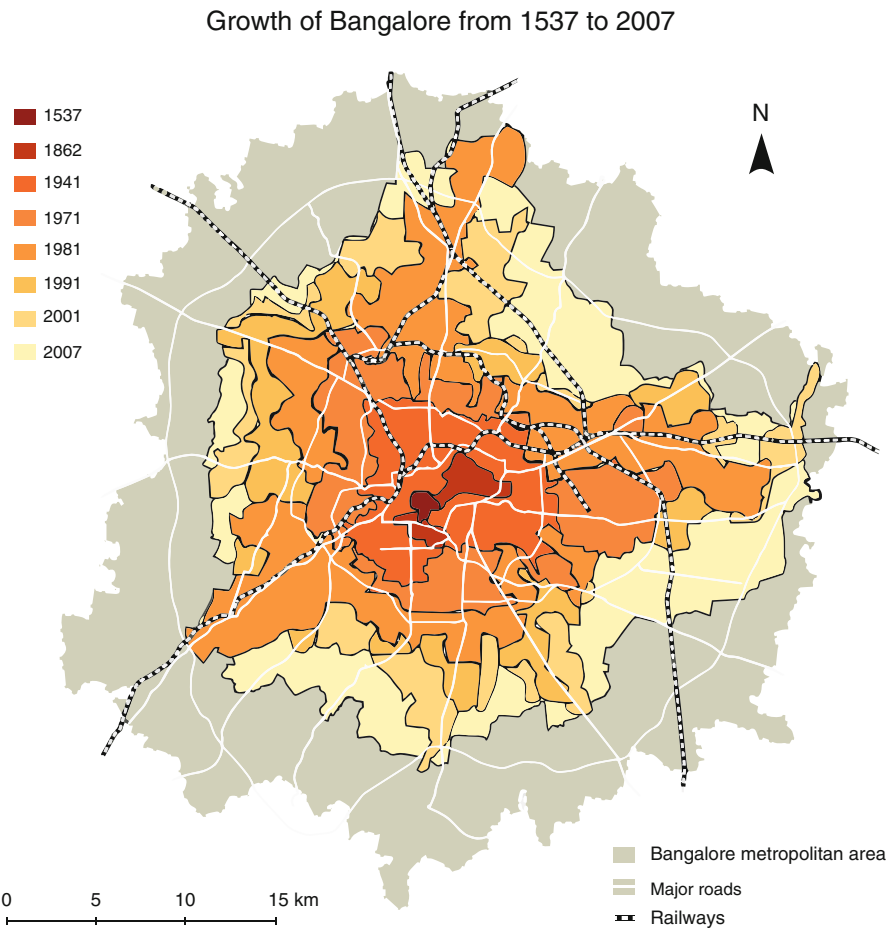


Fig. 7.1 Spatial growth of Bangalore from 1537 (*red*) to 2007 (*light yellow*) (Source data from Census of India. Prepared by H.S. Sudhira and modified by Jerker Lokrantz/Azote. Published with kind permission of ©H.S. Sudhira 2013. All Rights Reserved)

income of Rs. 2,625,920 lakhs (approx. US$ 5.8 billion) and a per capita income of Rs. 39,420, little more than twice of the state's average per capita income of Rs. 18,360 (Government of Karnataka 2005). Yet, economic inequities remain strong with prevailing housing poverty for an estimated 25 % of the city's population.

7.2 Urbanization, Ecosystem Services and Biodiversity; Scenarios and Trends

The economic growth in the city has had a major impact on ecosystems and biodiversity. Bangalore attracts a high traffic of migrants each year, and many of them indicate that they come to the city in part for its cool climate and greenery

(Nair 2005; Sudhira et al. 2007). Yet ironically, while the city was once known for its wide tree-lined avenues, historic parks, and expansive water bodies, this influx of growth has led to the encroachment and pollution of water bodies, the felling of thousands of trees, and large scale conversion of open areas and parks into commercial, industrial and residential settlements (Nair 2005; Sudhira et al. 2007; Nagendra and Gopal 2010, 2011). This is not a new phenomenon, and urban expansion has led to the disappearance of some patches of the city's iconic oldest botanical gardens even as far back as the early nineteenth century (Iyer et al. 2012), but the scale of impact has exploded in recent decades.

Further, urban growth in Bangalore – in common with many other Indian cities – is much less directed by state policies or colonial legacies than for many other parts of the world. This has resulted in patterns of growth that are irregular and complex, with reduced urbanization in the city core, but accelerated and fragmented processes of change at the periphery (Schneider and Woodcock 2008; Taubenböck et al. 2009). High land prices and scarcity of land in the city centre have led to the location of most new development at the city periphery (Sudhira et al. 2003; Shaw and Satish 2006). Consequently, patterns of change in green areas appear to be similarly constrained, with increased loss in vegetation and fragmentation in the city periphery compared to the city core (Nagendra et al. 2012). Urban expansion has also greatly transformed the land-use patterns and institutional forms of governance of many ecosystems located in former agricultural hinterland areas (Nair 2005; D'Souza and Nagendra 2011). The consequences of these combined changes in ecosystems, land use and governance have been manifold, with deterioration of biodiversity and soil quality, aggravation of urban heat island effects, increased pollution, flooding, water scarcity and epidemics, and consequent impacts on human health and well-being.

Bangalore contains a diversity of green spaces located within multiple land use categories including in parks, home gardens, office complexes, wooded streets, wetlands, and remnant forests (Sudha and Ravindranath 2000; Nagendra and Gopal 2010, 2011). Vegetation in the city core tends to harbour greater heterogeneity and species richness as well as a larger proportion of exotic species compared to rural and forested areas (Issar 1994; Neginhal 2006). Within the central, older parts of the city, few patches of remnant natural vegetation exist, and most ecosystems have been significantly modified by human influence, responding to social preferences that vary across location and time (Sudha and Ravindranath 2000). For instance, older wooded streets and parks tend to be dominated by large-canopied, slow growing long lived tree species that provide greater shade, biodiversity support, pollution reduction and microclimatic buffering while recent planting has focused more on ornamental species and short statured, small canopied, relatively short lived species that are easier to maintain but less likely to provide the same range of environmental and ecological services (Nagendra and Gopal 2010, 2011). Bangalore has a relatively high tree diversity but relatively low tree density compared to many other cities (Nagendra and Gopal 2010). As with other parts of the world, home gardens in Bangalore are rich in plant diversity but in contrast to cities in Europe and the USA, these tend to contain a large proportion of plants selected for their cultural, medicinal and culinary properties (Jaganmohan et al. 2012). The city flora contains a large proportion of exotic species, with three out of four park trees

coming from introduced species (Nagendra and Gopal 2011). Many of these species have however been planted for well over a century, with the view to creating a spectacular, scenic urban landscape with a succession of species flowering across all seasons. Many of the introduced species thus support a wide diversity of birds, insects and other fauna (Issar 1994; Neginhal 2006).

Trees in Bangalore provide a diversity of ecosystem services, decreasing ambient air temperatures in the summer by 3–5 °C, and road asphalt surface temperatures by as much as 23 °C, substantially reducing levels of noxious air pollutants including SO_2 and Suspended Particulate Matter (unpublished data), providing critical habitat for a diversity of birds, insects and other urban wildlife, and constituting important sources of recreational and sacred cultural services to city residents, especially in poor neighborhoods such as slums (Gopal 2011). Thankfully, despite the extensive clearing and fragmentation of vegetation in many parts of Bangalore, the city core still supports substantial vegetation. Given the city's colonial history as a former British military establishment, many of Bangalore's large green spaces are managed by a variety of public institutions including the military and defence establishments, public sector industries, and educational institutions (Nagendra et al. 2012). Bangalore also hosts two large, historic botanical gardens, a number of educational institutions and a number of historic cemeteries (Nair 2005). These locations harbour large numbers of majestic, visually spectacular trees that provide important biodiversity and environmental/ecosystem services to the city and have provided significant protection against vegetation clearing and fragmentation in recent years (Nagendra et al. 2012). A faunal checklist compiled in 1999 documented the presence of 40 species of mammals, over 340 species of birds, 38 species of reptiles, 16 species of amphibians, 41 species of fishes and 160 species of butterflies within a 40 km radius from the Bangalore city centre (Karthikeyan 1999). Pockets of native vegetation cover persisting in academic institution campuses and botanical gardens contribute significantly to faunal biodiversity. There is high insect diversity, with reports of rare species in the campuses of Bangalore University, the Indian Institute of Science and University of Agricultural Science in Bangalore, as well as in the city's two botanical gardens – Lal Bagh and Cubbon Park (Gadagkar et al. 1997; Kumar et al. 1997; Nayaka et al. 2003; Varghese 2006; Swamy et al. 2008). There has even been a report of the discovery of a new ant species in an Indian educational institution campus (Varghese 2006).

A number of small neighbourhood parks have also come up in the core of Bangalore in the last two decades. Their size and focus on exotic, landscaped features does appear to provide limitations in terms of the range ecological services they can provide (Nagendra and Gopal 2011).Yet, even these parks provide important recreational services for local neighbourhoods, and field surveys indicate that these constitute important habitats for migratory birds and other local biodiversity (Swamy and Devy 2010). In these and other human-impacted urban habitats in Bangalore, some taxa such as ants and earthworms are able to persist because of the availability of specialized microhabitats, leaf litter and soil organic matter (Kale and Krishnamoorthy 1981; Swamy et al. 2008), while other taxa such as lichens indicate patterns of species turnover and replacement by species more

tolerant to pollution (Nayaka et al. 2003). Yet, worryingly, fragmentation of vegetation connectivity has increased over time, within the city core as well as the periphery (Nagendra et al. 2012). This is especially critical for the Bangalore urban landscape, where many migratory birds and other species need to move between a number of small, scattered habitats of variable resource quality, making their survival and persistence especially challenging.

Although satellite remote sensing indicates the presence of recent greening in some peripheral areas, field research indicates that much of this can be traced to the short term plantation of water hungry, fast growing exotic timber species such as *Acacia auriculiformis* and *Eucalyptus* on formerly agricultural lands, which are eventually converted to urban development (Nagendra et al. 2012). Fortunately, some peripheral parts have witnessed citizen-government interactions efforts at plantation and restoration of urban environments, and are beginning to provide a positive example for other peripheral areas in the city (Nagendra 2010).

The expansion and intensification of Bangalore has also transformed the land-use patterns and institutional forms of governance of the city's wetlands and water bodies. There were once thousands of reservoirs in the area surrounding Bangalore, used for a number of purposes including agriculture, fishing, cattle washing, drinking, and domestic uses (Buchanan 1870). These water bodies were largely created and maintained by human effort, through damming rainfed streams to create networks of freshwater reservoirs topographically distributed throughout the region (Rice 1897a, b). These wetlands supported an impressive diversity of birds, fish, amphibians, reptiles, insects, and micro-organisms until quite recently (Krishna et al. 1996). Originally managed by adjacent village communities, lakes in Bangalore are now managed by a large number of government departments with overlapping jurisdictions and responsibilities (Gowda and Sridhara 2007; D'Souza and Nagendra 2011). Public perceptions and uses of lakes have also transformed as a consequence of urbanization, from community spaces valued for water and cultural services, to urban recreational spaces used largely by joggers and walkers (Srinivas 2004; D'Souza and Nagendra 2011).

Currently, over 200 lakes are located within greater Bangalore (BBMP 2010), while a much larger network of lakes surround the city at its periphery (Fig. 7.2). Rapid changes in land use have taken place around lake and wetland areas (D'Souza and Nagendra 2011) as water bodies have been encroached upon for conversion to urban land use, subjected to drying because of disruptions in the drainage networks, and polluted by domestic and industrial waste (ESG 2009).

7.3 Governance and Institutions

An important aspect of a city is how well it plans, manages and administers, activities which form the core part of an urban agenda – governance. Yet, environment hardly becomes a priority in most instances. In Bangalore, there has been an overall emphasis on economic development at the cost of environmental degradation.

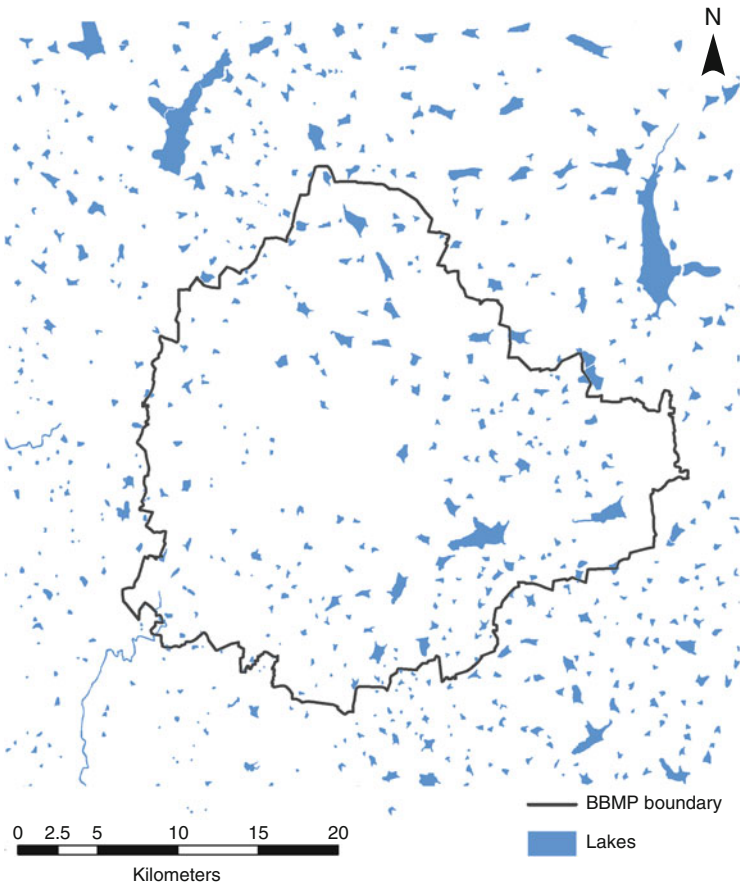


Fig. 7.2 Distribution of lakes within and surrounding Bangalore. Note the lack of lakes in the city center, indicating their encroachment and conversion to other land uses (Prepared by and published with kind permission of © Harini Nagendra 2012. All Rights Reserved)

Appropriate state mechanisms through institutions, policies and programs can enable the protection and maintenance of ecosystems. However, apart from the formal administrative structures, the presence and involvement of civil society significantly shapes the environmental agenda in Bangalore. The city, in the recent past, has witnessed non-governmental organizations (NGOs) and community based organisations (CBOs) taking an active and vibrant role in respect of environmental issues (Sudhira et al. 2007; Khandekar 2008).

A multiplicity of laws and institutions are known to have had control over provisioning of different ecosystem services including protection of lakes. Subramanian (1985) notes that even about a century ago, there were multiple agencies including the Government of Mysore (Public Works Department, Dewan), Government of India

Table 7.1 Institutions and their functional areas concerning the environment in Bangalore

Sl. No.	Institutions	Functional areas
1	Bruhat Bangalore Mahanagara Palike (BBMP)	Urban local body responsible for overall delivery of services – Development and Maintenance of Parks and Playgrounds (all open spaces), Solid Waste Management, Health, Storm Water Drains, Manages only 4 lakes currently, Responsible for Tree Cover as well
2	Bangalore Development Authority (BDA)	Land use zoning, planning and regulation within Bangalore Metropolitan Area; Develops and Maintains few Parks; Notification of Green Belts and Valley Zones implicates amount of development
3	Bangalore Water Supply and Sewerage Board (BWSSB)	Drinking water – pumping and distribution, sewerage collection, water and waste water treatment and disposal
4	Lake Development Authority (LDA)	Regeneration and conservation of lakes in Bangalore urban district
5	Department of Forests, Ecology and Environment	Formulation of programmes in the state on activities causing impact on ecology and environment, Responsible for setting up LDA
6	Bangalore Urban Division, Karnataka Forest Dept.	Has the key role in maintaining the green cover in and around the city, task of planting trees and increasing tree cover
7	Karnataka State Pollution Control Board- KSPCB	Responsible for enforcing various acts and rules concerning the Environment, monitors for air pollution, water pollution, solid waste (municipal, bio-medical and hazardous) disposal, and noise pollution. Also responsible for conducting public hearing in accordance with the EIA notification for any major projects that can potentially have environmental impacts

(Engineering Department, Secretary of State), Resident at Bangalore, Municipalities of the City and the Civil and Military station, and the Military Department, who were all involved in the water supply system, resulting in considerable delays in decision-making. The situation prevailing is no different today, with the involvement of the Bruhath Bangalore Mahanagara Palike (BBMP), Bangalore Development Authority (BDA), Bangalore Water Supply and Sewerage Board (BWS&SB), Lake Development Authority (LDA), Karnataka State Pollution Control Board (KSPCB), Department of Major and Minor Irrigation, Fisheries Department, Karnataka State Council for Science and Technology (KSCST), Agenda for Bangalore Infrastructure Development (ABIDe), Ministry of Environment and Forests, Government of India (MoEF), and Department of Science and Technology (DST), Government of India, all playing considerable roles in the various facets of ecosystem services in Bangalore (Table 7.1). However, the 74th Constitutional Amendment Act by the federal government mandates only the urban local body for protecting the environment.

With a prevailing political vacuum and the clear state-capture of the urban local body, the City Corporation appears to be in no position to re-assert its position in managing environmental issues (Sudhira 2008).

Formally, among the abovementioned institutions, the environment agenda is seen as primary only by the Karnataka State Pollution Control Board (KSPCB) and the Lake Development Authority (LDA). The KSPCB was initially set up under the provisions of the Water (Prevention and Control of Pollution) Act passed in 1974, and it has been extending the responsibility for enacting the Air (Prevention and Control of Pollution) Act, 1981 and Environment (Protection) Act, 1986. Thus, today, KSPCB is responsible for enforcing various acts and rules concerning the Environment. In the context of Bangalore, KSPCB monitors air pollution, water pollution, solid waste (municipal, bio-medical and hazardous) disposal, and noise pollution. KSPCB is also responsible for conducting public hearings in accordance with the Environmental Impact Assessment notification for any major projects that can potentially have environmental impacts. Since the jurisdiction of KSPCB extends throughout the state its focus and attention on environmental issues within the city of Bangalore is not commensurate to the importance of the problems and issues.

In a move to establish formal institutional structures towards the management of lakes and water bodies, and taking cognizance of the N. Lakshmana Rau Committee (1987), the Government of Karnataka set up the Lake Development Authority (LDA), as a registered society under the provisions of the law (Karnataka Co-operative Societies Registration Act, 1959), after the Government Order No. FEE 12 ENG 2002, Bangalore, dated 10th July 2002, as a non-profit organisation working solely for the regeneration and conservation of lakes in and around Bangalore city. LDA initially developed 5,00,000 in Bangalore using funding from the National Lake Conservation Program and later extended its jurisdiction to all major water bodies in Bangalore.

Recent attempts by LDA in a few lakes to explore public-private partnerships have also been extremely controversial, leading to uncontrolled disruptive activities such as motorized boating in some lakes, which have been effectively challenged by litigations by local individuals, civic activist groups and non-governmental organizations (Khandekar 2008). These litigations, including a series of long term efforts by the Environment Support Group, have been extremely successful in garnering support from the Karnataka High Court. In a series of extremely progressive rulings, the Court has intervened on a number of aspects relating to conservation and protection of lakes (High Court of Karnataka 2011). Coupled with recent efforts by the city government to fence, protect and rejuvenate many of the city's urban water bodies, with significant funding earmarked for these initiatives, these series of actions are beginning to reshape Bangalore's polluted wetland and lake environment and ecology. Despite expensive government restoration projects, many lakes continue to be degraded, encroached, silted, and contaminated by sewage. In contrast, a number of government efforts at lake restoration conducted in collaboration with local communities have resulted in the significant recovery of formerly polluted lakes, increase in ground water tables, and increase in native faunal and floral biodiversity (Nagendra 2010). Although some of these community efforts have been rightly

critiqued for their exclusion of specific socio-economic and livelihood groups (Sundaresan 2011), others hold significant potential for the development of similar restoration efforts in other parts of the city.

7.4 Urban Dynamics and Future Development

Bangalore's growth in the last few decades is particularly compelling as the city has, over two centuries, been continuously adapting from being a centre of trade during the early nineteenth century (Buchanan 1870) to a Network City (Heitzman 2004). While the city continues to evolve spatially, socially, economically and culturally at a rapid pace; for the ecological systems, these are too fast to adapt in such short time spans. The consequences are glaring: the change in land-use with loss of water bodies and green cover are evident. Clearly, the trend is not encouraging.

Transportation is another major factor impacting environmental sustainability in Bangalore, which has a vehicle population of about 3.8 million for a population of 8.5 million (Regional Transport Authority 2012) – a vehicle-to-person ratio that is far higher than other Indian cities. Much of this can be explained by the lack of sufficient public transport. CO_2 emissions from the road transport sector in Bangalore have been estimated at 24 million tonnes for the year 2005–2006, with emissions from other greenhouse gases, CH_4 and N_2O, estimated at 325 and 19 tonnes respectively. The study suggests that the total emissions projected for 2012 and 2017 would be 3.03 and 4.06 MT of CO_2 equivalents respectively (Greenhouse Gas Inventory of Karnataka 2007). In recent years, there have been efforts to address this by improving the public bus service system, and building a Metro. Bangalore is also embracing non-motorized transport, through a number of community-led cycling initiatives, and efforts by the government such as the ongoing implementation of a 45 km network of bicycle friendly streets within a residential neighbourhood, and support to a recently launched campus-based bicycle sharing system in an educational campus. These efforts show promise as alternatives to encourage Bangalore's citizens to use non-motorized modes of transport for shorter trips, and to reduce the city's environmental and ecological footprint.

The dynamics influencing land-use change resulting in urban sprawl and loss of water bodies and vegetation can be explained by adapting a causal loop diagram initially developed to explain the drivers of urban sprawl in Bangalore (Sudhira 2008). In Bangalore, master planning is the primary instrument that determines the land-use policy. Specifically, in the course of master planning exercise, one of the prominent measures to limit growth is by way of enforcing building height restrictions formalised through the floor area ratio (FAR) and corresponding zoning regulations tied to different land-use categories.

The analysis on land-use change resulting in urban sprawl suggests water dynamics is a crucial balancing feedback that can limit the outgrowth. In the prevailing scenario for Bangalore, wherein water is primarily sourced about 100 km away over a gradient of about 100 m for about 1,000 MLD (million litres per day), there is also

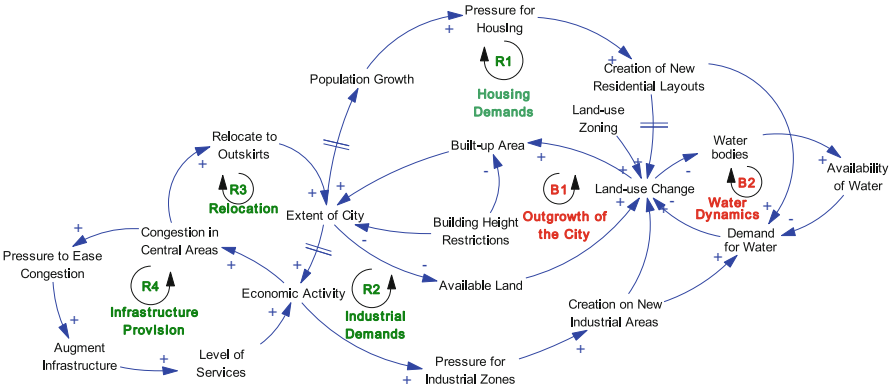


Fig. 7.3 Causal loop diagram for urban sprawl and resulting water dynamics (Prepared by and published with kind permission of © H.S. Sudhira 2013. All Rights Reserved)

huge energy costs involved in pumping this to different parts of the city. The piped water supply does not meet the demand for water, and many parts of the city depend on ground water extracted from borewells and supplied through private tankers, and over extraction of ground water, coupled with the shrinking of waterbodies and conversion of many open areas to impervious urban surfaces have led to alarming levels of depletion in the ground water table. This has a particularly severe impact on poor settlements, whose inhabitants are unable to afford the high costs of privatized water supply. With significant land-use changes in the recent past resulting in loss of water bodies, primarily, prevalence of water bodies and availability of water is going to be a crucial factor for the growth of the city. Accordingly, the key variables identified were: population growth, economic activity, pressure for new housing and industrial areas, land-use zoning, available land, availability of water, built-up area, water bodies, level of services and building height restrictions. The corresponding causal loop diagram is shown in Fig. 7.3.

The six feedbacks generated in this system were:

(i) Reinforcing feedbacks:

  (a) Housing demands (R1)
  (b) Industrial demands (R2)
  (c) Relocation (R3) and
  (d) Infrastructure provision (R4)

(ii) Balancing feedback:

  (a) Outgrowth of the city (B1)
  (b) Water dynamics (B2)

The reinforcing feedbacks, R1 and R2, quite naturally for most cities, set the demand for development of land into residential layouts/apartments or industrial estates, respectively. As the city grows, there is congestion in central areas forcing

residents to relocate in the outskirts. This is captured by the reinforcing feedback, R3. The other reinforcing feedback, R4, for infrastructure provision suggests that augmenting infrastructure in a congested area can be counter-productive. Indeed this insight is well established by the classic Braess paradox (Braess 1968). This was demonstrated by adding a link within the network to ease congestion, which would be counter-intuitive in a congested road network. Reinforcing feedbacks often generate exponential growth and then collapse. Systems that are self-regulating or self-correcting have been provided with balancing loops. The balancing feedback, B1, results in the outgrowth of the city through the process of land-use change limited by the availability of land for development. The other balancing feedback, B2, rise in demand for water and land-use change affects water bodies and will be limited by availability of water. The other control variable as envisaged by the land-use planning is land-use zoning and building height restrictions, which suggests that it influences the extent of outgrowth and built-up areas negatively.

Bertaud and Brueckner (2005) have shown that in unrestrictive building height conditions, the extent of the city spread is contained with higher densities in central areas. Further, the BangaloreSim model (Sudhira 2008) that was primarily developed as a spatial planning support system was used to generate scenarios for 2025. The model was used to generate forecasts of land cover for 2025 with higher FAR and siting of growth poles at key economic activity centres. The simulations revealed an increase of built-up areas (417 km^2) amounting to 31.55 % of the land cover and the water bodies declined to less than 3 km^2 with about 2.26 % of the land cover. The simulations also suggest a trend towards an increase in high-density built-up and decrease in low-density built-up areas. The increase in built-up areas with high densities suggests more congestion in certain parts of the city. While this exercise was useful in generating a scenario of urban land-use, there can be many more scenarios generated by undertaking the simulations for different policy settings to understand their respective consequences. However, as noted earlier, the reduction of water bodies is of particular concern.

With the current trends of urban growth Bangalore is experiencing, the forecast for 2025 gives pointers on possible implications despite several limitations in the model, including limited policy levers for testing. However, on the one hand, the increase in built-up areas and reduction of water bodies seem like a matter of concern, on the other hand the increase of high density and decrease of low density built-up (or sprawl) can be of some consolation.

7.5 Concluding Remarks

Further research is critically needed to understand how the larger climatic and ecological context influences urban ecosystems and ecosystem services in Bangalore (D'Souza 2011). In the context of increasing global warming, while the Indian monsoon has remained relatively stable, an increasing frequency of extreme rain events has been noted, ranging from floods to droughts (Goswami et al. 2006).

The fragmentation of green spaces and of lake connectivity, coupled with extreme rainfall events, is likely to result in an increase in the frequency of droughts as well as flooding in urban areas. Vulnerable socio-economic settlements, in particular slums, are likely to be especially affected by this double whammy of urbanization and climate change (D'Souza 2011). Women and children in slums in particular have to deal with the consequences of lack of access to clean water, lack of sanitation, and consequences in the form of increased susceptibility to infectious diseases in Bangalore. Adaptation measures, particularly those of ecosystem restoration and rejuvenation, can help to mitigate some of these impacts, but unfortunately these have been largely ignored by planners so far (Sudhira 2008). Recent studies have indicated that greenery and plants play an extremely significant role in the lives of slum residents in Bangalore, providing critical social, cultural, religious medicinal and food related ecosystem services (Gopal 2011). Thus, city planning needs to take into account the needs of vulnerable socio-economic populations, which are especially susceptible to the short term and long term impacts of urbanization including loss of green spaces, microclimatic variations, air and water pollution, flooding, lack of sanitation and epidemics (D'Souza 2011; Gopal 2011). Unfortunately, such approaches are currently missing in Bangalore and community action has largely been successful in engaging with city planners and administration only in wealthier localities, sometimes resulting in the further exacerbation of existing inequities and vulnerability (Ranganathan 2011; Sundaresan 2011).

Bangalore is known for its strong and active community networks. Thus a number of individual citizens, resident associations, civil society networks, naturalist groups, and citizen science and educational programs have also been influential in promoting awareness of, and organization around issues related to biodiversity and conservation in the city (Sudhira et al. 2007; Nagendra 2011). The environmental activist group "Hasiru Usiru" (loosely translated as "Greenery is Life") has been very active in Bangalore since their formation in 2005, with activities ranging from green awareness to protests against tree felling and urban governance. Social networks such as Hasiru Usiru have contributed substantially to keeping issues of urban conservation in the forefront of public awareness in recent years, in addition to initiating a number of Public Interest Litigations that have resulted in influential court rulings on issues of tree felling (Sudhira et al. 2007; Enqvist 2012). The bird-watching community in Bangalore, comprising mostly of amateurs with a few experts, has been very active, meeting at least once every month for over two decades, with an active email discussion group, "bngbirds", hosted at yahoo.com (a similar group exists on butterflies that also uses mailing lists and discussion groups to communicate and organise). Since the past 5 years, there has also been an annual Bird Race, with participants having cumulatively logged over 230 species of birds in and around Bangalore in a single day, and helping to provide systematic data that can eventually aid in long term assessment (available at http://birdrace.dhaatu.com/bangalore). Other popular citizen science initiatives that have been primarily developed and housed in Bangalore, though applied at wider geographic scales, are the 'Migrant Watch' program (http://www.migrantwatch.in/), and the Citizen Sparrow program, (http://citizensparrow.in/).

As urbanization poses greater challenges, compounded by effects of urban primacy on Bangalore, it remains to be seen how the city adapts and evolves in decades to come. Eventually, the sustenance of the city will depend on how effectively it retains its natural resources, particularly green spaces and water bodies. In this context, Bangalore's cultural character as a location of significant civic and collective action will play a very important role in shaping urban environmental protection and conservation efforts, with collaborations between citizens and government agencies playing an increasingly critical role in placing pressure on, negotiating with and shaping government responses to planning for ecosystem management and conservation (Sudhira 2008; Khandekar 2008; Nagendra 2010, 2011; Ranganathan 2011; Sundaresan 2011).

Acknowledgments The authors thank USAID for financial support through a PEER grant to Harini Nagendra.

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Parris, K. M., and A. Schneider 2008. Impacts of traffic noise and traffic volume on birds of roadside habitats. *Ecology and Society* **14**(1): 29. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art29/

Annexure A42 colly

Research, part of a Special Feature on Effects of Roads and Traffic on Wildlife Populations and Landscape Function

Impacts of Traffic Noise and Traffic Volume on Birds of Roadside Habitats

Kirsten M. Parris [1,2] *and Angela Schneider* [3]

ABSTRACT. Roadside habitats are important for a range of taxa including plants, insects, mammals, and birds, particularly in developed countries in which large expanses of native vegetation have been cleared for agriculture or urban development. Although roadside vegetation may provide suitable habitat for many species, resident animals can be exposed to high levels of traffic noise, visual disturbance from passing vehicles, and the risk of collision with cars and trucks. Traffic noise can reduce the distance over which acoustic signals such as song can be detected, an effect known as acoustic interference or masking. Studies from the northern hemisphere show that the singing behavior of birds changes in the presence of traffic noise. We investigated the impact of traffic noise and traffic volume on two species of birds, the Grey Shrike-thrush (*Colluricincla harmonica*) and the Grey Fantail (*Rhipidura fuliginosa*), at 58 roadside sites on the Mornington Peninsula, southeastern Australia. The lower singing Grey Shrike-thrush sang at a higher frequency in the presence of traffic noise, with a predicted increase in dominant frequency of 5.8 Hz/dB of traffic noise, and a total effect size of 209 Hz. In contrast, the higher singing Grey Fantail did not appear to change its song in traffic noise. The probability of detecting each species on a visit to a site declined substantially with increasing traffic noise and traffic volume, with several lines of evidence supporting a larger effect of traffic noise. Traffic noise could hamper detection of song by conspecifics, making it more difficult for birds to establish and maintain territories, attract mates and maintain pair bonds, and possibly leading to reduced breeding success in noisy roadside habitats. Closing key roads during the breeding season is a potential, but untested, management strategy to protect threatened bird species from traffic noise and collision with vehicles at the time of year when they are most vulnerable to their impacts. Other management options include reducing the speed and/or volume of traffic on such roads to an acceptably low level. Ours is the first study to investigate the effect of traffic noise on the singing behavior of birds in the southern hemisphere.

Key Words: *acoustic interference; ambient noise; bioacoustics; conservation biology; road ecology; signal design; traffic noise; vocal communication*.

INTRODUCTION

Interest in the ecological effects of roads and the traffic they carry has increased over the past two decades (Forman and Alexander 1998, Trombulak and Frissell 2000, Forman et al. 2003, Slabbekoorn and Ripmeester 2008). These effects include the loss and fragmentation of habitat, injury and death of wildlife attempting to cross roads, pollution of air, water, and soil, and constraints on acoustic communication in areas affected by traffic noise. Many animals including insects, frogs, birds, and mammals communicate via acoustic signals. Birds use calls and songs to attract and bond with mates, defend territories from rivals, maintain contact with social groups, beg for food, and warn of danger from approaching predators (Collins 2004, Marler 2004). Acoustic interference, also known as masking, occurs when background noise reduces the distance over which a signal can be heard (the active space; Marten and Marler 1977). Birds use a variety of strategies to maximize the active space of their signals in naturally noisy habitats (Brumm and Slabbekoorn 2005). However, those that live near

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roads must also compete with traffic noise, much of which occurs in the low-frequency bands below 2000 Hz (Patricelli and Blickley 2006, Warren et al. 2006). Because energy in the spectral region of an acoustic signal contributes more to masking than does energy remote from the signal (Egan and Hake 1950), low-frequency signals are expected to suffer greater acoustic interference from traffic noise than are high-frequency signals.

Most research to date on the impact of traffic noise on wildlife has focused on birds in the northern hemisphere (but see Sun and Narins 2005, Bee and Swanson 2007). A range of behavioral responses to urban noise has been observed, including singing at a higher frequency (pitch), thereby reducing acoustic interference from the low-frequency noise (a frequency shift; Slabbekoorn and Peet 2003, Fernández-Juricic et al. 2005, Slabbekoorn and den Boer-Visser 2006, Wood and Yezerinac 2006); singing more loudly (an amplitude shift; Brumm 2004); and changing diurnal singing patterns to avoid peak traffic periods (a temporal shift; Fuller et al. 2007). Traffic noise may also affect bird populations and communities (Katti and Warren 2004). Reijnen et al. (1995, 1996) suggested that the lower population densities of birds in habitats close to roads in The Netherlands were caused by traffic noise, although these results may be confounded with other differences among the noisy roadside sites and the quieter control sites away from roads. Traffic noise was also proposed as the primary cause of reduced breeding success in Willow Warblers (*Phylloscopus trochilus*) with territories close to busy roads; the males had difficulty attracting and maintaining a mate (Reijnen and Foppen 1994). Rheindt (2003) hypothesized that birds with low-frequency calls or songs would be less abundant at sites with high levels of traffic noise because they would experience greater acoustic interference from low-frequency noise. In an unreplicated study, Rheindt (2003) found some evidence that species with lower frequency signals were less abundant in noisy sites than they were in quiet sites.

Traffic volume and the number of vehicles traveling on an adjacent road could also affect birds in roadside habitats. The probability of a fatal collision with a vehicle is likely to increase with traffic volume (Clevenger et al. 2003), as will visual disturbance by passing cars and trucks. The impact of visual disturbance from passing vehicles on habitat suitability for birds is poorly understood (Goosem 2007), but could include avoidance of roadside areas for foraging and/or nesting, or reduced breeding success. Because both the level of traffic noise and the frequency of visual disturbance from passing vehicles increase with traffic volume, their effects are difficult to separate. However, Reijnen et al. (1995) controlled for the visibility of cars in their analysis of bird densities in woodland habitats adjacent to and distant from roads, and concluded that traffic noise had a greater effect on bird densities than did visual disturbance.

During the agricultural expansion of Australia, vast areas of native forest and woodland were cleared for pasture and crops. In many rural landscapes, much of the remnant vegetation is confined to narrow strips on public road reserves, forming a network of native habitat (Bennett 1991). Road reserves cover 567,000 ha (2.5%) of the state of Victoria (Land Conservation Council 1988). They provide important habitat for many species of plants and animals, including the threatened Grey-crowned Babbler (*Pomatostomus temporalis*), Squirrel Glider (*Petaurus norfolcensis*), and Brush-tailed Phascogale (*Phascogale tapaotafa*)(Adam and Robinson 1996, van der Ree 2002, van der Ree et al. 2006). A recent study of bird communities of roadside remnants on the Mornington Peninsula, Victoria recorded 39 native species across eight transects (Antos and White 2004). Similarly, roadsides provide valuable habitat for plants, insects, birds, and mammals in the USA, UK, and Europe (Way 1977, Munguira and Thomas 1992, Bellamy et al. 2000, Saarinen 2005, Shochat et al. 2005). The use of roadside habitats by animals that communicate using acoustic signals, such as birds, presents an interesting trade-off between the presence of suitable habitat and the potentially detrimental effects of traffic noise and passing vehicles on survival rates, maintenance of territories, attraction of mates, and breeding success (Mumme et al. 2000, Warren et al. 2006).

In this study, we assessed the impacts of traffic noise and traffic volume on birds in narrow roadside strips of vegetation (road verges) in southern Australia using two target species; the Grey Shrike-thrush (*Colluricincla harmonica*; Pachycephalidae) and the Grey Fantail (*Rhipidura fuliginosa;* Dicruridae). Both species are common, sedentary, and dependent on forest, woodland, or shrubland (Higgins and Peter 2002, Higgins et al. 2006); thus, individuals that inhabit roadsides are expected to experience traffic noise and other disturbances from the adjacent road throughout the year. The two target

species communicate using different parts of the frequency spectrum. The Grey Shrike-thrush sings at a lower frequency than the Grey Fantail, and therefore could be expected to suffer greater acoustic interference from traffic noise (Egan and Hake 1950, Warren et al. 2006). Our study sites were all located next to roads, but the roads ranged in size from narrow gravel roads with very little traffic to multi-lane freeways. This design reduced potentially confounding habitat differences between quiet and noisy sites. The study had two aims: (1) to assess the impact of traffic noise on song frequency in the Grey Shrike-thrush and the Grey Fantail, and (2) to investigate the effects of traffic noise and traffic volume on the probability of detecting each species on a single visit to a site. This is the first study to investigate the effect of traffic noise on the singing behavior of birds in the southern hemisphere.

METHODS

Study area

The Mornington Peninsula, southeast of Melbourne, Australia, is a temperate area that supports a variety of habitats including forest, woodland, coastal shrubland, and wetlands. The peninsula and adjacent Western Port Bay form a biosphere reserve that is part of the UNESCO Biosphere World Network. Extensive areas of the peninsula have been cleared for agriculture and residential development, and less than 15% of the original cover of native vegetation remains (Calder 1986). Large patches of remnant native vegetation are rare, so road reserves are an important part of the network of remnant habitats on the Mornington Peninsula.

Study species

The Grey Shrike-thrush is a medium-large bird with an average length of 25 cm. The subspecies present in the study area, *C. harmonica harmonica,* inhabits a variety of forests, woodlands, and shrublands (Higgins and Peter 2002). Populations have reportedly declined following clearing for agriculture and urban development, but the species can persist in suitable patches of native vegetation within urban areas (Sewell and Catterall 1998, White et al. 2005). In addition, it is known to live and breed successfully on roadside strips of remnant woodland (Lynch et al. 1995, Antos and White 2004). The Grey Shrike-thrush is a sedentary species that remains in all-purpose territories throughout the year. Territories in large areas of habitat are thought to be > 5 ha in size (Higgins and Peter 2002), but the size of territories in linear strips of habitat such as road reserves is uncertain. The species has a varied diet and forages at all levels from the ground to the canopy (Higgins and Peter 2002). Males sing to attract a mate, whereas both males and females sing to defend territories from neighbors. Mates sing in response to each other, and the species also uses a variety of alarm and distress calls (Higgins and Peter 2002). The song of the Grey Shrike-thrush is melodious and highly variable, containing pure tones, trills, and whistles (Fig. 1). Much of the acoustical energy in the song occurs in the frequency band between 1500 and 4000 Hz.

The Grey Fantail is a small-medium bird with an average length of 15.5 cm. The subspecies present in the study area, *R. fuliginosa alisteri,* commonly inhabits eucalypt forest and woodlands with a shrubby midstory, but is also known to occur in grassy woodland and coastal shrubland (Higgins et al. 2006). It can persist in roadside strips of vegetation in agricultural areas and in remnant patches of vegetation in urban areas, but it has not been observed in developed urban or suburban habitats (Antos and White 2004, White et al. 2005, Higgins et al. 2006). In Victoria, the Grey Fantail is considered to be a resident species, although a proportion of the population may migrate north during autumn (April–May) and return in late winter or early spring (August–September; Higgins et al. 2006). The species forages arboreally for invertebrates, usually at mid-levels of the forest or woodland. It defends all-purpose territories during the breeding season and throughout the year. Territory size is estimated at 1–2 ha in large areas of habitat (Higgins et al. 2006), but is unknown for linear strips of habitat such as road reserves. Adults use songs and calls for territorial advertisement, forming and maintaining pair bonds during courtship, incubation, and brooding, and to warn of danger from intruders or predators (Higgins et al. 2006). The characteristic adult song is a complex and variable sequence of high-pitched tones and frequency-modulated cheeps, both of which may include a series of harmonics (Fig. 2). Much of the acoustical energy in the song occurs in the frequency band between 4000 and 7500 Hz.

Fig. 1. Sonogram and power spectrum of a song of the Grey Shrike-thrush (*Colluricincla harmonica*), produced using Adobe Audition 2.0. The lowest tonal note is indicated with a circle and an arrow.

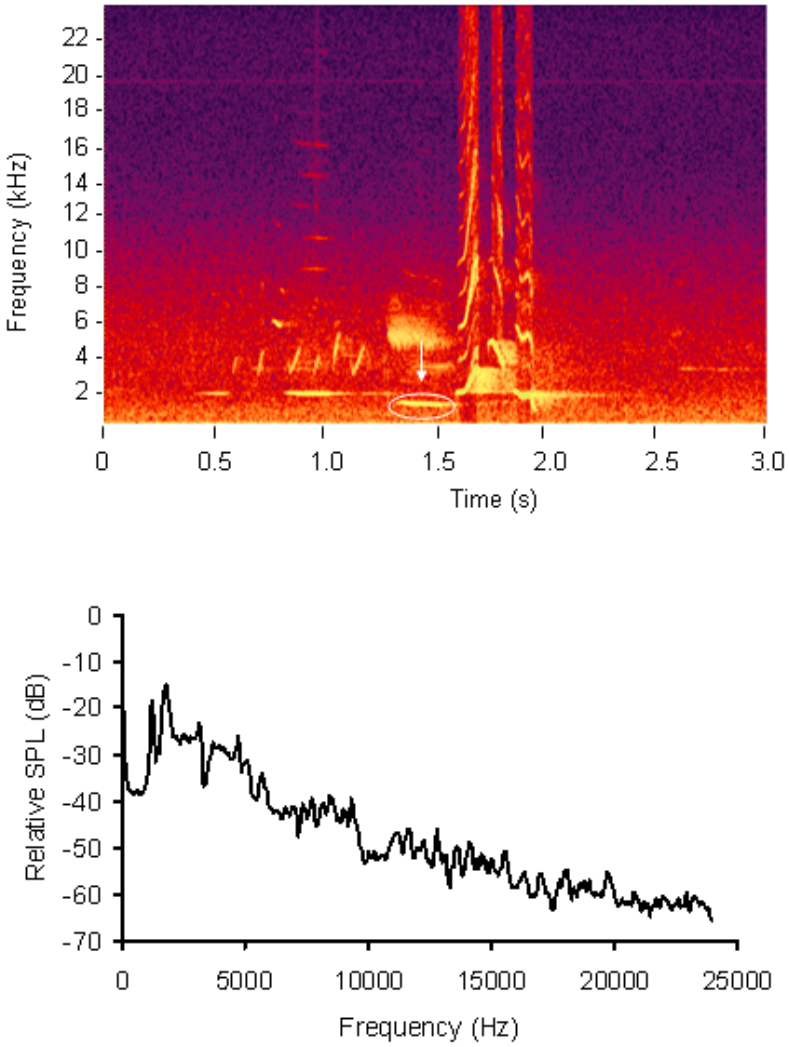
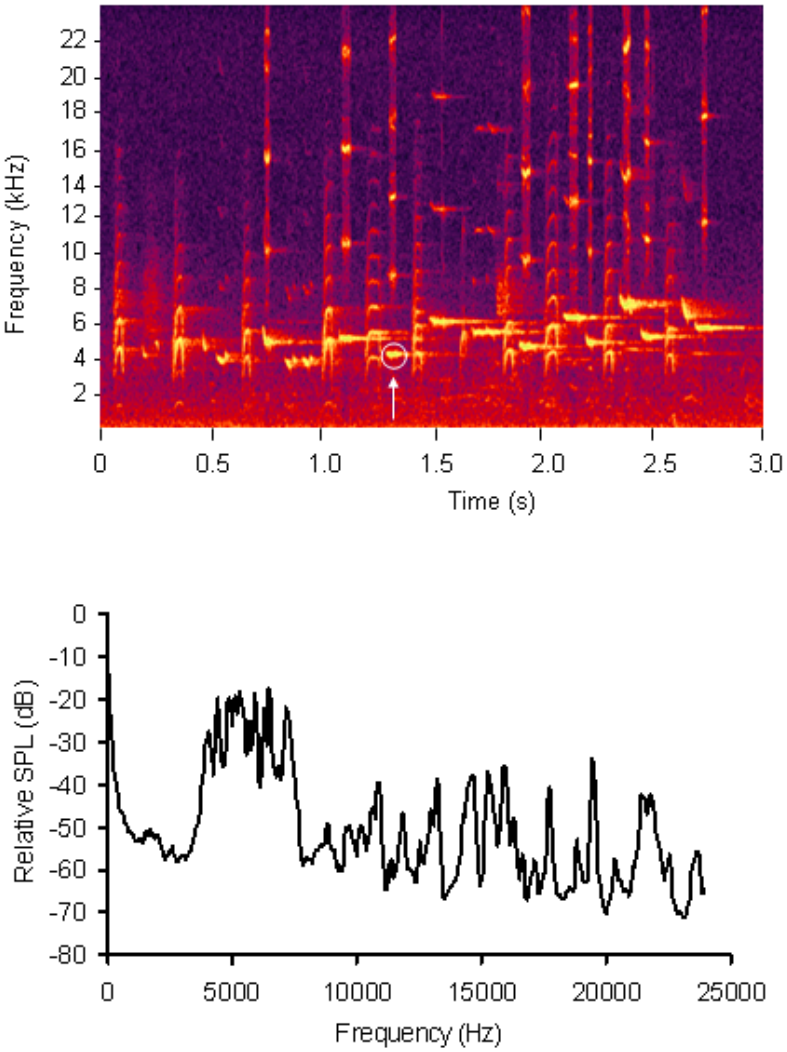


Fig. 2. Sonogram and power spectrum of a song of the Grey Fantail (*Rhipidura fuliginosa*), produced using Adobe Audition 2.0. The lowest tonal note is indicated with a circle and an arrow.



Study sites

We identified 58 study sites in narrow strips of roadside vegetation on the Mornington Peninsula using aerial photographs and a digital map of roads with the GIS program ArcView 3.2. The roads ranged in size from narrow, unsealed roads carrying fewer than 25 vehicles/d, to multilane freeways carrying 32,000 vehicles/d. The roadside vegetation at a given site was one of three types; shrubby *Eucalyptus* woodland (40 sites), grassy *Eucalyptus* woodland (7 sites), or coastal shrubland (11 sites). At the woodland sites, *Eucalyptus obliqua, E. radiata,* and *E. viminalis pryoriana* were the most common species in the overstory, with occasional intrusions of the exotic pine *Pinus radiata*. The midstory, when present, was typically composed of *Acacia* spp., *Leptospermum* spp., and/or *Melaleuca* spp., whereas the understory contained bracken *Pteridium esculentum* and a variety of native and exotic grasses and herbs. The coastal shrubland sites were dominated by *Leptospermum* spp. and/or *Melaleuca* spp., with *Acacia* spp. often present. The roadside strips of vegetation were 10–50 m wide, and occurred on one or both sides of the road. In addition, some dual carriageways had vegetation planted on the median strip. Each study site was 100 m long, parallel to the road, and included vegetation on each side of the road and the median strip, when present, up to a total width of 80 m (average = 42 m). The landscape context of the sites was either cleared agricultural land (rural), low-density residential development (suburban), or a combination of the two (rural-suburban fringe). The sites were located at least 1 km apart and at least 250 m from the nearest large patch of native vegetation. Data on the vegetation type and the width of the vegetation at each site, the landscape context of each site, and the distance to the nearest large patch of native vegetation were collated to assess the correlation between these variables and the traffic volume or level of traffic noise at a site. We did this to ensure that any observed relationships between the probability of detecting our target species and traffic noise and traffic volume were not confounded with other habitat differences between sites.

Field sampling

One researcher visited each site to survey for and record the songs of the target bird species during spring and summer (October 2005–February 2006 and September–October 2006). Birds were detected visually and by their song. Sites were visited more than once if a satisfactory recording was not obtained during the earlier visit(s), i.e., example, if there were unfavorable recording conditions, or if one of the target species was present but not singing. Four sites were visited for the first time rather late in the breeding season (December–February) when we suspected that singing activity had declined. These sites were visited again during the peak of the breeding season in October 2006. Recordings were made using a Marantz PMD670 portable solid-state digital recorder (Longford, UK) and a Sennheiser MKH 815T shotgun microphone (Wennebostel, Germany) with a basket windshield to reduce wind noise. The recordings had a sampling frequency of 48 kHz, and were made on dry, still days. When the target bird species were detected during a visit to a site, the researcher took up to six recordings of 1–5 minutes in length, depending upon the singing activity of the birds. All individuals singing at a site were recorded, whenever possible.

Estimation of traffic volume and traffic noise

Data on daily traffic volume and the percentage of heavy vehicles on a road were provided by local councils and the state road authority, VicRoads. In most cases, these data were in the form of exact numbers (e.g., 3500 vehicles/d). However, data for traffic volumes on some of the smaller, unsealed roads were only available in the categories < 200 or 200–399 vehicles/d (Mornington Peninsula Shire 2006). For the purposes of our analysis, we converted these figures to 100 and 300 vehicles/d, respectively. For roads on which no traffic volume data were available, we used the median value for roads of that class on the Mornington Peninsula: 100 vehicles/d for local roads, 4000 vehicles/d for collector roads and secondary roads, and 7800 vehicles/d for main roads with a single carriageway. Six study sites were located on roads with estimated traffic volume data.

We estimated the level of traffic noise at each site using the calculation of road traffic noise (CoRTN) model (Department of Transport Welsh Office 1988). This model expresses noise levels as L_{10} 18 h dB(A) SPL, which is the 90th percentile of the distribution of traffic noise experienced in the 18 h from 0600 until 2400 h. Thus, it estimates the level of traffic noise experienced by the birds throughout the day, using data on daily traffic volume, traffic speed, and percentage of heavy vehicles. We

calculated the noise levels at each study site and along other nearby roads corrected for traffic speed, proportion of heavy vehicles, and distance. We then combined these values to give a single noise level for each site. We assumed that the gradient of all roads was 0%, that traffic speeds were constant, and that the sources and reception points were at the same height. Following the CoRTN protocol, only roads with a traffic volume ≥ 50 vehicles/h were included in the calculation (Department of Transport Welsh Office 1988). The estimated traffic-noise levels at the study sites ranged from 31 to 75 L_{10} 18 h dB(A) SPL. The CoRTN model estimates noise levels based on the hearing range, or audibility curve of humans, which is similar to the average audibility curve observed for birds (Dooling 2004).

Analysis of songs

We analyzed the recordings of the Grey Shrike-thrush and the Grey Fantail with Adobe Audition 2.0 to determine the dominant frequency of the lowest tonal note of each song, using a Blackman-Harris window and a fast Fourier transformation (FFT) length of 1024. The dominant frequency of a note is the frequency containing the greatest amount of acoustical energy. The songs of the Grey Shrike-thrush and Grey Fantail are complex and variable, containing tones, whistles, cheeps, and trills (Figs. 1 and 2). We selected the lowest tonal note, i.e., the lowest note with a consistent, narrow-band frequency, as the unit of analysis because tonal notes give a clear frequency signal, and because we expected the lowest notes of a song to suffer the greatest masking by the low-frequency traffic noise. The lowest tonal notes in each song were not necessarily homologous among songs or among individuals. We included all recorded songs of the target species in the analysis.

Statistical framework

The use of conventional statistical methods in ecology is problematic for a number of reasons (Johnson 1999, Anderson et al. 2000, McCarthy 2007). The null hypothesis chosen by researchers often makes no biological sense, the Type 1 error (alpha) is set arbitrarily, and statistical power is often ignored. Furthermore, ecologists commonly misinterpret the results of statistical tests, equating statistical significance with biological significance, and/or considering the absence of a statistically significant effect as evidence of no effect (Johnson 1999, Anderson et al. 2000, Fidler et al. 2006). Presenting effect sizes with some measure of variance or precision, such as confidence intervals, is generally more informative than presenting *P* values alone, and enables the results of a study to be included in future meta-analyses (Anderson et al. 2000, Fidler et al. 2006). We used a Bayesian framework for our statistical analyses, with an emphasis on effect sizes and precision. In Bayesian statistics, estimates of parameters are described by posterior density functions or probability distributions, representing the uncertainty in the estimates. These posterior distributions are obtained by combining prior information, if it exists, with new data (McCarthy 2007). The Bayesian framework is well suited to analyzing hierarchical models that include random and fixed effects (Clark 2005), such as those used in this study.

Effect of traffic noise on the frequency of bird song

We estimated the effect of traffic noise on the dominant frequency of the lowest tonal note of each species' song using hierarchical, Bayesian multiple linear regression in OpenBUGS (Spiegelhalter et al. 2006, McCarthy 2007). The regression models included flat (uninformative) priors to reflect an absence of prior information, and a random site effect to account for variation in song frequency that was not explained by traffic noise. Using uninformative priors gives results that are numerically similar to those based on maximum likelihood estimation. The models also accounted for dependence between the songs recorded at a survey site, treating each song as a random sample of all possible songs at a site. We calculated the mean and standard deviation of the posterior distributions of the model coefficients, along with the 2.5th and 97.5th percentiles. This interval represented a 95% Bayesian confidence interval (95% credible interval). The standard deviation of the posterior distribution of an estimated parameter is the Bayesian equivalent of a standard error. We centered the explanatory variables (centered value = the variable - its mean) to help reduce autocorrelation between successive samples obtained from the Markov chain Monte Carlo (MCMC) algorithm in OpenBUGS. To ensure that the models were sampling from the stationary distribution, we discarded the first 100,000 samples

as a burn-in before taking 500,000 samples from the posterior distribution to estimate parameters. We checked stationarity by examining the history of samples obtained from OpenBUGS, and by running models with alternative initial values for the Markov chain.

Effects of traffic noise and traffic volume on the probability of detection

Across all 58 sites, we estimated the probability of detecting the Grey Shrike-thrush and Grey Fantail on a visit to a study site as a function of traffic noise and the daily volume of traffic on the road at a site using hierarchical, Bayesian logistic regression in OpenBUGS. As the values for traffic volume ranged over several orders of magnitude, we log-transformed these data before including them in the regression models. Even though multiple roads contributed to the level of traffic noise experienced by the birds at many of the sites, traffic noise and the traffic volume on the road at the site were correlated ($r^2 = 0.72$). Consequently, we modeled their effects separately, and then assessed which model fitted the data best using the deviance information criterion (DIC; Spiegelhalter et al. 2002) and the area under the receiver-operating characteristic curve (AUC; Hanley and McNeil 1982, Wintle et al. 2005). We also managed to separate the effects of traffic noise and traffic volume by modeling the probability of detecting our two target species as a function of traffic noise at the 19 sites with a traffic volume of < 200 vehicles/d. The level of traffic noise at these sites was dominated by the noise from the nearest busy road, and ranged from an estimated 31 to 56 L_{10} 18 h dB (A) SPL. This enabled us to assess the impact of traffic noise while holding traffic volume at a low level.

DIC values reflect a trade-off between the fit of a model and its complexity, with smaller values indicating a better model. DIC values can be interpreted in a similar way to Akaike's information criterion (AIC) values (Burnham and Anderson 2002, Spiegelhalter et al. 2002). When comparing models, a difference of < 2 between their DIC values indicates that they are largely indistinguishable. A difference ≥ 3 indicates that the model with the smaller DIC value is probably superior. The AUC evaluates how well a model discriminates between sites at which a species was detected and those at which it was not, and therefore measures its predictive discrimination (Pearce and Ferrier 2000). The AUC ranges in value from 0 to 1. A score of 1 corresponds to perfect discrimination, and a score of 0.5 indicates that the predictive discrimination of the model is no better than random (Bambar 1975). We calculated the DIC value and AUC for each model of the probability of detecting the Grey Shrike-thrush and Grey Fantail across all 58 sites in OpenBUGS.

Our logistic regression models included flat priors to reflect an absence of prior information, and a random site effect to account for variation in the probability of detecting the birds at a site that was not explained by traffic noise or traffic volume. That is, variation in the probability of detection related to characteristics of the habitat at a site, or weather conditions during a visit, was accounted for as long as these variables were not systematically correlated with traffic noise or traffic volume. This approach of minimizing the number of explanatory variables in a model and including a random site effect simplifies model interpretation and comparison (Burnham and Anderson 2002). As for the linear regression models described above, we calculated the mean and standard deviation of the posterior distributions of the model coefficients, along with the 2.5th and 97.5th percentiles. We centered the explanatory variables to help reduce autocorrelation between the successive samples obtained from the MCMC algorithm in OpenBUGS. To ensure that the models had attained the stationary distribution, we discarded the first 20,000 samples as a burn-in before taking 200,000 samples from the posterior distribution. Stationarity was checked by examining the history of samples obtained from OpenBUGS, and running models with alternative initial values for the Markov chain.

RESULTS

Effect of traffic noise on the frequency of bird song

During a total of 79 visits to 58 study sites, we detected the Grey Shrike-thrush at 27 sites and the Grey Fantail at 22 sites. We recorded 310 songs of the Grey Shrike-thrush and 116 songs of the Grey Fantail for acoustical analysis. Regression modeling indicated that the Grey Shrike-thrush sang at a higher frequency in traffic noise. The predicted increase in the dominant frequency of the lowest tonal note of a song was 5.8 Hz/dB of traffic noise

(95% CI: -2.5, -14.5; Table 1; Fig. 3A). This represents an increase of 209 Hz or 14.2% over the range of the data, and a proportional increase of 0.39%/dB of traffic noise. In contrast, there was little evidence of an increase in the frequency of the Grey Fantail song with increasing traffic noise, and the effect was predicted to be small. Regression modeling predicted an increase of 0.27 Hz/dB of traffic noise (95% CI: -8.1, - 8.5; Table 1; Fig. 3B). This corresponds to an increase of 11 Hz or 0.25% over the range of traffic noise levels observed, and a proportional frequency shift of 0.006%/dB of traffic noise. However, the credible intervals around the mean effect were very wide (Fig. 3B), indicating a lack of precision in the data that could be improved with a larger sample size.

Effects of traffic noise and traffic volume on the probability of detection

The probability of detecting both the Grey Shrike-thrush and the Grey Fantail on a visit to a site decreased with increasing traffic noise and increasing traffic volume. The louder the traffic noise or the greater the number of passing vehicles, the less likely we were to find the target bird species (Tables 2 and 3; Figs. 4 and 5). Across all 58 study sites, the predicted probability of detecting the Grey Shrike-thrush on a visit to a site ranged from 0.86 (95% CI: 0.61, 1.0) at the quietest site to 0.10 (95% CI: 0.00, 0.28) at the noisiest site (Table 2, Model 1; Fig. 4A). This represents a decrease in the probability of detection (effect size) of 0.76 between the quietest and noisiest sites. The predicted probability of detecting the species ranged from 0.63 (95% CI: 0.23, 0.93) at the sites with the fewest passing vehicles to 0.13 (95% CI: 0, 0.43) at the site with the most vehicles (Table 2, Model 2; Fig. 4B), with an effect size of 0.50. The noisiest site at which we detected the Grey Shrike-thrush had an estimated traffic-noise level of 67 L_{10} 18 h dB(A) SPL. The road at this site carried an estimated 4000 vehicles/d, the highest traffic volume at any site at which the Grey Shrike-thrush was detected. The wide credible intervals around the mean effects (Fig. 4) indicate a lack of precision, which could be improved with a larger sample size. The DIC values for the two models differed by > 3 units, indicating that the traffic–noise model was probably superior to the traffic-volume model (Table 2). The AUC of the traffic-noise model was also superior to that of the traffic-volume model, indicating that the former had better discriminatory power (Table 2). Thus, all three lines of evidence (effect sizes, DIC values, and AUC values) support traffic noise as a more important influence than traffic volume on the probability of detecting the Grey Shrike-thrush in roadside habitats. Furthermore, when we restricted our analysis to the 19 sites with a traffic volume of < 200 vehicles/d, the results were consistent with those of the model that included all 58 sites; the relationship predicted in Model 3 fell within the credible intervals of Model 1. This indicated that when the traffic volume at a site was held constant at a low level, there was still an important negative effect of traffic noise on the probability of detection (Table 2, Model 3).

The two models of the Grey Fantail across all 58 study sites yielded similar results to those of the Grey Shrike-thrush. The predicted probability of detecting the Grey Fantail on a visit to a site ranged from 0.71 (95% CI: 0.43, 0.94) at the quietest site to 0.10 (95% CI: 0, 0.27) at the noisiest site (Table 3, Model 1; Fig. 5A). The probability of detecting the Grey Fantail ranged from 0.52 (95% CI: 0.25, 0.76) at the sites with the fewest passing vehicles to 0.11 (95% CI: 0, 0.32) at the site with the most vehicles (Table 3, Model 2; Fig. 5B). The effect sizes for the two models were therefore 0.61 and 0.41, respectively. The noisiest site at which the Grey Fantail was detected had an estimated traffic-noise level of 72.3 L_{10} 18 h dB(A) SPL, and the road at this site carried 13,700 vehicles/d. Again, wide credible intervals indicate a lack of precision in our data. The DIC values for the two models differed by > 3 units, indicating that the traffic-noise model was probably superior to the traffic-volume model (Table 3). The AUC of the traffic-noise model was also superior to that of the traffic-volume model. As for the Grey Shrike-thrush, all three lines of evidence support traffic noise as the more important variable influencing the probability of detecting the Grey Fantail in roadside habitats. Furthermore, the probability of detecting the Grey Fantail as a function of traffic noise at the 19 sites with a traffic volume of < 200 vehicles/d was consistent with that predicted by the analysis that included all 58 sites (Table 3, Models 1 and 3).

Neither the type of vegetation at a site, the width of vegetation at a site, nor the distance to the nearest large patch of remnant vegetation showed an important correlation with traffic volume or the level of traffic noise at a site (r = -0.22, 0.07). However, there was a moderate correlation between

Table 1. Coefficients (mean, SD, and 2.5th and 97.5th percentiles) of the variables included in the models of song frequency (dominant frequency of the lowest tonal note) as a function of traffic noise.

	Colluricincla harmonica				*Rhipidura fuliginosa*			
Variable	**Mean**	**SD**	**2.5%**	**97.5%**	**Mean**	**SD**	**2.5%**	**97.5%**
Constant	1583	52	1480	1687	4352	53	4248	4456
Traffic noise	5.81	4.31	-2.52	14.5	0.265	4.20	-8.07	8.53

traffic noise and landscape context (Spearman's $\rho = 0.53$) and between traffic volume and landscape context (Spearman's $\rho = 0.56$), because all three suburban sites were located on busy, noisy roads. To ensure that landscape context was not influencing the predicted relationships between the probability of detection of the target species and traffic noise or traffic volume, we re-ran our models, excluding the three suburban sites. These models were qualitatively identical to those that included all 58 sites, indicating that landscape context did not explain the decline in the probability of detection with increasing traffic noise or traffic volume.

DISCUSSION

Effect of traffic noise on song frequency

At sites at which the Grey Shrike-thrush occurred, the species sang at a higher acoustic frequency with increasing traffic noise. The predicted increase of approximately 200 Hz in the dominant frequency of its song between the quietest and noisiest sites would be clearly detectable by conspecific birds. This frequency shift would serve to increase the active space of an individual's song in traffic-noisy conditions, but is unlikely to fully compensate for the acoustic interference experienced. Thus, birds singing at a higher frequency in traffic noise would still achieve a smaller active space than birds singing at the baseline frequency in quiet conditions. Furthermore, the frequency shift observed for the Grey Shrike-thrush could reduce a bird's attractiveness to potential mates, as hypothesized for Great Tits *Parus major* (Slabbekoorn and Ripmeester 2008). However, preferences for low-frequency song, as a potential indicator of larger body size or overall condition, have not been investigated in the Grey Shrike-thrush. The impact of a frequency shift in traffic noise on the ability to attract a mate, maintain a pair bond, and successfully fledge young in roadside habitats is an important avenue for further research.

Detailed studies of song frequency within individuals over time would address the question whether the observed frequency shift is a short-term, plastic response to noise or a more consistent phenomenon such as a dialectical change in noisy areas. Songbirds learn their songs from parents and neighbors, and some species can incorporate new songs into their repertoire throughout their lives (Hultsch and Todt 2004). Low-frequency components of songs will be more difficult to detect in noisy roadside habitats, and may not be learned by other neighboring birds (Slabbekoorn and Peet 2003, Brumm 2006). This could lead to the relatively rapid development of dialects with improved detectability in noise among populations occupying noisy roadside habitats (Slabbekoorn and den Boer-Visser 2006). A dialectical change may be more likely to occur at sites with constant, high levels of traffic noise such as those adjacent to freeways or in the center of cities.

In contrast to the frequency shift observed in the Grey Shrike-thrush, there was little evidence that the frequency of Grey Fantail song changed with increasing levels of traffic noise. This supports the hypothesis that birds with low-frequency signals will show a larger frequency shift in traffic noise than birds with higher frequency signals, because the former will experience greater acoustic interference from the low-frequency noise (Egan and Hake 1950, Warren et al. 2006). All bird species

Fig. 3. The effect of traffic noise on the frequency of bird song (dominant frequency of the lowest tonal note). (A) Song of the Grey Shrike-thrush (n = 27); (B) song of the Grey Fantail (n = 22). Solid lines show the predicted relationships, dashed lines the 95% credible intervals, and circles the mean song frequency observed at each site.

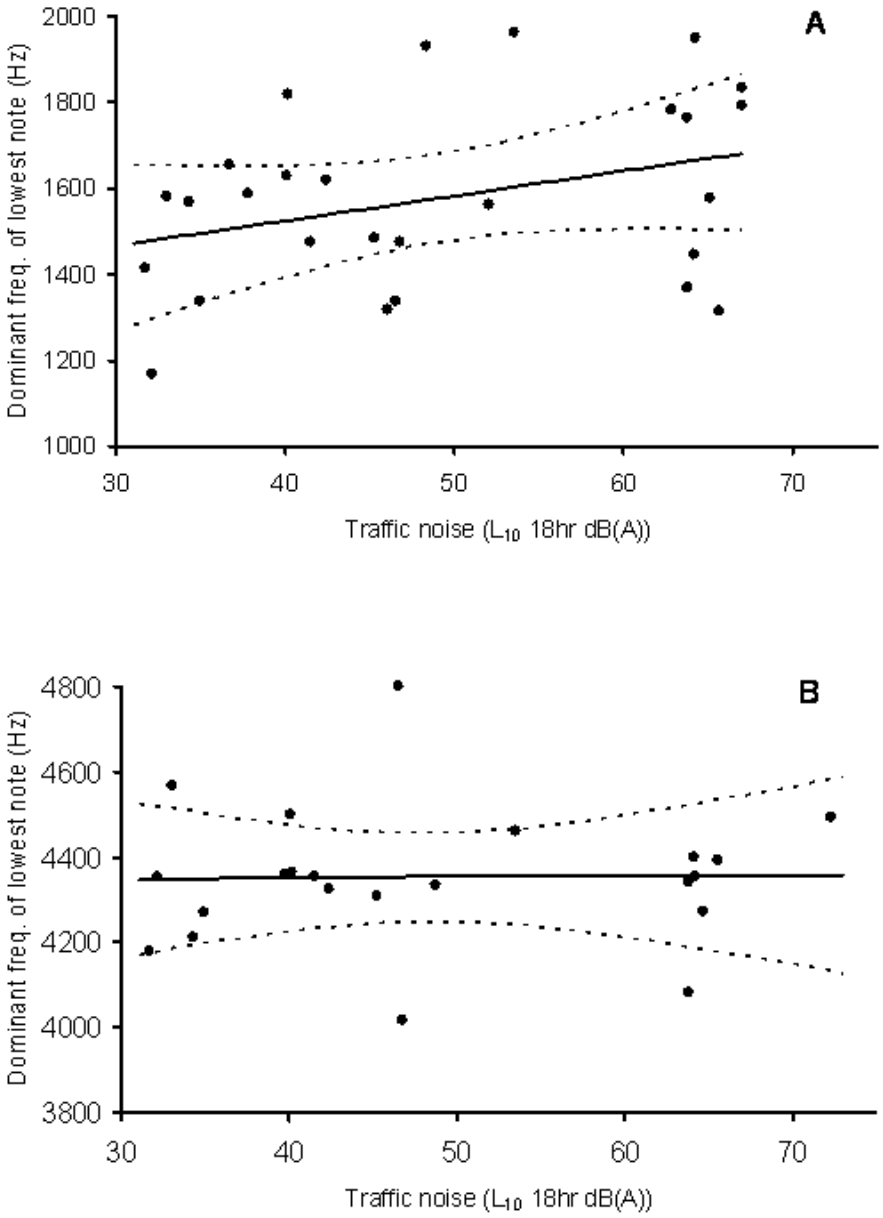


Table 2. Coefficients (Mean, SD, and 2.5th and 97.5th percentiles) of the variables included in the models of the probability of detecting the Grey Shrike-thrush on a visit to a site, as a function of traffic noise (Models 1 and 3) and traffic volume (Model 2), with the deviance information criterion (DIC) and receiver-operating characteristic curve (AUC) values for models 1 and 2. Models 1 and 2 include data from all 58 study sites, whereas Model 3 includes data from the 19 study sites in which traffic volume was < 200 vehicles/d.

	Variable	Mean	SD	2.5%	97.5%	DIC	AUC
Model 1	Constant	-0.609	0.710	-2.19	0.258	102.7	0.76
	Traffic noise	-0.114	0.066	-0.28	-0.041		
Model 2	Constant	-0.743	0.851	-2.87	0.335	106.6	0.64
	Traffic volume	-1.340	1.030	-3.99	-0.024		
Model 3	Constant	-0.116	0.428	-0.87	0.819		
	Traffic noise	-0.122	0.063	-0.26	-0.007		

previously observed singing at a higher frequency in urban noise have songs in the frequency range below 3500 Hz (Slabbekoorn and Peet 2003, Fernández-Juricic et al. 2005, Slabbekoorn and den Boer-Visser 2006, Wood and Yezerinac 2006). In contrast, Grey Fantail song predominantly occupies the frequency band between 4000 and 7500 Hz, with the dominant frequency of the lowest tonal note around 4300–4400 Hz.

Although acoustical energy in the spectral band of a signal makes the greatest contribution to masking, high-frequency signals can still suffer acoustic interference from low-frequency noise (Egan and Hake 1950), a phenomenon known as the upward spread of masking. Traffic noise masked the contact calls of the budgerigar, canary, and Zebra Finch, each with a dominant frequency around 3000 Hz during a controlled laboratory experiment (Lohr et al. 2003). Masking noise with the spectral distribution of traffic noise substantially reduced the distance over which the calls could be detected by conspecific birds. Signals higher than 4000 Hz may not experience important levels of acoustic interference from traffic noise; however, data on additional species are required to evaluate this further.

Traffic noise, traffic volume, and the probability of detection

Our results show clearly that both the Grey Shrike-thrush and Grey Fantail were more likely to be detected on a visit to a site in quieter roadside habitats, although this effect was more pronounced for the Grey Shrike-thrush. As traffic-noise levels approached 60 L_{10} 18 h dB(A) SPL, the probability of encountering the target bird species on a visit to a site fell below 0.3 (Figs. 4 and 5). We did not detect *C. harmonica* at the 11 noisiest sites, at which traffic noise levels exceeded 67 L_{10} 18 h dB(A) SPL, and did not detect the Grey Fantail at the 8 noisiest sites (> 72.3 L_{10} 18 h dB(A) SPL). This finding is consistent with the hypothesis of Rheindt (2003) that birds with low-frequency signals will show a greater decline in abundance than those with high-frequency signals in habitats affected by traffic noise. Although we only have information on the probability of detecting each species on a visit to a site, rather than its actual presence or abundance, this probability is correlated with it presence and abundance. When a species occurs consistently at a high density, the probability of detection on a given visit will be high; when density is low and/or a site is only occupied sporadically, the probability of detection will be lower. Further surveys are required to determine, with confidence, the presence or

Table 3. Coefficients (Mean, SD, and 2.5th and 97.5th percentiles) of the variables included in the models of the probability of detecting the Grey Fantail on a visit to a site, as a function of traffic noise (Models 1 and 3) and traffic volume (Model 2), with the deviance information criterion (DIC) and receiver-operating characteristic curve (AUC) values for models 1 and 2. Models 1 and 2 include data from all 58 study sites, whereas Model 3 includes data from the 19 study sites in which traffic volume was < 200 vehicles/d.

	Variable	Mean	SD	2.5%	97.5%	DIC	AUC
Model 1	Constant	-0.971	0.536	-2.29	-0.209	102.3	0.72
	Traffic noise	-0.082	0.038	-0.18	-0.026		
Model 2	Constant	-0.952	0.546	-2.30	-0.171	106.1	0.66
	Traffic volume	-1.050	0.573	-2.40	-0.155		
Model 3	Constant	-0.066	0.472	-1.00	0.846		
	Traffic noise	-0.208	0.082	-0.39	-0.068		

absence of the target bird species at the study sites, and to quantify their density and breeding activity.

We were more likely to detect both the Grey Shrike-thrush and Grey Fantail at roadside sites that had fewer passing vehicles. We did not observe the two species at sites at which traffic volumes exceeded 4000 and 13,700/d, respectively. However, traffic noise had a greater effect than traffic volume on the probability of detecting each species because the probability of detection declined more with traffic noise than with traffic volume. Furthermore, the predictive discrimination of the two traffic-noise models was superior to that of the traffic-volume models as indicated by their AUC values, and DIC values also favored the traffic-noise models as superior to the traffic-volume models. Our analysis at the 19 sites with fewer than 200 passing vehicles/d demonstrated that the effect of traffic noise on the probability of detection remained strong when traffic volume was held constant. Thus, a variety of evidence supports traffic noise as having a more important effect than traffic volume on habitat suitability for the Grey Shrike-thrush and Grey Fantail.

There are a number of possible explanations for the observed results. First, traffic noise could be the real factor limiting populations of the Grey Shrike-thrush and Grey Fantail in roadside habitats, and the observed decline in the probability of detection with increasing traffic volume might be spurious, i.e., an observation attributable to the high correlation between traffic volume and traffic noise. Alternatively, both traffic noise and traffic volume might reduce habitat suitability and affect the persistence of populations of the Grey Shrike-thrush and Grey Fantail in roadside habitats. The probability of a fatal collision between a bird and a passing vehicle is likely to increase with traffic volume (Oxley et al. 1974, Clevenger et al. 2003), thereby reducing survival rates of adults and/or juveniles in roadside habitats. If this reduction were sufficiently large and not offset by immigration, it could lead to local extinction. Mumme et al. (2000) investigated the population-level response of Florida Scrub Jays (*Aphelocoma coerulescens*) to an adjacent two-lane highway with a traffic volume of 500 vehicles/d. They concluded that roadside habitats were acting as a population sink in which deaths of breeding birds from road-kill outweighed the number of fledglings that survived to adulthood. A mathematical model developed by Jaeger et al. (2005) also supported traffic volume as an important determinant of the persistence of wildlife populations in habitats near roads.

Passing vehicles reflect sunlight by day and flash headlights at night (Goosem 2007); their movement may disturb birds, lower rates of occupancy, and/or

Fig. 4. Predicted probability of detecting the Grey Shrike-thrush on a visit to a site as a function of (A) traffic noise and (B) traffic volume, across all 58 sites. Solid lines show the predicted relationships and dashed lines indicate the 95% credible intervals.

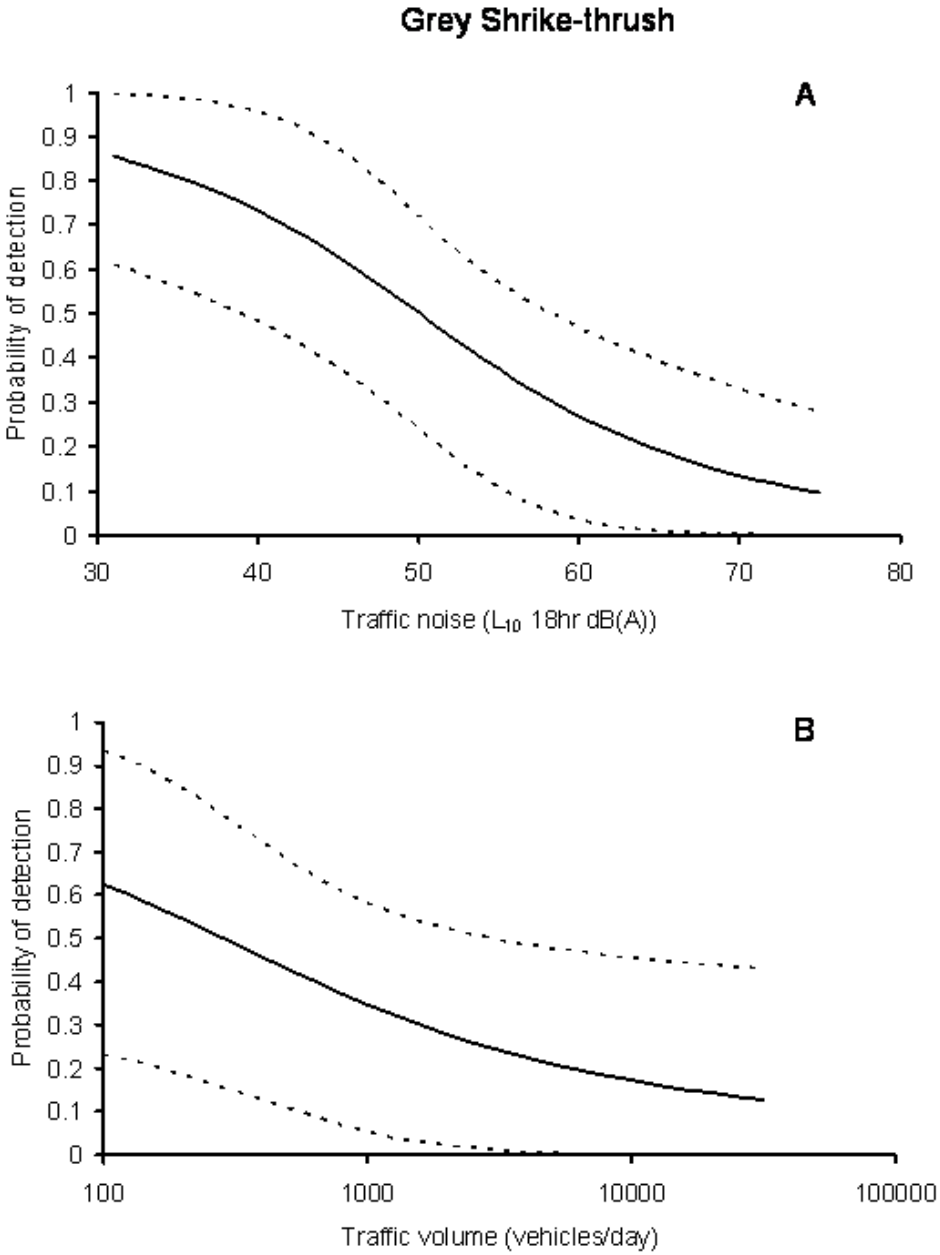
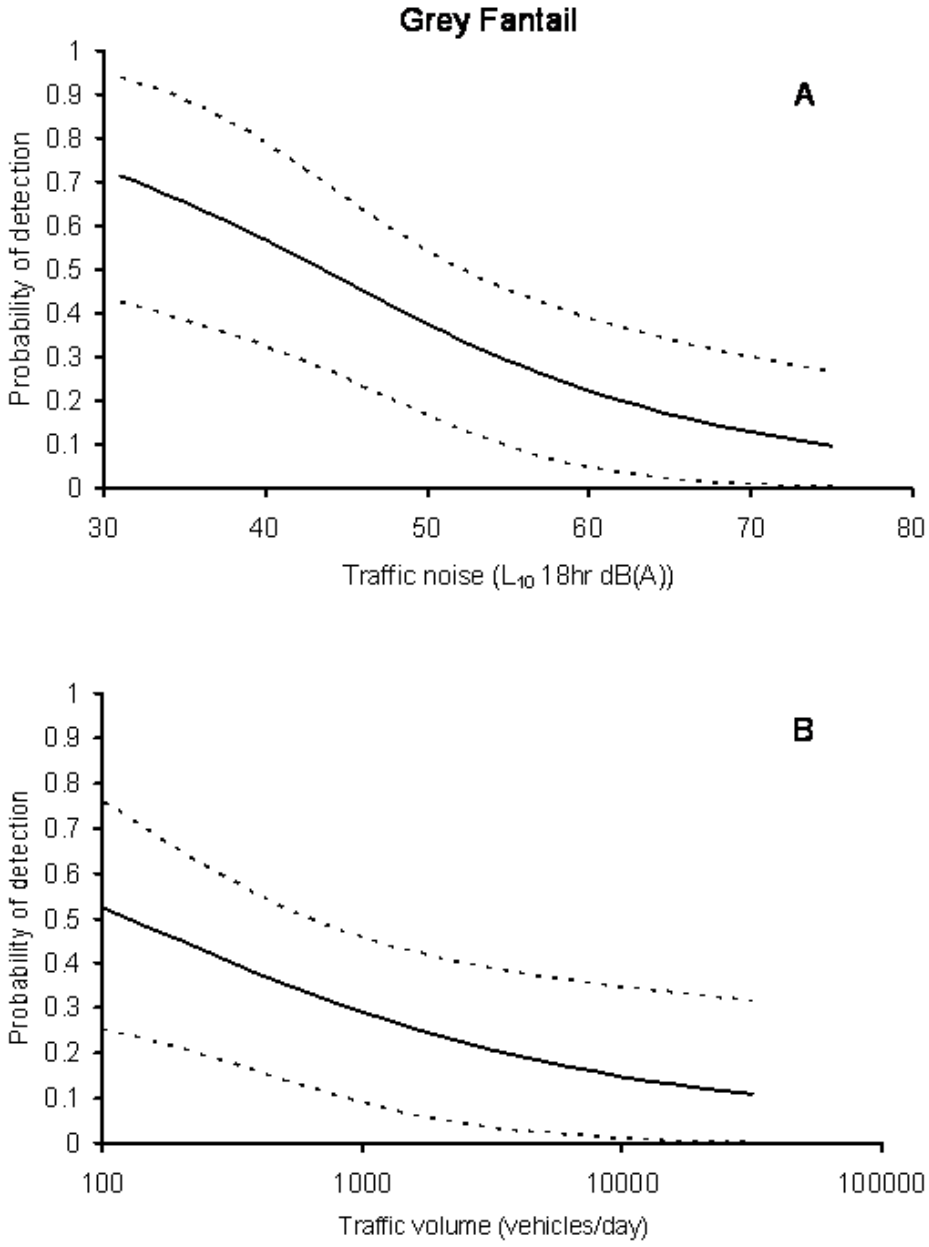


Fig. 5. Predicted probability of detecting the grey fantail on a visit to a site as a function of (A) traffic noise and (B) traffic volume, across all 58 sites. The solid lines show the predicted relationships and dashed lines the 95% credible intervals.



reduce breeding success at busy sites with high traffic volumes. However, it is difficult to separate the biological effect of visual disturbance from passing cars and the effect of disturbance by traffic noise, and only one other study has attempted to do so. Reijnen et al. (1995) assessed the effect of each variable while controlling for the other. They found that traffic noise reduced the density of more species of birds in woodlands than did the visibility of passing cars. Disturbance by pedestrians is known to interrupt activities such as foraging, nest building, and chick feeding in woodland and heathland birds, leading to reduced breeding success (e.g., Fernández-Juricic 2000, Murison et al. 2007), whereas disturbance by vehicles can reduce the breeding success of ground-nesting birds in open coastal habitats (e.g., McGowan and Simons 2006). However, the way in which birds of roadside habitats respond to disturbance by vehicles is uncertain.

A third explanation for our results is that traffic noise may have reduced the probability of detecting the Grey Shrike-thrush and Grey Fantail, not because the birds were less likely to be present at noisy sites, but because high levels of noise might have interfered with our ability to detect them when they were in fact present. However, this is unlikely given the narrowness of the roadside strips of vegetation and the active nature of the target bird species. And finally, sites with high noise levels, high traffic volumes, or both might have other characteristics that make them less suitable habitat for the target species. We found no important correlations between the habitat characteristics at a site and traffic-noise level or traffic volume, and accounted for the moderate correlations between landscape context and traffic noise and volume. Consequently, we think it unlikely that the decreasing probability of encountering the target bird species with increasing noise and traffic volume could be explained by differences in the habitat among sites.

Impact of traffic noise on bird populations

Traffic noise could affect bird populations in a number of ways. Acoustic interference from noise could hamper the detection of song by conspecifics, making it more difficult for birds to establish and maintain territories, attract mates, and/or maintain pair bonds (Reijnen and Foppen 1994, Habib et al. 2007, Swaddle and Page 2007). This, in turn, may reduce breeding success in noisy roadside habitats. When begging for food, nestlings may need to call louder to elicit the desired response from their parents (Leonard and Horn 2005), thereby increasing the energetic cost of obtaining food and potentially decreasing fitness. High levels of traffic noise may also interfere with the detection of alarm calls such as those signaling the presence of predators, which could lead to higher rates of predation. There is evidence from studies in the northern hemisphere that traffic noise reduces the density of bird populations (Reijnen et al. 1995, 1996, Forman et al. 2002), but more research is needed to establish the generality of these patterns. These studies have inferred effects of traffic noise on bird populations from increases in the occurrence and/or density of birds with increasing distance from roads (Reijnen et al. 1995, 1996, Forman et al. 2002). However, such changes could be partially a result of other differences between roadside and road-distant habitats. Ours is the first study to investigate the effect of traffic noise on the occurrence of birds by locating all study sites next to roads; thus, holding distance from the road constant and reducing potentially confounding habitat differences between quiet and noisy sites. Therefore, it is an important addition to the literature on the responses of birds to traffic noise.

The results of our study present an interesting scenario for the Grey Shrike-thrush and Grey Fantail in roadside habitats on the Mornington Peninsula. As the traffic noise and traffic volume at a site increase, the chance of detecting the Grey Shrike-thrush declines substantially. However, the species can persist at roadside sites with traffic-noise levels up to 67 L_{10} 18 h dB(A) SPL and traffic volumes up to 4000/d, partly by increasing the frequency of its song to reduce acoustic interference. The higher singing Grey Fantail can persist at roadside sites with higher traffic-noise levels and higher traffic volumes than the Grey Shrike-thrush, and does not appear to change the frequency of its song with traffic noise. But, it too is excluded from roadside habitats with the highest levels of traffic noise and the greatest number of passing vehicles. Instead of, or in addition to, singing at a higher frequency, birds could reduce acoustic interference from traffic noise by singing at a higher amplitude (Brumm 2004), or by singing outside peak-traffic periods (Fuller et al. 2007). We did not measure song amplitude or assess temporal song patterns in our study, so cannot comment on whether the target species are using these strategies. Singing at a higher amplitude could have an

energetic cost (Oberweger and Goller 2001), and may alert potential predators to the location of the singer. Songbirds probably use a combination of approaches to reduce acoustic interference in traffic-noisy habitats.

CONCLUSION

A range of evidence supports an important effect of traffic noise on birds in roadside habitats on the Mornington Peninsula, and there is also some evidence supporting an effect of traffic volume. The lower singing Grey Shrike-thrush sings at a higher frequency in traffic noise, but it appears that the higher singing Grey Fantail does not. If the Grey Fantail is not changing its song in the presence of noise, but is less likely to be found at sites with high traffic noise and traffic volume, this provides support for an effect of traffic volume on population persistence. Traffic noise and traffic volume may act in synergy to exclude birds from habitats next to noisy, busy roads. It will be difficult to elucidate their effects on bird populations experimentally; thus, comparative studies such as ours are particularly useful. Additional studies of other species with low-frequency and high-frequency songs will enable a meta-analysis to separate further the effect of noise from that of traffic volume.

Roadsides provide important habitat for birds in many countries around the world. They currently support a variety of threatened species (e.g., Adam and Robinson 1996, Mumme et al. 2000, Williford et al. 2007). Such species may be more vulnerable to the combined effects of traffic noise and passing vehicles than the common and widespread Grey Shrike-thrush and Grey Fantail. If roadside habitats are otherwise suitable for threatened species, this could be an argument for protecting them from noise and/or passing vehicles. But how do we do this? Installing sound barriers in urban habitats, as suggested by Slabbekoorn and Ripmeester (2008), would create barriers to movement for a variety of terrestrial animals, contributing to landscape fragmentation and the isolation of populations (Forman and Alexander 1998, Forman et al. 2003). Sound barriers are also expensive to construct and install, and contain substantial amounts of embodied energy. Alternatives to sound barriers include more careful consideration of the impact of traffic noise on animals that communicate acoustically when new roads are being planned, reducing traffic noise by changing road surfaces or decreasing the speed of vehicles, re-routing existing roads around important habitats for threatened species, or even closing roads during certain times of the year (Slabbekoorn and Ripmeester 2008). Since 1992, the seasonal closure of a road in Tilden Park, California has reduced roadkill of migrating California newts (Hilty et al. 2006), thereby setting a precedent such a management approach. Closing key roads during the breeding season could help to protect populations of threatened bird species from traffic noise and collision with vehicles at the time of year when they are most vulnerable. However, the effectiveness of such a strategy has yet to be examined for birds.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol14/iss1/art29/responses/

Acknowledgments:

We are grateful to VicRoads, the City of Casey, the City of Frankston, and the Mornington Peninsula Shire for data on traffic volumes, and to Michael McCarthy for assistance with data analysis. We thank Andrew Bennett, Henrik Brumm, and Murray Littlejohn for discussions, and Michael McCarthy for comments on the manuscript. This research was approved by the Deakin University Animal Welfare Committee, and supported by an ARC Discovery Grant to K. M. P., the Baker Foundation, and the Applied Environmental Decision Analysis research hub. This hub is funded by the Commonwealth Environment Research Facilities (CERF) programme, an Australian Government initiative that promotes world class, public-good research.

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Appendix 1. Song of the grey shrike-thrush Colluricincla harmonica, as shown in Fig. 1. File in .wav format – will run in a variety of programs including Windows Media Player, iTunes, and Adobe Audition.

Please click here to download file 'appendix1.wav'.

Appendix 2. Song of the grey fantail Rhipidura fuliginosa, as shown in Fig. 2. File in .wav format – will run in a variety of programs including Windows Media Player, iTunes, and Adobe Audition.

Please click here to download file 'appendix2.wav'.

Economic Associations among Causes of Species Endangerment in the United States

BRIAN CZECH, PAUL R. KRAUSMAN, AND PATRICK K. DEVERS

Scientific assessment of the causes of species endangerment is essential for formulating and implementing sound conservation policy. Under the Endangered Species Act (ESA), a species is listed as threatened or endangered only upon federal examination of its status, including the reasons for its demise (Rohlf 1989). Beyond the listing process, critical habitat designation and recovery planning require federal knowledge of endangerment causes. As a result of these requirements, information on species endangerment has consistently appeared in the *Federal Register* since the ESA was passed in 1973. Researchers rely on that body of information to assess patterns of species endangerment in the United States, yet surprisingly few studies have addressed the causes of species endangerment.

For example, Dobson et al. (1997) analyzed the geographical distribution of endangered species in the United States, but the causes of endangerment were not categorized in that work. Czech and Krausman (1997), cautioning that a strictly geographic analysis might result in a focus on "hotspots" and thus lead to imprudent policy decisions, provided a preliminary quantification of the causes of species endangerment in the United States. Wilcove et al. (1998) conducted a more thorough assessment, which included 700 "imperiled" species that were not federally listed. Easter-Pilcher (1996), Foin et al. (1998), and Flather et al. (1998) assessed to various degrees the causes of species endangerment in the course of investigating related topics. Other researchers have looked at the causes of species endangerment for smaller areas or for specific taxa. Collectively, the studies have shown that habitat loss is the most prevalent cause of species endangerment, with non-native species ranking second.

Several aspects of these studies suggest areas for further investigation. First, the studies have generally considered historical as well as current threats. Although the knowledge of historical threats is useful, ascertaining current policy implications depends on the analysis of current threats. Second, none of the studies examined the association of one cause of endangerment with another (or others). These associations among causes of endangerment carry implications for public land managers and policymakers. For example, if outdoor recreation and vandalism are strongly associated as endangerment causes, environmental assessments for recreational developments should address this association. (If, say, an environmental assessment takes into account only the impact of recreational facility construction or that of the recreational activity itself—neglecting the association between the recreational activity and vandalism—the magnitude of the effect on the species will be underestimated.) Finally, none of the studies investigated the implications of the causes of species endangerment for the American economy. As pointed out in the April 2000 special issue of *BioScience* on

ASSOCIATIONS AMONG CAUSES OF SPECIES ENDANGERMENT IN THE UNITED STATES REFLECT THE INTEGRATION OF ECONOMIC SECTORS, SUPPORTING THE THEORY AND EVIDENCE THAT ECONOMIC GROWTH PROCEEDS AT THE COMPETITIVE EXCLUSION OF NONHUMAN SPECIES IN THE AGGREGATE

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Table 1. Causes of endangerment for American species classified as threatened or endangered by the US Fish and Wildlife Service.

Cause	Number of species endangered by cause, as indicated by Lowe et al. (1990), Moseley (1992), and Beacham (1994)	Estimated number of species endangered by cause, derived by extrapolation of 5% sample from *Federal Register*
Interactions with non-native species	305	340
Urbanization	275	340
Agriculture	224	260
Outdoor recreation and tourism development	186	200
Domestic livestock and ranching activities	182	140
Reservoirs and other running water diversions	161	240
Modified fire regimes and silviculture	144	80
Pollution of water, air, or soil	144	140
Mineral, gas, oil, and geothermal extraction or exploration	140	140
Industrial, institutional, and military activities	131	220
Harvest, intentional and incidental	120	220
Logging	109	80
Road presence, construction, and maintenance	94	100
Loss of genetic variability, inbreeding depression, or hybridization	92	240
Aquifer depletion, wetland draining or filling	77	40
Native species interactions, plant succession	77	160
Disease	19	20
Vandalism (destruction without harvest)	12	0

integrating ecology and economics, communicating the economic implications of ecological investigations is crucial for biodiversity conservation.

In this study, we provide a taxonomically comprehensive account of current causes of species endangerment in the United States and Puerto Rico. By subcategorizing habitat loss into components that correspond to various economic sectors, we hope to foster a better understanding of what government agencies—and the nation as a whole—need to do to conserve species. We also investigate some of the more consequential associations among causes that may have policy implications for public land managers or for economic sectors and explore some of the geographical characteristics of the causes of species endangerment.

Data considered

A World Wildlife Fund compendium by Lowe et al. (1990), Moseley (1992), and Beacham (1994) contains accounts of the 877 US (including Puerto Rican) species that were listed as threatened or endangered through August 1994. It is the only contiguous source that describes the threats to listed species and provides an efficient vehicle from which to assess the causes of species endangerment. It illustrates the many ways in which species become endangered, but the causes may be grouped into 18 categories based on similarities of economic activity or biological phenomena involved. For example, the category of agriculture encompasses the economic activities of clearing land for crop production, tilling soil, planting seed, growing crops, and harvesting. The category of genetic problems encompasses the biological phenomena of inbreeding depression, loss of genetic variability through drift, and hybridization.

To find out whether the material in the compendium, much of which derives from information in the *Federal Register*, faithfully reflects the causes of endangerment listed in the *Federal Register*, we drew a 5% ($n = 44$) sample of the 877 study species and ascertained the endangerment causes listed for those species in the *Federal Register*. We extrapolated these results and used Pearson's chi-square statistic to test the corroboration of the compendium data and the extrapolated *Federal Register* data. There is not a significant difference in the distributions of frequencies across the categories of endangerment as compiled from the compendium and extrapolated from the *Federal Register* sample ($\chi^2 = 22.08$, $P = 0.18$, 17 df). Of course, this lack of difference cannot validate the accuracy of either source in representing the causes of species endangerment, but it does suggest that the compendium is an unbiased representation of *Federal Register* data. Both sources indicate that, when the broad category of habitat loss is subcategorized, interactions with non-native species, urbanization, and agriculture are the three leading causes of endangerment (Table 1).

Species are rarely endangered by only one of the 18 causes, however. For most species, it is easier to determine multiple causes of endangerment than it is to determine the relative importance of each cause. However, by the time a species is endangered, any loss of individuals is important, rendering the relevance of "relative importance" questionable in many cases.

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We classified causes as associated in cases where multiple causes endangered the same species. Association of endangerment causes can be supportive, effective, or incidental. Supportive association occurs when one cause of endangerment depends on another. For example, logging a particular area may depend on road construction, and both activities may endanger the same species. Effective association occurs when a species is endangered by independent causes that produce the same effect. For example, aquatic species can be endangered by farming, mining, logging, and other erosive practices that cause siltation. Incidental association occurs when a species is endangered by independent causes that produce different effects. For example, agriculture may endanger a species in one portion of its range by destroying habitat, whereas disease endangers the species in another portion of its range.

To detect regional trends of endangerment, we assigned each endangered species to a state, based on the distribution maps used in the compendium. Species existing in more than one state were assigned to the state in which the species remains most numerous. If that information was unavailable, then the species was assigned to the state encompassing the estimated geographic mean of the species' distribution. Most endangered species, however, exist in only one state, and many exist in only one county (Dobson et al. 1997).

Associations of species endangerment

For each species, every pairing of one cause of endangerment with another constitutes an instance of association. For each endangerment cause, the sum of these instances of association may be called "total association." Of the 18 categories of endangerment causes, urbanization ranks highest in total association. It endangers 275 species, which are endangered also by the other 17 causes in 836 instances (Table 2). For example, urbanization endangers the Florida snail kite (*Rostrhamus sociabilis plumbeus*), but the kite is endangered also by non-native species, agriculture, groundwater depletion, and pollution (Lowe et al. 1990).

For some purposes, the proportion of associations to the number of species endangered, or the "proportional association," is a more relevant parameter than total association. Roads—their construction, presence, and maintenance—are the endangerment cause with the greatest proportional association (Table 2). The 94 species endangered by roads are also endangered by other activities in 408 instances; the proportional association is 408/94 = 4.3. The cause with the least proportional association is disease. The 19 species endangered by disease are also endangered by other activities in only 38 instances; the proportional association is 38/19 = 2.0.

Urbanization and agriculture are associated in more cases (n = 124) of endangerment than any other pair of

Table 2. Associations among species endangerment causes. Each cell indicates the percentage of species endangered by the cause specific to the column that is simultaneously endangered by the cause specific to the row. For example, 19% of the species endangered by cause 2 (urbanization) are simultaneously endangered by cause 1 (non-native species), while 17% of the species endangered by cause 1 (non-native species) are simultaneously endangered by cause 2 (urbanization). To find the cause most frequently associated with recreation, for example, look for the highest figure in column 4, not in row 4. (The cause most frequently associated with recreation is urbanization.)

Cause	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total[a]	Proportional[b]
1. Non-native spp.		19	20	25	40	30	***47*** [c]	19	13	***50***	10	18	17	***71***	31	25	***58***	33	769	2.52
2. Urbanization	17		***55***	39	37	28	41	34	40	***50***	33	37	***55***	12	36	35	16	25	836	3.04
3. Agriculture	14	***45***		22	37	***50***	31	***53***	43	41	18	43	***49***	11	***45***	18	5	25	809	3.61
4. Recreation	15	26	15		32	6	24	10	27	29	26	19	31	13	9	23	5	5	533	2.87
5. Livestock	24	24	30	32		24	40	26	31	43	18	28	34	24	12	22	11	25	699	3.84
6. Reservoirs	16	16	36	6	21		12	***59***	35	24	3	30	31	11	29	12	0	17	539	3.35
7. Modified fire	22	21	20	18	31	11		13	16	***44***	10	26	27	24	4	12	0	0	538	3.74
8. Pollution	9	18	34	8	20	***53***	13		37	29	9	33	29	10	23	16	0	8	540	3.75
9. Mining	6	20	27	20	24	30	16	36		23	18	39	37	8	6	12	0	0	509	3.64
10. Industry	22	24	24	20	31	20	40	26	21		6	19	30	14	10	3	0	17	563	4.30
11. Harvest	4	15	9	17	12	2	8	8	15	5		12	11	15	8	3	16	42	273	2.28
12. Logging	7	15	21	11	16	20	19	25	30	16	11		37	7	3	6	32	8	406	3.72
13. Roads	5	19	21	16	18	18	17	19	25	21	8	32		5	13	16	5	25	408	4.34
14. Genetics	21	4	4	6	12	6	16	6	5	10	12	6	5		17	1	5	8	295	3.21
15. Aquifers	8	10	16	4	5	14	2	13	4	6	5	2	11	14		6	0	8	211	2.74
16. Native species	6	10	6	10	9	6	6	8	6	5	6	5	13	1	6		16	33	198	2.57
17. Disease	4	1	0	1	1	0	0	0	0	0	3	6	1	1	0	4		8	38	2.00
18. Vandalism	1	1	1	3	2	1	0	1	0	2	4	1	3	1	1	5	5		41	3.42

[a]This column provides the total number of associations exhibited by the cause.
[b]This column provides proportional associations; total associations divided by the number of species endangered.
[c]Pairwise proportional associations comprising the upper five percentile are in bold and italics.

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Everglades snail kite* (Rostrhamus sociabilis plumbeus). *The Florida snail kite is endangered by multiple causes. Photo: US Fish and Wildlife Service.

causes. The species simultaneously endangered by both causes include 45% of the species endangered by urbanization and 55% of the species endangered by agriculture. This strong association—most likely a product of the drastic modification of habitat at the urban–rural interface—is supportive, in that agricultural areas tend to support urbanization for the sake of market efficiency (Cramer and Jensen 1994).

The greatest proportional pairwise association involves species endangered by genetics problems, 71% of which are endangered also by interactions with non-native species. This strong association may reflect the preponderance of Hawaiian species that are threatened by non-native species; island species may be predisposed to low heterozygosity because of the relative frequency with which island populations are exposed to population bottleneck events (MacArthur and Wilson 1967). It may also reflect the rapid development of genetics expertise and the resulting attention granted to genetic phenomena in recent years; Hawaiian species have generally been listed more recently than other species.

To further explain and explore the causes of species endangerment, to reveal other noteworthy associations of causes, and to describe prevalent geographic patterns, we discuss each of the 18 causes in decreasing order of endangerment frequency. Implications for policy and research follow.

Interactions with non-native species. When a species suddenly appears in an ecosystem (e.g., when it is introduced by humans), it can cause the rapid extinction of native species. Non-native species are typically exotics from other countries, but they include North American species that have become established in ecosystems outside the limits of their natural range or those that have rapidly become prominent in areas where they were historically rare and relatively unimportant. We did not include domesticated crops and animals in this category, but we did include feral livestock and pets.

The non-native species category is the eighth most important cause of endangerment on the mainland, where urbanization endangers over twice as many species (n = 247) as do non-native species (n = 115). However, non-native species endanger 182 species in Hawaii, almost all of which are plants (n = 156) and birds (n = 25). Most of the problem with exotic species in Hawaii involves grazing by feral pigs, goats, sheep, and cattle that originate from nearby farms and ranches, helping to explain why the association with domestic livestock grazing is stronger than any other association involving non-native species (Table 2). Other notorious exotics include rats (*Rattus* spp.), mongooses (*Herpestes* spp.), feral house cats, axis deer (*Axis axis*), mynas (*Gracula* spp.), mosquitoes (*Culex* spp.), phibiscus snow scale (*Pinnaspis strachani*), water hyacinth (*Eichhornia crassipes*), strawberry guava (*Psidium cattleyanum*), and various hymenopterids (mainly parasitic wasps and predaceous ants; Lowe et al. 1990, Moseley 1992, Beacham 1994).

Urbanization. When a minimum of 1000 people per 1.6 km^2 reside in a contiguous area with at least 50,000 people, the area is classified by the US Bureau of the Census as urban (Edmondson 1991). Urbanization endangers species by replacing habitat directly and by depleting resources needed to support urban economies. The diversity of effects on species is reflected in the aforementioned preponderance of associations with other endangerment causes. Next to agriculture, urbanization is the most ubiquitous threat, endangering 275 species in 31 states and Puerto Rico. Sixty-one species are endangered in California, 64 in Florida, and 26 in Texas—three of the most rapidly urbanizing states. In the combined area of Utah, Nevada, and Idaho, only two species are endangered by urbanization, at least in part because the majority of the Great Basin is owned by the public and unavailable for private development.

Agriculture. The most obvious ecological effect of agriculture is habitat destruction. Some species coexist with farming to a degree, but soil erosion, siltation of nearby water bodies, and modification of species assemblages are processes that eventually take their toll on many species. Incidental take can also occur, as when a farmer plows through the shallow burrow of a kangaroo rat (*Dipodomys* spp.). Agriculture has more endangerment associations than any other cause except urbanization (Table 2).

Among the regions, the Southeast has the greatest number (n = 98) of the 224 species endangered by agriculture;

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among the states, California has 43, tying with Florida for having the greatest number of species endangered by agriculture. Agriculture is also the most ubiquitous of endangerment causes, endangering species in 35 states and Puerto Rico.

Outdoor recreation and tourism development. This category includes disturbance created by hikers, hunters and fishermen, horseback riders, skiers, rock climbers, dirt bikers, 4-wheel drivers, tourists, and the construction of facilities for any of these. It represents a spectrum of human activity ranging from solitary wilderness pursuits to organized social pleasures, and it blends into the category of urbanization when the construction of tourist facilities endangers species in urbanizing areas. Also, the outskirts of urban areas tend to support high levels of recreation, and the strongest association of outdoor recreation is with urbanization (Table 2).

California hosts the greatest number (n = 32) of species endangered by recreation, followed by Hawaii (n = 26) and Florida (n = 19). In terms of ecosystems, the Mojave Desert and the Great Basin are areas of high recreation impact. Twelve species in Utah and Nevada (and several from eastern California) are endangered by recreation.

Domestic livestock and ranching activities. Livestock grazing and related ranching activities have been a cause of species endangerment since the 1800s (Carrier and Czech 1996). The strongest association of this category is with non-native species (Table 2). This association is supportive, in the sense that livestock grazing modifies plant and animal community composition. In another sense, however, this association is incidental, because many of the species endangered by grazing live in Hawaii, where non-native species are rampant for a variety of reasons unrelated to grazing.

Reservoirs and other surface water diversions. The Southeast and Southwest have the most species endangered by water diversions. Species that are geographically limited to an inundated area may be obliterated. Reservoirs and dams block movements of species that need access to other portions of a river for part of their life cycle (e.g., spawning). Reservoirs modify water temperature, depth, and other in-stream characteristics, and they often host introduced predatory species (Minckley and Douglas 1991). In addition to their association with pollution in the Southeast, reservoirs have a supportive association with agriculture in the West (Table 2).

Modified fire regimes and silvicultural practices. Modifications of fire regimes and silvicultural practices have been implicated in the endangerment of 144 species. Fire suppression is the problem in nearly all cases. A formidable array of ecological, social, and political factors have the cumulative effect of suppressing natural fire (Czech 1996). Nearly half of the species endangered by fire suppression are in Florida. Modification of a natural fire regime often changes the composition of biotic communities (Wright and Bailey 1982), suggesting that the strong association of this category with non-native species (Table 2) is largely supportive.

Pollution of water, air, or soil. Of the 144 species endangered by pollution, 85 are found in the Southeast. All except 18 of these species are fish or mussels. Most of the rest are plants, snails, and other invertebrates of aquatic or mesic environments. Pollution is most strongly associated with reservoirs (Table 2), but this association is largely incidental and reflects the fact that pollution and reservoirs are especially problematic for riverine species and that pollutants tend to accumulate in reservoirs. Mining, logging, farming, ranching, and industry are supportively associated with pollution. Urban developments are supportively and effectively associated with pollution.

Mineral, gas, oil, and geothermal extraction or exploration. Mining destroys habitats by removing vegetation and, in many cases, the soil beneath it. Moreover, every viable mine entails the exploration of nonviable areas. Of the 140 species threatened by mining, 134 exist on the mainland. There are more species endangered by mining in Tennessee, Georgia, Alabama, Arkansas, Louisiana, and Florida than in the rest of the United States combined, which is attributable to high levels of mining in areas with high levels of biodiversity and endemism (Lydeard and Mayden 1995).

Mining is most strongly associated with urbanization, agriculture, and pollution (Table 2). The association with pollution is supportive to the extent that mining produces pollution and results in heavy traffic in the vicinity of mines. The association with agriculture is largely effective, because the modified limnology of many southeastern rivers is a function of erosion and siltation caused by mining and agriculture. The association with urbanization is probably well represented by supportive, effective, and incidental factors.

Industrial, institutional, and military activities. This category includes industrial development, military practices, and a few cases of government facility construction in rural areas. This category's strongest association is with urbanization (Table 2), and the association is clearly supportive. Industrialization is also supportively associated with pollution, which is a simultaneous source of endangerment for almost half (n = 38) of the species endangered on the mainland under this category.

The strong association of this category with non-native species (Table 2) is largely incidental. Military activities endanger a variety of species on Hawaii (Lowe et al. 1990,

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Moseley 1992, Beacham 1994), where non-native species are most problematic.

Harvest. The harvest of wild species has little association with other endangerment causes; among all causes of species endangerment, only disease has lower proportional association. Harvesting threatens a disproportionate share of large, charismatic, or economically valuable species. It has long been a threat to raptors such as the bald eagle (Trefethen 1975) and remains an important factor of endangerment for the thick-billed parrot (*Rhynchopsitta pachyrhyncha*), Snake River chinook salmon (*Oncorhynchus tshawytscha*), and numerous sea turtle and whale species. Harvesting also threatens reintroduction efforts for the Rocky Mountain gray wolf (*Canis lupus*; Barker 1993).

Logging. Forests cover 32% of the land area in the United States (Cubbage et al. 1993), and the logging of forests endangers 109 species. The northern spotted owl (*Strix occidentalis caurina*) is the best known species endangered by logging, but similar situations exist outside the Pacific Northwest—in the Southwest, for example, the Mexican spotted owl (*Strix occidentalis lucida*) is endangered by logging, as is the red-cockaded woodpecker (*Picoides borealis*) in the Southeast.

Logging is supportively associated with pollution and roads and effectively associated with agriculture and mining (Table 2). Logging, agriculture, and mining contribute to siltation of streams in the Southeast, endangering a variety of mussel species. The main objective of most logging is timber extraction, although logging is frequently incidental to agricultural and industrial development.

Road presence, construction, and maintenance. Roads range from two-track jeep trails to eight-lane interstate highways and are known to endanger 94 species. Mammals such as the San Joaquin kit fox (*Vulpes macrotis mutica*), which hunt nocturnally along habitat edges, are run over by automobiles, as are reptiles that are attracted to warm roadbeds, such as the blunt-nosed leopard lizard (*Gambelia silus*). Roadside mowing destroys habitat for the elfin tree fern (*Cyathea dryopteroides*). The dwarf lake iris (*Iris lacustris*) is endangered by chemicals (including salt) used in road and roadside maintenance, while the building of roads in anakeesta shale results in sulfuric acid runoff that endangers the Smoky madtom (*Noturus baileyi*). Several sites of Minnesota trout-lily (*Erythronium propullans*) were simply obliterated by road construction, and road improvements were sufficient to destroy some patches of San Diego mesa mint (*Pogogyne abramsii*; Lowe et al 1990, Moseley 1992, Beacham 1994).

Roads are strongly associated in the supportive sense with urbanization, mining, agriculture, industrial activities, and logging (Table 2)—indeed, none of these activities is likely to intensify without concomitant road building, maintenance, or use.

Genetic problems. Inbreeding depression, loss of genetic variability through drift, and hybridization are known or suspected to endanger 92 species. Most of the genetic problems documented thus far affect fish and plant species. Genetic problems are particularly ominous because of their permanence. Whereas an aquifer can be recharged once water conservation is implemented, a depleted or hybridized genome may never regain its integrity. For species like the Florida panther (*Puma concolor coryi*), which numbered less than 50 in 1989 and exhibits signs of inbreeding (Roelke et al. 1993) and genetic invariability (Maehr and Caddick 1995), it is probably too late to salvage a vigorous genotype.

In a sense, any cause of a population decline is supportively associated with genetic problems because loss of genetic variability is a function of declining numbers (Li and Graur 1991). The strongest association of genetic problems is with non-native species (Table 2). Most of the species endangered by genetic problems are Hawaiian species that have reached extremely low numbers, often because non-native species have modified their habitats.

Aquifer depletion and wetland drainage or filling. Efforts to meet increased agricultural demands include irrigating drylands and draining wetlands to make them tillable. Wetlands are also filled for construction. These activities modify hydrological processes, and species composition changes accordingly. Of the 77 species endangered by aquifer depletion and wetland loss, 73 inhabit the mainland (especially Florida and coastal and central California, where wetland drainage and filling are rampant, and the arid Southwest, where groundwater pumping depletes aquifers).

One species serves to illustrate the ends of the hydrological spectrum that are susceptible to alteration resulting in species endangerment. The Amargosa niterwort (*Nitrophila mohavensis*) is endangered because much of the wetlands it inhabits in Nevada were drained for peat mining. Since then, groundwater pumping for irrigation has reduced the spring flows that feed the remaining wetland. The niterwort now exists at only two sites and is vulnerable to demographic and genetic stochasticity (Lowe et al. 1990).

Native species interactions. We limited this category to species that lack native prey, species that are being preyed on by native species at unprecedented levels, or species that are missing part of a critical life cycle because of the absence of a native species. For example, the cave crayfish (*Cambarus aculabrum*) feeds on organic matter and detritus in the groundwaters of its cave system. Historically, much of the necessary organic matter was provided by gray bats (*Myotis grisescens*). With the drastic decline of the gray bat (another federally listed species; FWS 1982), the cave crayfish's existence was threatened. This category illustrates how endangerment may spread

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via food webs and other types of interspecific interactions. Such complexities may arise in any ecosystem, and there are no major geographic or thematic patterns associated with this cause.

Disease. Disease is known to endanger 19 species. Although it is a natural occurrence in the evolutionary history of most species, disease is unnaturally endangering when it threatens the existence of a species that has been decimated by other unnatural causes. For example, canine distemper has been an important factor in driving the black-footed ferret (*Mustela nigripes*) nearly to extinction in the past two decades (Reading et al. 1996). Were ferrets not already limited in distribution by the decline of prairie dogs (*Cynomys* spp.), their primary prey, disease would not have been as threatening.

Vandalism. The relatively small number (n = 12) of species endangered by vandalism reflects the pathological nature of such activity. However, the documented cases of vandalism may represent only a small fraction of actual occurrences. Species and their habitats are sometimes vandalized by landowners attempting to evade the provisions of the ESA's Section 9, which prohibits the taking of listed species by any party, public or private. Evasion of Section 9 may be the motive of, for example, vandals who have repeatedly destroyed Virginia round-leaf birch (*Betula uber*) trees and seedlings (Lowe et al. 1990).

Species endangerment and economic growth

We have noted how the causes of species endangerment tend to correspond to various economic sectors, especially agriculture, mining, logging, ranching, outdoor recreation and tourism, and wild species harvest. We have also described some of the prominent geographical characteristics of species endangerment. Many of the species endangerment hotspots noted by ourselves and others (Dobson et al. 1997, Flather et al. 1998) are likewise hotspots of economic growth—most notably, southern Florida, southern California, and east–central Texas—where many or all economic sectors are active.

Although Table 1 is sufficient to identify various economic sectors as causes of species endangerment, Table 2 illustrates how species tend to be endangered by networks of associated causes, not by single causes that can be addressed via technical means. For example, the cause with the least proportional association is disease; therefore, research and management focusing on disease should be rendered inconsequential by other causes in relatively few cases. However, disease is the second least important of the endangerment causes (Table 1). Furthermore, although species endangered by disease are endangered by only two other causes on average, in no case is disease the only cause of endangerment. This fact supports our earlier proposition that most species do not become endangered by disease until they have been decimated by other causes, which are dominated by economic phenomena.



Florida panther* (Puma concolor coryi). *The Florida panther is an example of species that are first endangered by economic activities and then by genetic problems stemming from low population size. Photo: US Fish and Wildlife Service.

Table 2 also supports the assertion of ecological economists that the economy grows as an integrated whole (Boulding 1993). The causes of species endangerment that we identified represent not only sectors of the economy but infrastructure and activity designed to support or protect these sectors (roads, reservoirs, wetland drainage, fire suppression, and silvicultural activities) or byproducts of these sectors (pollution). Another cause—industrialization—encompasses a vast array of economic activities that depend on the basic sectors for raw materials and in turn produce goods used by those sectors, which explains the high proportional association exhibited by industrialization. Urbanization, the primary cause of species endangerment on the mainland United States, occurs because it offers economic advantages and represents an amalgamation of sectors or a process by which economic activities are concentrated geographically (Dunn 1983). The list of endangered species is growing because the scale of the integrated economy, and therefore the causal network of species endangerment, is increasing.

Table 2 is also consistent with the ecological principles of niche breadth and competitive exclusion. In the economy of nature, the success of one species comes at the expense of another, according to the principle of competitive exclusion (Pianka 1974). Because of the tremendous breadth of the human niche, the increasing scale of human economy amounts to the competitive exclusion of nonhumans in general (Czech 2000a).

These observations suggest that the implications of species endangerment assessments are primarily economic.

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Black-footed ferret* (Mustela nigripes). *Were ferrets not already limited in distribution by the decline of prairie dogs, their primary prey, diseases would not have been as threatening. The prairie dog decline is attributable largely to the livestock production sector. Photo: Larry Shanks, US Fish and Wildlife Service.

Conservation policy, in other words, may amount to macroeconomic policy, and macroeconomic policy may largely define conservation policy. We therefore concur with Angermeier and Karr (1996), who stated that "conservation biologists should play a major role in articulating the value of biota [and] demonstrating links between biological integrity and economic stability" (p. 273).

Policy implications

Neoclassical economists assert that economic carrying capacity perpetually increases via the principles of resource substitutability, increasing productive efficiency, and human capital (Solow 1988). However, the cumulative substitution may be of a diverse economic system for a diverse ecological system, and increasing productive efficiency may amount to a more efficient capability to extract the natural resources that comprise nonhuman species' habitats. The US economy is clearly becoming more diverse (Frank 1999) and its efficiency in extracting natural resources is clearly increasing (Simon 1996), all in concert with proliferating species endangerment (NRC 1995, Czech and Krausman in press).

Our results indicate that the use of increasing economic carrying capacity for the sole purpose of economic growth will result in a lengthier list of endangered and extinct species. However, if economic carrying capacity can grow without a concomitant increase in the scale of human economy, then species endangerment may subside. In other words, if substitutability and efficiency gains are employed as a buffer between the scale of human economy and economic carrying capacity, that buffer could constitute a growing source of nonhuman habitats. Similarly, profits resulting from advances in substitutability and efficiency could be invested in ecological restoration rather than manmade capital.

Some have asserted that the American economy has been undergoing a transformation from an industrial to an "information" economy—that is, an economy in which an increasing proportional expenditure is committed to information services and in which, theoretically, fewer natural resources are liquidated (Rothschild 1990). Based on the principles of trophic ecology, we do not believe that the transformation to an information economy will halt species endangerment. Information as a product is analogous to a high trophic level that appears only when the trophic pyramid achieves a certain volume. Alternatively, information services are analogous to a new niche that only appears when the ecosystem reaches an adequate complexity, which itself is a function of pyramid volume (Fortey 1998). In either case, the information economy requires a large base to commence and requires an expanding base to grow (Czech 2000b).

Research implications

Identifying hotspots of species endangerment is not the same as identifying extraordinary opportunities for species conservation. In most cases, species conservation is a matter of real property acquisition, government regulation, cooperative management (often necessitated by regulation), or a combination thereof. As an area becomes a hotspot—economically and ecologically—acquisition becomes more costly and regulation more contested. The relationship between species endangerment prevalence and the value of species conservation efforts should be assessed across and within ecosystems.

We hypothesize that there is a cost per hectare that optimizes the number of species to be conserved, and that this cost per hectare would be intermediate. *Across* ecosystems, low cost per hectare would tend to be associated with areas that are low in economic and ecological diversity (e.g., playas in the desert Southwest). High cost per hectare would tend to be associated with areas of high economic diversity and high but already compromised ecological diversity (e.g., areas being subdivided in coastal and estuarine areas). In both cases, we hypothesize, species conservation effected per dollar invested would be low. *Within* ecosystems, it seems clear that the least expensive areas (i.e., those with little economic activity) would offer the greatest conservation value.

The most difficult aspect of investigating the relationship between species endangerment prevalence and the value of conservation efforts would be determining what constitutes conservation value. Is the conservation of a large, relatively natural area with no endangered species more valuable than the conservation of a small, relatively unnatural area with several endangered species? Species prioritization and risk assessment will play prominent roles in such investigations. For example, based on a synthesis of genetic, evolutionary, and ecological considerations, some would favor conserving the large area if the species to be conserved in the small area were primarily invertebrates (Czech and Krausman 1998). Others, basing their judgment largely on ethical concerns, would probably opt to conserve the small acreage no matter what species were involved (Windsor 1995).

Finally, there is an urgent need for ecologists and economists to collaborate on research designed to refine the

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relationship between economic scale and species conservation. This is the type of "consilient" research that Wilson (1998) promoted. With regard to species endangerment and ecological sustainability in general, Daly (1993, p. 29) posited that "the limits regarding what rates of depletion and pollution are tolerable must be supplied by ecology." Ecologists will certainly be helpful in ascertaining those limits, but their calculations will be of little utility unless economists concurrently and more precisely describe the relationship between economic scale and natural capital (and therefore nonhuman habitat) liquidation. Knowledge of that relationship is required to prescribe macroeconomic policies that are tantamount to conservation policies in the twenty-first century.

Acknowledgments

The authors thank Bob Steidl, Mark Borgstrum, and Steven DeStephano for statistical and other advice. The late Eugene Maughan also provided assistance.

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Mitigation Measures for Highway-caused Impacts to Birds[1]

Sandra L. Jacobson[2]

Abstract

Highways cause significant impacts to birds in four ways: direct mortality, indirect mortality, habitat fragmentation, and disturbance. In this paper I discuss highway-related impacts, and suggest solutions from a highway management perspective. Non-flying birds (either behaviorally or structurally) such as gallinaceous birds and ducklings; waterbirds such as terns; owls; ground-nesters; scavengers; Neotropical overwater migrants; frugivorous birds; and birds attracted to salt are often killed from highway-related causes. Suggested solutions include highway crossing structures, diversion poles on bridges or medians, modified right-of-way mowing regimes, road kill removal, appropriate median vegetation, and modified deicing agents. Indirect mortalities caused by highway construction or maintenance include habitat loss and decreased quality; predator attraction or bridges to nesting habitat; increased incidence of invasive species; increased associated lethal structures; and maintenance practices that disrupt reproduction. Suggested solutions include highway management strategies that consider avian needs.

Key words: birds, direct mortality, disturbance, fragmentation, highway, indirect mortality, mitigation, vehicle-animal collision, wildlife crossing structure.

Introduction

As the most mobile of terrestrial wildlife, birds are not often considered significantly affected by highways (Keller et al. 1996). However, highway impacts to birds occur in four major ways, some of which are unique to birds: by fragmentation, disturbance, and direct and indirect mortality. These impacts could have considerable negative effects on populations, especially when considered in combination with other sources of mortality and habitat loss. The mitigation measures reviewed here have the potential to reduce impacts to birds from all four categories.

Many mitigation techniques reviewed in this paper have been developed for other taxa, particularly ungulates and large carnivores, but are applicable to birds as well. Further information on the projects from which these suggested solutions are drawn can be found at the USDA Forest Service's 'Wildlife Crossings Toolkit' at http://www.wildlifecrossings.info. This database is the most complete compilation available of case histories of highway impact mitigation for all taxa. It includes a glossary for biologists unfamiliar with highway infrastructure terminology[3].

Several publications have reviewed highway impacts to birds, with most focusing on direct mortality and few offering suggestions for mitigation. A thorough review of impacts of linear developments, including highways, to birds and other wildlife is found in Jalkotzy et al. (1997); suggested mitigation measures focus on large mammals. Forman and Hersperger (1996) review mitigation measures for most taxa, but include relatively little information on measures effective for birds. A review of the impact of forest roads on wildlife, including some information on birds, is in Gucinski et al. (2000).

The current transportation paradigm dictates that highways will continue to be built and expanded to meet increasing transportation needs, and impacts to birds and other wildlife will continue as a result. No mitigation by itself or in combination with others can totally remove the impacts to wildlife. Several methods suggested here might reduce impacts to birds, however, and are based on successes with other taxa. Expensive structural mitigation techniques such as wildlife overcrossings are unlikely to be initiated to mitigate avian impacts alone, but additional benefits to birds might raise the benefit/cost ratio. The first step to reducing the impacts of highways on birds through improved highway design and retroactive mitigations is to understand how highways affect birds. In this paper I review

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[1]A version of this paper was presented at the **Third International Partners in Flight Conference, March 20-24, 2002, Asilomar Conference Grounds, California.**

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[3]The purpose of the website is to provide a database of known mitigation techniques for terrestrial wildlife for use by professional biologists and highway engineers. The Wildlife Crossings Toolkit was developed by a partnership of the USDA Forest Service's San Dimas Technology and Development Center, Utah State University's College of Natural Resources. Montana State University-Bozeman's Western Transportation Institute, and the Federal Highway Administration.

the current state of knowledge regarding these impacts and effective mitigations.

Fragmentation

Highways can fragment bird populations and habitats in three ways: loss of large carnivores, habitat dissection, and the isolation of less mobile species (*table 1*).

Loss of Large Carnivores

When highways fragment large carnivore populations, birds can suffer increased depredation from smaller carnivores such as bobcats, skunks and weasels (Crooks and Soulé 1999). Many structural designs for encouraging large carnivores to cross highways have been developed, and are being increasingly if not universally considered in appropriate highway projects. Large underpasses or extended bridges are used successfully for such species as Florida panthers (*Puma concolor coryi*), black bears (*Ursus americanus*), and wolves (*Canis* spp.) (Foster and Humphrey 1995; Roof and Wooding 1996; Clevenger and Waltho 2000). In most cases, barrier fencing is needed to encourage these highly mobile species to use the prepared crossing.

Habitat Dissection

Highways are designed to minimize costs. These routes are often the shortest distance between two points, in areas without human development to avoid the cost of land acquisition and to avoid noise effects to homes, and with minimal elevation changes. This may result in rare habitats such as wetlands being disproportionately affected by highway development (FHWA 2000). Habitat dissection may result in patches of habitat too small to complete a territory. Woodland species are more affected by habitat dissection than grassland species, which appear to be more willing to cross highways as part of their territories (Keller et al. 1996).

Planning the location of a highway to avoid environmental as well as construction costs may be the simplest but least considered solution. If the lands crossed are public lands, then an environmental analysis might develop an alternative that keeps habitat patches intact over one that bisects them. The public's role as stakeholders in this process is very important because many public land managers are still awakening to the avoidable impacts of highway design.

Crossing structures can be a tool to reduce impacts. Structures that are high, wide and open tend to retain the most functional ecosystems (Ruediger 2002). Causeways, viaducts, and expanded bridges provide the most opportunities for birds to cross under a highway because of their openness and the surrounding vegetation is usually continuous under the structure. In Europe, woodland bird species use wildlife over-crossings with planted vegetation significantly more to cross highways than direct overflights, and in some cases have incorporated the over-crossing into territories (Keller et al. 1996).

Isolation

Highways can isolate small populations or individuals because of habitat dissection. Isolation is a variant of habitat dissection, but it also includes those situations where a portion of a daily or annual habitat is difficult or dangerous to access because of the presence of a highway. The tendency of Mountain (*Oreortyx picta*) and California (*Lophortyx californica*) quail to avoid large openings (Gutierrez 1980) may make seasonal habitat virtually unavailable if multiple-lane, high volume highways bisect seasonal or daily movements, and their low flight and tight flocking behavior may increase the risk of mortality when crossing highways.

Correctly locating crossing structures is critical to their effectiveness. Although many wildlife travel along ridges and drainages, some animals, such as Mountain Quail, might have consistent but less obvious crossings. Knowing the location of frequent crossings can help situate the most effective structure.

Table 1— *Fragmentation impacts to birds from highways.*

Impact	Problem	Suggested solution
Loss of large carnivores	Increased small carnivores prey disproportionately on birds.	Highway crossing structures for large carnivores.
Habitat dissection	Habitat parcels are too small to contain complete territories.	Avoid dissection by highway placement. Use causeways or viaducts to maintain small scale habitat continuity.
Isolation	Highways are barriers to less mobile or reclusive birds.	Overall connectivity strategy. Use open-span bridges, viaducts or wildlife over-crossings.

Disturbance

Disturbance from highways may be most pronounced during the breeding season, but can also affect other life history periods (*table 2*).

Noise

Territorial song is only effective if it is heard by other birds, and noise from traffic can be so loud that bird song may be distorted, resulting in difficulties in attracting and keeping females (Reijnen and Foppen 1994). While the mechanism causing decreased numbers of woodland breeding birds next to highways (Riejnen and Foppen 1994) is not clearly understood, noise can disturb birds and render otherwise suitable habitat next to highways less effective (Reijnen et al. 1995, Stone 2000). Increased predation may also occur due to the inability of birds to hear predators (Scherzinger 1973).

Most noise from highways is produced by engines and tires as they contact the surface, with noise varying by tire and surface qualities (FHWA 2000). Noise can be mitigated by providing a barrier to the source of noise, or reducing the source itself. Because most of the noise derives from the road surface, a change in elevation of the road surface may reduce noise, and cuts and fills can be used to advantage. Noise barriers are commonly used in city situations and can be seen as large cement block walls along city highways. While this effectively reduces noise in lower vegetation layers, it also eliminates permeability for most essentially non-flying species, and is expensive. A variant of the common city sound wall can be created by less dense material such as wood, vegetation, or fabric.

The Federal Highway Administration (FHWA) has commissioned much research on environmental noise reduction. Smooth surfaces have been developed to reduce noise while retaining safe traction control; in addition, some tires are much less noisy than others. Land management agencies could reduce noise through public lands by considering road surface design when constructing or upgrading highways.

Lights

One method of migrant navigation is by reference to stars (Emlen 1975). Light pollution from all sources reduces the visibility of stars, and may entrap migrating birds in dangerous environments especially during inclement weather, causing collision, apparent confusion, and mortality (Ogden 1996). Highway lighting standards are based on the Illuminating Engineering Society of North America's (IES) standards, and newer designs are available that meet the IES standards but have reduced light pollution effects. Lower wattage flat lens fixtures on highways and city streets direct light down and reduce glare, thus reducing light pollution. They are currently being used in a major retrofitting project in Calgary, Alberta to reduce light pollution and to save money and energy (City of Calgary 2002). Increasing the reflectivity of signs and road striping (retro-reflectivity) is a method of increasing the visibility of roads to drivers while reducing the need for electrical lighting (Hasson 2000).

Direct Mortality

Direct mortality is the impact most people likely associate with highways. Birds are listed as killed most frequently in most multiple taxa road mortality studies (Forman et al. 2003). One estimate of bird mortalities from all causes lists vehicle deaths as the fourth or fifth most numerous at 60 million or more per year in the United States, after pesticides and high-power transmission lines (U.S. Fish and Wildlife Service 2002), both of which can be associated with highways and cause cumulative impacts. The extent of mortality from highways is underestimated (as it is in most studies of mortality from man-made structures) because scavengers pick up small bird carcasses rapidly, often within minutes (Morris 2002). Bird mortality from vehicle collisions affects some groups more than others (*table 3*).

Table 2— *Disturbance impacts to birds from highways.*

Impact	Problem	Suggested solution
Noise	Noise disrupts song or intimidates shy species.	Noise barriers. Reduce noise sources such as tires and road surfaces.
Lights	Migrants can't see stars to navigate.	Coordinate light-pollution reduction. Ensure lights are necessary before installation. Use lower wattage flat lens fixtures on highways, retroreflective elements on signs and pavement.

Table 3— *Direct mortality from highways.*

Impact	Problem	Suggested solution
Walking birds	Non-flying birds incur greater mortality risk.	Crossing structures with large openness ratios (underpasses) or wildlife over-crossings.
Water birds	Winds over bridges can slam flying birds into vehicles.	Diversion poles on bridge decks.
Owls	Owls hunt at headlight height.	Diversion poles or short fences along highway medians and rights-of-way.
Ground nesters	Mowing rights-of-way kills nesters.	Mow after August 1.
Scavengers	Corvids or raptors are killed while foraging on roadkill.	Reduce roadkill.
	Attracted scavengers reduce productivity adjacent to highways.	Remove roadkill from road.
Migrant landfalls	Exhausted cross-gulf migrants fly into vehicles.	Low temporary fences to encourage higher flight across roads.
Frugivores	Fruiting median plants attracts birds across traffic.	Plant non-fruiting varieties.
		Remove fruiting varieties.
Winter finches	Deicing salt or sand attracts birds to road surface.	Velocity spreaders.
		Road temperature sensors to reduce quantities.
		Concentrate runoff appropriately.
		Public education program.

Ground-Dwelling Birds

Birds that fly infrequently because of morphology, foraging behavior or age are at greater risk of vehicle collisions because they spend longer time on the roadway, and often have a shallow escape flight trajectory. Species affected include gallinaceous birds, juvenile anatids, and *Melanerpes* woodpeckers foraging on roadkilled insects (Stoner 1925). Crossing structures such as open bridges, large V-shaped underpasses, viaducts or causeways with vegetation maintained beneath highways can be used to mitigate impacts to these species. Causeways elevated on pilings or other intermittent supports across wetlands maintain ecological function better than causeways built on dikes because they allow water flow and uninterrupted movement of marshland species of all taxa.

Water Birds

When bridges are approximately perpendicular to wind direction they can cause downdrafts that increase the risk of collisions between birds and traffic or bridge structures. At Sebastian Inlet State Park, Florida, Royal Terns (*Sterna maxima*) and Brown Pelicans (*Pelecanus occidentalis*) suffered mortality particularly during northeasterly winds. In one case, a semi truck killed several Brown Pelicans at once (A. Bard, pers. comm.). The installation of aluminum fence poles spaced at intervals along the edge of the bridge created an apparent barrier that caused birds to fly higher, resulting in significantly fewer mortalities (Bard et al. 2002). On Queen Isabella Causeway on South Padre Island, Texas, avian mortalities during certain wind directions included Common Loons (*Gavia immer*), Peregrine Falcons (*Falco peregrinus*), and Brown Pelicans. Signs warning of the danger of pelican collisions on the bridge may not be effective at reducing mortalities (G. and S. Colley, pers. comm.).

Owls

Several species of owls, particularly Barn Owls (*Tyto alba*), Great Horned Owls (*Bubo virginianus*), and Short-eared Owls (*Asio flammeus*), often forage near roads at about the same height as vehicle windshields and are common victims of vehicle collisions. In the Central Valley of California, juvenile Barn Owls suffer heavy mortality from vehicles along Interstate 5 and smaller county roads (Moore and Mangel 1996). No mitigation has been attempted in this case, however, a concept similar to the Sebastian Inlet State Park barrier poles may be effective for owls as well. If so, a low fence or fence material such as plastic construction fence or closely spaced, frangible reflective highway markers may be effective if installed along highway verges and medians.

Ground Nesters

Birds nesting in highway rights-of-way are vulnerable to direct mortality due to mowing practices. Most states mow rights-of-way to maintain sight distances and for esthetic reasons. The most vigorous spring growth and onset of mowing in May or June coincides with nesting season. Mowing affects primarily grassland species or waterfowl by directly killing eggs, fledglings or adults attending nests. An estimated 4,500 ducks are killed on

highway rights-of-way each year in the prairie pothole region of North Dakota because about a third of nesting ducks have not hatched by the early July mowing (Cook and Daggett 1995). Illinois Department of Transportation currently delays mowing until August 1 to protect nesting birds (Cook and Daggett 1995). Mowing for esthetic purposes instead of vegetation control may be possible to forego. Highway users in several states supported unmowed verges when the environmental ramifications were explained (Harper-Lore 2000). In addition, naïve fledglings of many species nesting near roadways are vulnerable to collisions with passing vehicles.

Scavengers

Scavengers such as corvids and raptors are at risk of being hit by vehicles as they forage on other road killed carcasses (Mumme 2000). At the same time, because road kills are a reliable source of food, the same avian and mammalian scavengers patrol highways for food, and thus are at higher densities along highways. These scavengers may then turn to adjacent habitat for other foraging opportunities, including nesting birds. In most states, the state Department of Transportation (DOTs) is responsible for removing road kills (Cook and Daggett 1995). Where this is the case, it may be helpful to encourage agencies to expeditiously follow the policy to remove large animal carcasses, or create one where no policy exists.

Migrant Landfalls

Exhausted cross-Gulf migrants can congregate by the thousands at first landfall. Some of these locations are now prime oceanfront real estate with developments that include highways. In 1996, many cross-Gulf migrants were blown off course and landed in the Florida Keys. Florida State Park road kill records indicate a huge number of warblers and vireos that year (Fahrig et al. 2002), suggesting a situation likely to be repeated at many other locations. Some normal landfalls such as the Mississippi and Alabama coastline contain highways immediately adjacent to the nearest vegetation after shoreline, thus concentrating birds near a high mortality risk (B. Sargent, pers. comm.). While land use planning to maintain habitat adjacent to the shoreline is the ultimate solution, some areas known to be mortality hotspots, such as Highway 180 near Fort Morgan, Alabama (B. Sargent, pers. comm.), may need to be monitored after heavy flights (predictable by radar images broadly available over the Internet) and extraordinary measures taken to prevent birds from attempting low flights across highways while still exhausted. In some of these locations, it might be possible to erect temporary fences or other barriers that encourage migrants to fly at some height over passing traffic, in a manner similar to the Sebastian Inlet State Park approach.

Frugivores

Frugivores such as Cedar Waxwings (*Bombycilla cedrorum*) and thrushes are attracted to fruiting plants grown in highway medians as barriers to vehicles. In many eastern states, thorny eleagnus (*Elaeagnus pungens*) has been planted in medians, causing the attraction and death by collision of hundreds of waxwings, American Robins (*Turdus migratorius*) and Common Grackles (*Quiscalus quiscula*) (Watts and Paxton 2001). Removal of thorny eleagnus is being accomplished in Virginia as a result of the identification of the problem and effective negotiations with the Virginia DOT.

Winter Finches

Deicing highways in snow country costs transportation agencies considerable expense and time. Solutions to this safety concern are continually being sought. Both sand and salt as deicing agents are deadly for gregarious winter finches such as Pine Siskins (*Carduelis pinus*) and crossbills (*Loxia* spp.) when ingested. Salt is highly toxic to birds and causes lethargy or passive escape reactions to vehicles; the combination of salt and sand sometimes causes massive mortality (Environment Canada 2001). Solutions are complex but may include continued research into better deicing agents, velocity spreaders, and temperature sensors in roadways to minimize application rates. In Glacier and Mount Revelstoke National Parks in Canada, visitors are given a brochure explaining the issue and advising motorists to honk their horns at congregated birds to give them time to escape (Morris 2002).

Indirect Mortality

Habitat Loss and Habitat Sinks

Habitat loss to highway development is huge and insidious because highways may facilitate further development. Highways cover about 1 percent of the land base of the United States, or an area about the size of South Carolina (Forman 2000). Land use planning, and transportation options such as mass transit, intermodal transportation (transportation between public and private modes), and intelligent transportation systems are urgently needed. It is probably safe to assume that at least some percentage of that highway growth forever alters valuable bird habitat.

Highway medians and rights-of-way do provide some habitat for species in heavily developed areas, particularly grassland species in the eastern states, but it is still

unknown whether or not these small, linear habitats function as overall population sinks or as sources.

Predator Bridges

Land-filled bridges across open waterways can allow predators to access previously predator-free island seabird nesting colonies. Following the construction of a new highway in Norway, foxes, martens and badgers were able to cross to the island of Tuatara on rocky fill below the highway. Remedial measures such as noisemakers and an open-grid drawbridge have been unsuccessful to date (Quell 2001). Avoidance of these situations is the best policy.

Brood Parasitism and Noxious Species

The expansion of Brown-headed Cowbirds (*Molothrus ater*) and several species of noxious plants and animals is facilitated by the cleared line of sight along highways, particularly where these species had been limited by blocks of unsuitable habitat. Line of sight clearing is a safety measure that normally is a minimum of 10 m (30 ft). Where cowbird brood parasitism is a concern, large blocks of minimally cleared rights-of-way may be part of a suite of mechanisms used to control this species.

Lethal Associated Structures

When associated with highways, powerlines, railroads and canals are a few structures cumulatively more hazardous to birds. Vehicle traffic may cause birds to fly higher to avoid cars only to collide with parallel powerlines. Raptors continue to be electrocuted on powerlines, possibly in greater numbers along highways because of the attraction of roadkill scavenging opportunities. Gallinaceous species are attracted to canals in desert areas only to become vehicle mortalities (or drowned). Some of these structures can be buried, relocated or made safer if planners are aware of the cumulative impacts to birds because of their proximity to highways. The guidelines recommended by the Avian Power Line Interactions Committee to minimize electrocutions and collisions should be followed whenever possible (APLIC 1994, 1996).

Maintenance Practices

Peregrine Falcons and Cliff Swallows (*Hirundo pyrrhonota*), among others, may use bridges as nesting habitat. Bridge maintenance, however, typically occurs in warmer seasons, so it can conflict with successful nesting. Washington DOT developed specific and strict protocols to minimize impacts to Peregrine Falcons, formerly a State- and Federally-listed endangered species (Carey 1998). Under the Migratory Bird Treaty Act active nests containing eggs or young, or colonies with at least one such nest, are protected; intermitted take sometimes occurs regardless. On a bridge in Montana, DOT officials removed Cliff Swallow nests prior to the breeding season and applied a sticky repellent. The repellent was removed after maintenance was completed, limiting the loss of productivity to at most one year (Wabash et al. 2002).

Table 4 is a summary of these indirect sources of mortality to birds from highways, associated structures, and maintenance activities.

Conclusion

There are few data regarding the impacts of highways on birds and fewer on the effectiveness of the relatively few mitigation measures devised to reduce those effects. Nationwide, estimates of direct mortality from bird-car collisions range from 10 to 380 million (see Erickson et al. this volume). These are based on extrapolations from local studies, none of which corrected for the unquestionably large bias from carcass scavengers and searcher efficiency. There are no estimates for the sub chronic effects on populations from habitat loss, fragmentation, disturbance and other indirect effects of highway construction. Thus, there is a need for systematic efforts to assess these impacts locally and nationwide. Without these data, it is difficult to promote effective mitigations to highway planners. There might be little to be done to minimize impacts along the majority of the roughly 4 million miles of roadway in the United States, but protective measures addressed in this paper and other innovative solutions should be attempted along certain highly vulnerable locations, e.g. next to wetlands, over rivers, through riparian areas, and along migration corridors or fallout locations.

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Table 4— *Indirect mortality from highways.*

Impact	Problem	Suggested solution
Habitat loss	Highways facilitate development.	Land use planning; Mass transit or other change in transportation paradigm.
Habitat sink	Suitable habitat near highway increases mortality.	Make habitat unsuitable; Haze birds away; Reduce mortality through above methods.
Predator bridges	Bridges or land causeways allow access to nesting islands.	Design to avoid predator crossings; Drawbridge or open grid deck on bridge; Noise.
Brood parasitism	Cowbirds increase along cleared rights-of-way.	Reduce line-of-sight clearing; Other cowbird control mechanisms to break continuous pathway.
Noxious species	Highways facilitate noxious species travel.	Plants: herbicides, biological controls; Work with local DOTs to emphasize control.
Lethal structures	Birds fly into associated structures; Additional structures increase distance to cross.	Follow APLIC guidelines; Attach visibility markers; Bury telephone/power lines; Require raptor-safe power poles; Consider cumulative impact of railroads, power lines, canals, frontage roads.
Maintenance practices	Maintenance often occurs during nesting season.	Maintenance protocols; Timing restrictions; Acceptance of one year loss of productivity.

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Publication Date
2001-09-24

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IMPACTS OF HIGHWAY CONSTRUCTION AND TRAFFIC ON A WETLAND BIRD COMMUNITY

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Abstract: Here I report the ecological impact assessment of a section of European Highway E18 east in Helsinki, Finland. This two-lane section of highway was constructed through the shore pastures of the Pernajanlahti Bay, which is one of the most important nature conservation areas on the southern coast of Finland. It is a wetland area characterized by extensive shore meadows and reed swamps offering habitats to a diverse and abundant birdlife. Wetland bird populations in the target area as well as in a control area were monitored before, during, and after the road construction. The results indicated that after the highway had been opened for traffic, the mean conservation value of the wetland bird community in the target area had decreased by 25 % as compared with the control area. The decline in conservation value was mainly due to the loss of several habitat specialist species, such as European bittern (*Botaurus stellaris*), ruff (*Philomagnus pugnax*) and little gull (*Larus minutus*). Abundance of breeding wader birds also declined in areas near the highway, where the traffic noise level exceeded 56 dB, but did not change much in areas with lower noise load. In contrast to wader birds, population abundance of passerine birds did not show any directional response to disturbance by the highway, regardless of noise level. Despite the negative effects of the highway on conservation value and on many bird populations in the Pernajanlahti Bay, the highway is currently being expanded with another two-lane roadway. The effects of traffic noise could be to some extent mitigated by noise barriers.

Introduction

Environmental impact assessment (EIA) is currently part of the road design process in Finland. However, when the Highway 7, which is part of the international Highway E18, was planned along the southern coast of Finland, no ecological assessment of the alternative routes was implemented. Therefore, the route chosen for the two-lane section of this highway 70 km east of Helsinki was taken through the shores of a wetland nature reserve with high conservation value. This area, the Pernajanlahti Bay, is protected mainly due to its abundant and diverse bird community where wetland birds are especially well represented.

Here I report on preliminary results of a post-project analysis (PPA) of ecological impacts (Wathern 1992) of the construction of the highway on the bird populations of the wetland area. In addition to their conservation value in this area, birds were chosen as the target taxon because they are particularly useful indicators of the ecological state of the environment in which they live (Furness & Greenwood 1993). This is partly due to the fact that the habitat and other ecological requirements as well as population status of most European bird species are well known (Tucker & Heath 1994) and bird monitoring methods are well-developed (Bibby et al. 2000).

Study Areas and Methods

Pernajanlahti Bay (the target area) is one of the most valuable nature conservation areas on the southern coast of Finland. It is characterized by shallow brackish water with submerged vegetation surrounded by extensive reed swamps and shore meadows. The highway was built through the shore pastures on the northern edge of the Bay.

Wetland and marshland bird populations in the Pernajanlahti Bay were monitored by standard bird census methodology (Koskimies & Väisänen 1991). Bird censuses were conducted before the road was built, during the construction, and after the highway had been opened for traffic. The number of monitoring years before, during and after the road construction were two, one and two, respectively. At the same time bird populations were monitored with similar methods in the control area, which is situated about 20 km from the target area. Habitats and bird species composition in the control area (Pieni Pernajanlahti Bay) were very similar to the target area. Possible changes in bird populations as well as in conservation value and diversity of the bird communities in the two areas were compared. Furthermore, changes in bird abundances in the target area were related to the level of traffic noise (Lahti 1994).

The index of conservation value of the bird community is based on species-specific indices of population size, species endangerment, and rarity in the particular biogeographical area in question. It was calculated separately for the two years of each period, i.e. before and after the road construction. Hence it is a

comparable value for comparison between the two periods. Factorial analysis of variance (ANOVA) and repeated measures ANOVA (Zar 1996) were used for the statistical analysis of the data. Prior to the analyses the data were $\log_{10}$-transformed.

Results

Conservation value

Road construction caused habitat changes and disturbance, and traffic noise accounted for extra disturbance. The mean conservation value of the wetland bird community in the target area declined by 25 % as compared with the control area after the highway had been opened for traffic. This reduction is derived from 23.3 % reduction in the target area (from 79.5 ± 3.5 to 61 ± 5.6 points) and 2.4 % increase in the control area (from 60.5 ± 6.4 to 62 ± 1.4 (mean ± SD)) over the same period of time. This difference in the change of the mean conservation value through time in the two areas was statistically significant (ANOVA, interaction between period and noise level, $F_{1,4} = 9.195$, $P = 0.039$). Much of the decline in conservation value in the target area was due to the loss of several habitat specialist species with high conservation value, such as European bittern (*Botaurus stellaris*), marsh harrier (*Circus aeruginosus*), crane (*Grus grus*), ruff (*Philomachus pugnax*) and little gull (*Larus minutus*) during and after the road construction. These species are restricted to wetland and marshland habitats and all but marsh harrier have declining population trends in Europe (Tucker & Heath 1994).

Population changes of waders and passerines

The abundance of wader birds breeding in the shore meadows near the highway (up to 200 meters) dropped by 50 % during the road construction and the decline was almost 80 % after the highway had been opened for traffic (Fig. 1). Farther off from the highway the decline in the wader populations was less steep and it leveled off when the distance from the road was more than 800 meters (Fig. 1). In addition to habitat destruction, the

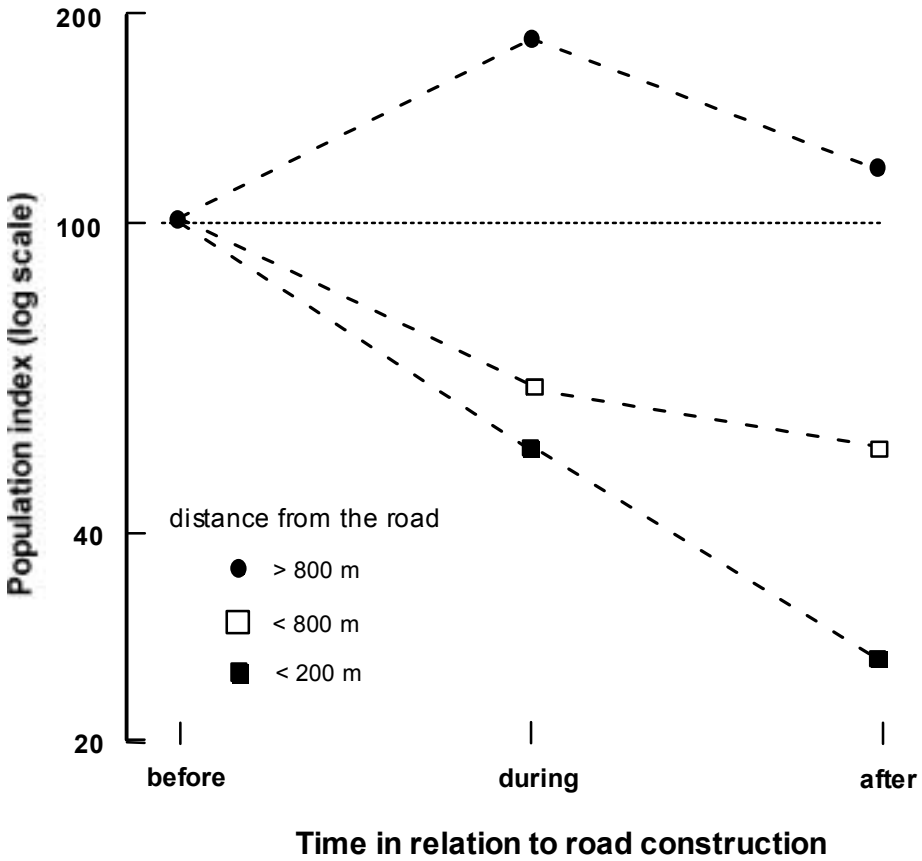


Fig. 1. Changes in population index (log scale) of breeding waders in relation to the distance (in meters) of from the highway before (index value 100), during and after the construction.

main reason for the severe decrease in the number of breeding waders near the highway was probably traffic noise. This is demonstrated when wader populations are compared before and after the highway was opened for traffic in the zones where traffic noise was more than 56 dB and less than 56 dB (Table 1). In the zone where traffic noise was > 56 dB, the number of breeding waders declined, whereas in areas where traffic noise was < 56 dB wader abundance remained fairly constant (Table 1). The wader population changes in the two noise zones were significantly different from each other (Table 1; repeated measures ANOVA, interaction between period and noise level, $F_{1,8} = 5.434$, $P = 0.048$).

On the contrary, the passerine birds breeding in the meadows did not show any clear responses to the highway and traffic noise (Table 1). Therefore, there was no significant difference in the population trends in the two traffic zones (Table 1; $F_{1,4} = 0.156$, $P = 0.713$). Thus, passerine birds seemed to be less vulnerable to disturbance caused by road construction and traffic disturbance than waders.

Table 1
Population indices of waders and passerines in the zones of traffic noise load of > 56 dB and < 56dB before and after the highway (see text for details).

	Noise load	> 56 dB	< 56 dB
Waders	before	100	100
	after	38	100
Passerines	before	100	100
	after	90	105

Discussion

Reduction in wader populations

The results of this long-term monitoring study indicate that habitat changes and disturbance caused by road construction and traffic noise had considerable effects on breeding populations of waders, while passerine populations showed minor responses. In the open shore meadows, through which the highway was built, the number of breeding wader birds declined considerably due to the highway and the consequent increased disturbance to the distance of 800 m. Although it is not possible to tell apart the effects of habitat changes and traffic noise completely, it is probable that the latter factor was more important here. This finding is in accordance with the results reported by van der Zande et al. (1980). They found that road traffic reduced the densities of the waders lapwing (*Vanellus vanellus*) and black-tailed godwit (*Limosa limosa*) up to two kilometers away from the road in open field habitats.

Similar results have been demonstrated by correlative studies in the Netherlands. For example, in a study based on regression between traffic load and bird densities, Reijnen et al. (1996) showed that out of the four wader species studied, three species showed a decrease in density adjacent to the road. Disturbance distance caused by traffic load for Oystercatcher (*Haematopus ostralegus*) was found to be as high as 3000 m along roads with high traffic densities (50,000 cars per day). In the Pernajanlahti Bay the traffic density was approximately from 15,000 to 20,000 cars per day, and therefore the disturbance distance for the wader species was probably found to be most significant up to 200 meters, though clear disturbance effects were found up to 800 m away from the highway.

No directional change in passerine populations

In the present study waders responded to the highway and traffic noise, but passerine species showed no effect. Earlier studies have also shown a similar difference between these groups of birds. For example, Haworth and Thompson (1990) found that many wader species avoided areas with strong human disturbance, but the occurrence of passerine birds was more clearly related to habitat quality than to human disturbance. However, the response to traffic noise and other disturbance caused by roads and their construction can vary depending on the bird species (e.g., Ferris 1979). In fact, in the abovementioned study Reijnen et al. (1996) found that passerines skylark (*Alauda arvensis*) and meadow pipit (*Anthus pratensis*), which breed in open landscapes, also suffered from disturbance by traffic. Their disturbance distances were roughly half of that of the wader species. Both species also occur in the shore meadows of the Pernajanlahti Bay, but because of low breeding densities and short disturbance distance, no significant effect of the car traffic was observed in this study.

Mechanisms of traffic disturbance

One finding of the present study was that the bird species specialized in wetland habitats proved to be most vulnerable to disturbance. For example, territories of European bitterns used to be located in the reed beds considerably far off from the road line. Therefore, habitat changes probably had no effect on their disappearance, but disturbance by car traffic is the most probable reason. Bittern males attract females by a deep and loud mating call. Frequency range of the call (Cramp & Simmons 1977) is similar to the most dominant part of the traffic noise spectrum in the Pernajanlahti Bay area (Lahti 1994). In the areas where the bittern territories were located before the highway the level of the traffic noise is now about 53-55 dB in the summertime (Lahti 1994), which exceeds the loudness of the mating call by male bittern (40 dB; Cramp & Simmons 1977). This means that bittern mating calls are masked by the traffic noise and remain inaudible for the females, and maybe therefore the males abandoned the area.

Mitigation of disturbance

On the basis of this study, extra care should be taken in planning new roads in open wetland areas. Despite the fact that the present highway has been shown to have negative effects on conservation value and on many bird populations in the Pernajanlahti Bay, the highway is currently being expanded with another two-lane roadway. From a conservation point of view, it is also important to explore how the present effects could be reduced. As the most severe disturbance here is caused by traffic noise, it seems that noise barriers could be used to mitigate the existing disturbance.

Acknowledgements: I thank Jukka Rintala and Kalevi Hiironniemi for their valuable help in the bird censuses. The study was partly financed by Finnish National Road Administration.

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Sustainable Cities and Society 22 (2016) 19–28

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Assessment of urban heat islands (UHI) of Noida City, India using multi-temporal satellite data

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ARTICLE INFO

Article history:
Received 21 October 2015
Accepted 4 January 2016
Available online 6 January 2016

Keywords:
Thermal data
Urban heat island
Land surface temperature
Noida

ABSTRACT

In the present research work an integrated use of Landsat thermal data sets of year 2000 and 2013, field data and meteorological observation were used to assess the temporal changes in rising trends of urban heat island (UHI) in Noida city, India. The temperature estimation was performed on the basis of grid level analysis and compared with the land cover pattern for validation of temperature with reference to urban land use/land cover. During 2000, the total built up area was 28.17 km^2 which it further increased to 88.35 km^2 during 2013. Over the period of thirteen years from 2000 to 2013 it was observed that the built up area has increased by 26.94% of the total area (203 km^2). In order to study the relationship between UHI and land cover, statistical analysis was performed between temperature and Normalized Difference Built-up Index (NDBI), Normalized Difference Vegetation Index (NDVI), Albedo and Emissivity. The correlation between NDVI, Emissivity and temperature was negative but NDBI, Albedo and temperature showed a positive correlation. Results showed that the change in temperature was mainly due to increase in impervious areas. The results of this study will be useful to the urban planners and environmentalists in formulating local policies.

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1. Introduction

Over the last five decades, the fast growth of urban area and conversion of natural landscape into anthropogenic structure results in change of local atmosphere and elevated land surface temperature compared to the surrounding open areas. The temperature variability represents human-urban and rural contrast, which is due to deforestation and conversion natural land surface into impervious land due to the urbanization (Chakraborty, Kant, & Mitra, 2015).

Un-planned and non-managed urbanization activities are generally having negative outcomes loss in green spaces, loss of water bodies and environmental degradation. Urban heat island (UHI) was described by Luke Howard on the onset of 1833 (Howard, 1833), described as the urbanized areas which are having higher temperature than the nearby rural areas and ever since this subject matter has received a lot of interest (Detwiller, 1970; Dousset & Gourmelon, 2003; Fukui, 1970; Johnson et al., 1993; Katsoulis & Theoharatos, 1985; Wang, Zheng, & Karl, 1990). UHI is a familiar effects, which is an exemplification of environmental degradation (Hove et al., 2015; Ramachandra & Aithal, 2013; Streuker, 2002) and leads to adverse impact on the human health, it is expected to exacerbate in the upcoming years. The variation in land use/land cover (LULC) and population ballooning also caused a substantial change in the spatiotemporal patterns of the UHI due to the loss of water bodies and vegetated areas (Ramachandra, Aithal, & Sowmyashree, 2015; Zhang et al., 2013). In comparison with the surrounding lands, the dense-built up areas exhibits higher land surface temperature (LST) (Mallick, 2014), results in urban warming; globally urban cities are warmer compared to surrounding rural areas (Oke, 1973), the day temperature variation between rural and urban regions varies from 3 °C to 5 °C whereas the night time difference is observable as high 12 °C mainly due to slow release of heat from the urban surfaces.

A study on UHI carried out for China stated that during the past 50 years UHI contributed to 0.2–0.33 °C of the overall warming in China. The differences in the thermal properties of the radiating surfaces and a decrease in the rate of evapo-transpiration are the major reasons responsible for the formation of UHI (Streuker, 2002).

The temperature in the mega cities of India which houses nearly 18 million people is expected to increase to 46 °C. The Delhi-based

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http://dx.doi.org/10.1016/j.scs.2016.01.005
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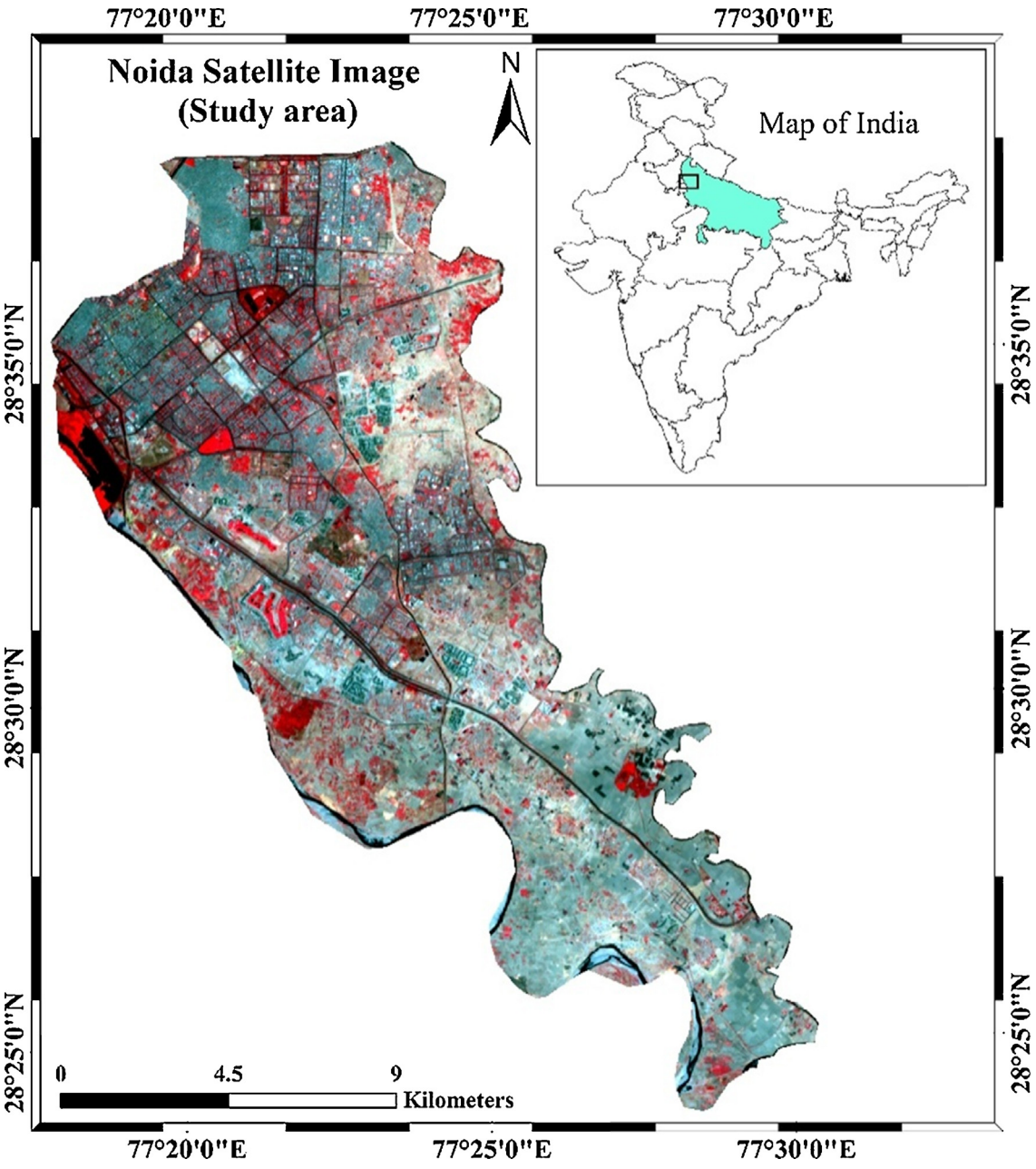


Fig. 1. Map of study area, Noida, India.

Energy and Resource Institute (TERI) carried out a primary survey which showed that the temperature in the mega-cities of India, i.e., Delhi and Mumbai had risen by 2 °C to 3 °C in just about 15 years. Nesarikar-Patki1 and Raykar-Alange (2012) study of Pune, India from 1999 to 2006 to see the impact of the changing land use pattern in the trend of LST. As a result it was observed that the built up area has increased by 32.68% which resulted to a decline of the area of agricultural land by 10%, vegetative land by 10% and barren land by 21.91% and as a consequence an increase in the LST was observed with rise in temperature from 1 °C to 4 °C. A case study for the Delhi was undertaken to evaluate and compare the UHI hotspots based on Remote Sensing observations and in situ measurements (Mohan et al., 2012). The areas occupied by dense built up infrastructures and commercial centers were found to have higher temperatures and the intensity of UHI was seen to be higher in magnitude during both the afternoon and midnight hours. On comparing this field campaign results with the MODIS-Terra data of the LST, they found that the UHI hotspots were comparable only during the night hours.

The aim of the study was to provide information about the major land use factors which is contributing to the rise in LST. This study also assesses the impact of built-up growth in Noida on its surface temperature using remote sensing and GIS techniques.

2. Study area and data

2.1. Study area

New Okhla Industrial Development Authority (NOIDA) is located at 28°.57′ N 77°.32′ E, lies in northern India in Gautam Buddha Nagar District of state Uttar Pradesh, India. It is bound on the west and south-west by the Yamuna River, on the north and north-west by the city of Delhi, on the north-east by the cities of Delhiand Ghaziabad, and on the north-east, east and south-east by

Table 1
Data used and their source.

Data used	Data acquisition date	Data source
LANDSAT ETM LANDSAT 8	1st May 2000 29th May 2013	http://earthexplorer.usgs.gov/

the Hindon River. Noida is spread over an area of 203 km^2, and has a population of around 0.64 million. Noida has hot and humid climate for most of the year. The weather remains hot during summers, i.e., from March to June, and temperature ranges from maximum of 48 °C to minimum of 28 °C. Monsoon season prevails during mid-June to mid-September with an average rainfall of 93.2 cm (36.7 in.), but sometimes frequent heavy rain causes flood. Temperatures fall down to as low as 3 to 4 °C at the peak of winters. Noida also has fog and smog in winters (http://noida.trade/cityClimatesection). Due to a rapid industrialization and urbanization and infrastructure development in Delhi and Noida, develops ecological imbalance due to exploitation and overuse of environmental resources which have adverse effect as UHI (Fig. 1).

2.2. Data used

2.2.1. Satellite data and other auxiliary data

The details of satellite images are given in Table 1 and other auxiliary data as Survey of India Toposheets and MOSDAC data has been used in the study.

2.2.2. Preprocessing

Satellite data pre-processing was carried out using ENVI 4.7 software. Each Landsat ETM and Landsat 8 data consisted of independent distinct band images which was first layer stacked and combined into a multi-band image. These images have a spatial resolution of 30 m per pixel. In this study the band 6 (thermal infrared band) of ETM and band 10 (thermal infrared band) of Landsat 8 was used to retrieve the LST by converting the Digital number (DNs) into radiances. The bands within solar reflectance spectral range were used for extracting the vegetation and built up indexes. After pre-processing, the images of the study area were used for the analysis of UHI study. Further, processing has been carried out on Arc GIS 10.2.1 software. Statistical analysis was carried out using SPSS software.

3. Methodology used

3.1. Mono-window algorithm for the retrieval of LST

Mono-window algorithm proposed by Qin, Karnieli, and Berliner (2001), for the retrieval of LST from Landsat TM 6 data have been used in the study (Liu & Zhang, 2011). This algorithm necessitates three main parameters – emissivity, transmittance and mean atmospheric temperature. Band 6 of Landsat ETM and band 10 of Landsat 8 records the radiation with spectral range from 10.40 to 12.50 μm for Landsat ETM and 10.60 to 11.19 μm for Landsat 8. The following expression is given below as Eq. (1):

$$T_s = \{a(1 - C - D) + [b(1 - C - D) + C + D]T_i - D * Ta\}/C \quad (1)$$

where $a = -67.355351$, $b = 0.4558606$, $C = \varepsilon_i * \tau_i$, $D = (1 - \tau_i)[1 + (1 - \varepsilon_i) * \tau_i)$, ε_i = emissivity and τ_i = transmissivity.

3.1.1. Conversion of digital numbers to radiance

In order to convert the DN data of band 6 of Landsat ETM and band 10 of Landsat 8 into spectral radiance Eqs. (2) and (3) can be written in band math of ENVI 4.7 as:

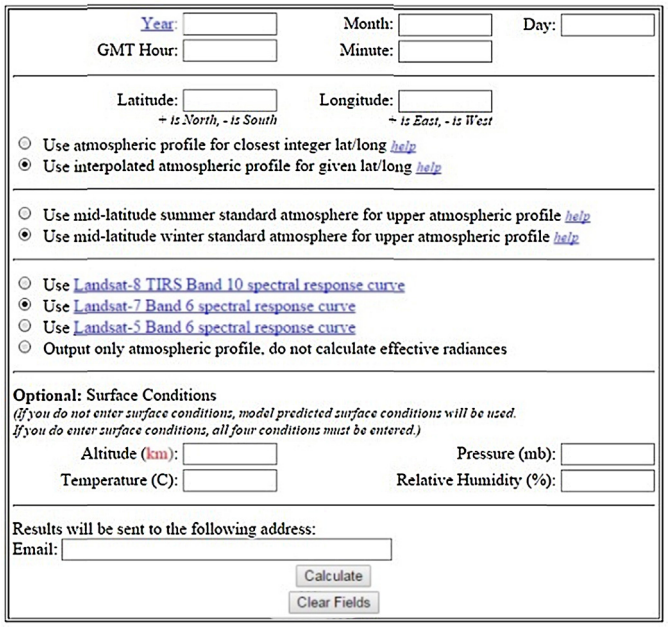


Fig. 2. NASA webpage for atmospheric correction.
Source: atmcorr.gsfc.nasa.gov/

(a) For Landsat ETM

$$CV_{R1} = \frac{(LMAX_\lambda - LMIN_\lambda)}{(QCALMAX - QCALMIN) * (QCAL - QCALMIN) + LMIN_\lambda} \quad (2)$$

where CV_{R1} is the cell value as radiance, $QCAL$ = Digital Number, $LMIN_\lambda$ = spectral radiance scales to $QCALMIN$, $LMAX_\lambda$ = spectral radiance scales to $QCALMAX$, $QCALMIN$ = the minimum quantized calibrated pixel value (typically 1) and $QCALMAX$ = the maximum quantized calibrated pixel value (typically 255).

(b) For Landsat 8

$$L_\lambda = MLQ_{Cal} + A_L \quad (3)$$

where L_λ = TOA spectral radiance (Watts/(m^2 × srad × μm)), M_L = band-specific multiplicative rescaling factor from the metadata (*RADIANCE_MULT_BAND_x*, where x is the band number), A_L = Band-specific additive rescaling factor from the metadata (*RADIANCE_ADD_BAND_x*, where x is the band number), Q_{Cal} = quantized and calibrated standard product pixel values (DN). These useful values can all be obtained from the meta-data file of the satellite image data.

3.1.2. Calculation of brightness temperature

Once the radiance values have been calculated using the DNs of the thermal bands, the inverse of the Plank function is applied to derive the temperature values (Wang et al., 1990) expressed as Eq. (4).

$$T = \frac{K_2}{\ln\left(\frac{K_1 \times \varepsilon}{CV_{R1}} + 1\right)} \quad (4)$$

where T = degrees (in K), CV_{R1} = cell value as radiance. K_1 and K_2 values can be obtained from the meta-data file.

3.1.3. Calculation of atmospheric transmittance

The atmospheric transmittance for Landsat ETM and Landsat 8 data was calculated using the "NASA webpage for atmospheric correction" module (Fig. 2).

Table 2
Emissivity estimation using NDVI.

NDVI	Land surface emissivity
NDVI < −0.185	0.995
−0.185 ≤ NDVI < 0.157	0.970
0.157 ≤ NDVI ≤ 0.727	1.0094 + 0.047ln(NDVI)
NDVI > 0.727	0.990

3.1.4. Calculation of land surface emissivity

Land surface emissivity estimation can be done using NDVI. The following equation can be applied when the values of NDVI ranges from 0.157 to 0.727. Van de Griend and Owe (1993) proposed this method (Eq. (5)).

$$i = 1.0094 + 0.0047 \ln(NDVI) \quad (5)$$

Zhang, Wang, and Li (2006) proposed another complete land surface emissivity estimation method and the following equations can be used for calculating emissivity using NDVI (Table 2).

3.2. Retrieval of land surface parameters

3.2.1. Derivation of NDVI

NDVI from Landsat ETM and Landsat 8 is calculated from reflectance measurements in the red and near infrared (NIR) portion of the spectrum (Liu & Weng, 2011). The NDVI expressed as in Eq. (6):

$$NDVI = \frac{NIR - R}{NIR + R} \quad (6)$$

where *NIR* = Band 4 (For Landsat ETM) and Band 5 (For Landsat 8) and *R* = Band 3 (For Landsat ETM) and Band 4 (For Landsat 8).

3.2.2. Derivation of NDBI

NDBI from Landsat ETM and Landsat 8 is calculated from reflectance measurements in the red and mid infrared (MIR) portion of the spectrum (Liu & Weng, 2011). The NDBI expressed as in Eq. (7):

$$NDBI = \frac{MIR - R}{MIR + R} \quad (7)$$

where *MIR* = Band 5 (for Landsat ETM) and Band 6 (for Landsat 8) and *R* = Band 3 (for Landsat ETM) and Band 4 (for Landsat 8).

3.2.3. Derivation of Albedo

Albedo from Landsat ETM and Landsat 8 is calculated from the reflectance measurements (Coakley, 2003; Liang, 2000) expressed by Eq. (8) as:

Formula:

$$\alpha = \frac{0.356\alpha 1 + 0.130\alpha 3 + 0.373\alpha 4 + 0.085\alpha 5 + 0.072\alpha 7 - 0.0018}{1.016} \quad (8)$$

where α_i = Band number 1, 3, 4, 5 and 7 (for Landsat ETM) and Band number 2, 4, 5, 6 and 7 (for Landsat 8).

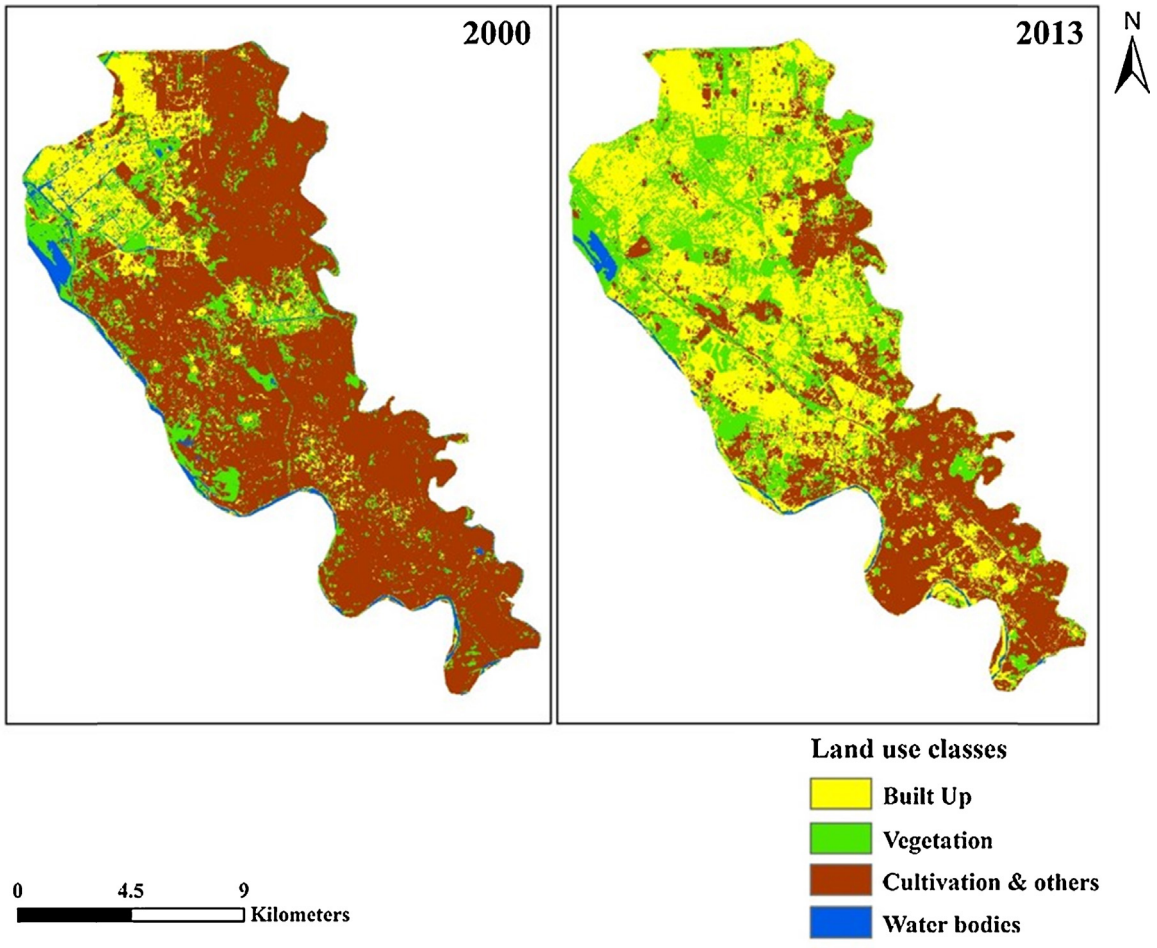


Fig. 3. LULC map of Noida of May 2000 and May 2013.

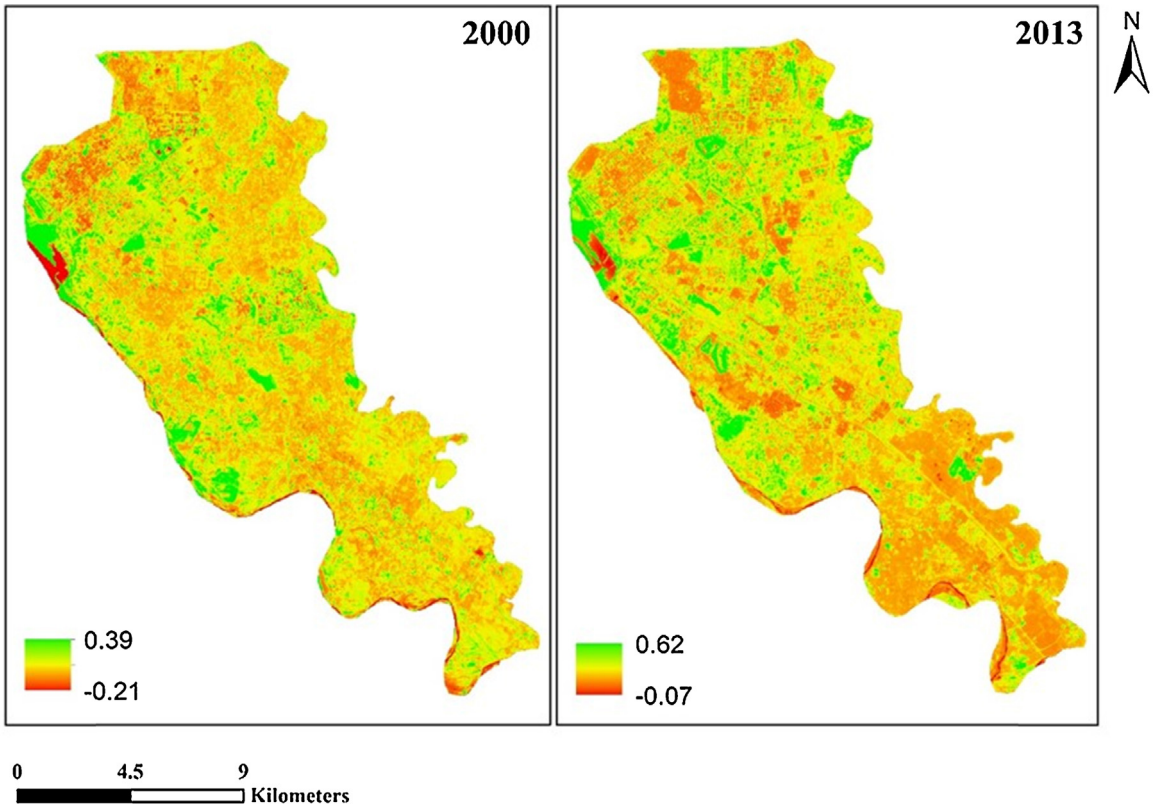


Fig. 4. NDVI map of Noida of May 2000 and May 2013.

Table 3
Noida temporal LULC.

Date	1st May 2000		29th May 2013	
	Sq km	%	Sq km	%
Built up	28.17	13.09	88.35	41.03
Vegetation	29.33	13.62	54.56	25.34
Cultivation and others	150.21	69.79	69.29	32.18
Water bodies	7.49	3.48	3.06	1.42

4. Results

The spatial distribution of LST, NDVI and LULC within the study area is shown in figure below. LST is carried out on the basis of these LST parameters.

4.1. Spatio-temporal analysis of LULC

Maximum Likelihood Classifier, a statistical decision in which the pixels are allotted based on the class of highest probability, results was obtained as LULC types, i.e., built-up, vegetation, water bodies and cultivation and others (Fig. 3, Table 3).

In Noida, the percentage of Built up area has increased rapidly from 2000 to 2013. During 2000, the total built up area was 28.17 km^2 which it further increased to 88.35 km^2 during 2013. Over the period of thirteen years from 2000 to 2013 it was observed that the built up area has increased by 26.94% of the total area (203 km^2). The changes in the land cover category also showed some positive land use analysis in which the wastelands are getting reduced as it is getting replaced by vegetative area which is showing an increasing trend over the years. Vegetative land was found to be 29.33 km^2 in 2000 which increased to 54.56 km^2 during 2013. Thus, most of the increase in the urban area resulted from the conversion of agricultural land to other land use classes in which cultivated lands and other open lands were replaced by buildings, roads, pavements and other infrastructures which also resulted in the increase of urban vegetation.

Table 4
Noida mean NDVI (temporal change).

Date	Minimum NDVI	Maximum NDVI	Mean NDVI
1st May 2000	−0.21	0.39	0.04
29th May 2013	−0.07	0.62	0.06

4.2. Spatio-temporal analysis of NDVI

Fig. 4 shows the spatial distribution of NDVI from Landsat image for the years 2000 and 2013 in the city of Noida. The minimum and maximum NDVI values of 2000 are in the range between −0.21 and 0.39 and during 2013, the range was between −0.07 and 0.62. The city was showing an overall increase in the trend of vegetation over the years. It was observed that with the increase in urbanization, the urban plantations are also increasing due to which the NDVI is showing an increasing trend over the years. According to the India State of Forest Report 2011, brought out by the Union Ministry of Environment and Forests, over the decade Delhi's green cover has doubled up from 151 km^2 in 2001 to 296.2 km^2 in 2011. Around 367 km^2 of land officially classified as forest was lost countrywide between the years 2009 and 2011. According to the report, Delhi lists a remarkable 20% of their area under forest cover despite the other major cities in India having less than 15% of forest cover. It is claimed by the city's forest department that the number has increased at least by 2% now and is set to keep increasing over the years. The area having value more than zero represents green areas with increasing value of NDVI showing more greener areas whereas values below zero or near to zero represents non-vegetated features such as barren lands and water (Fig. 5, Table 4).

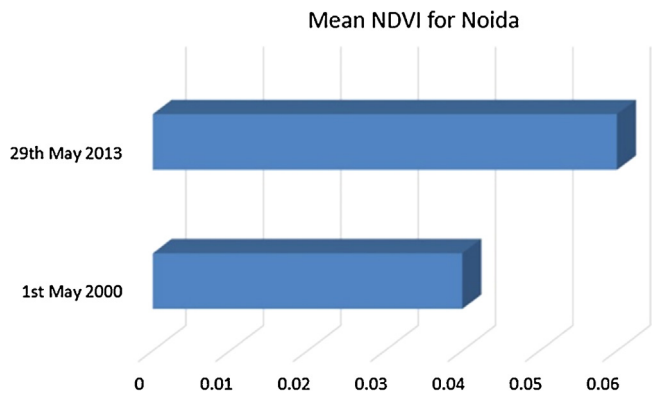


Fig. 5. Bar graph showing mean NDVI for Noida (temporal change) of May 2000 and May 2013.

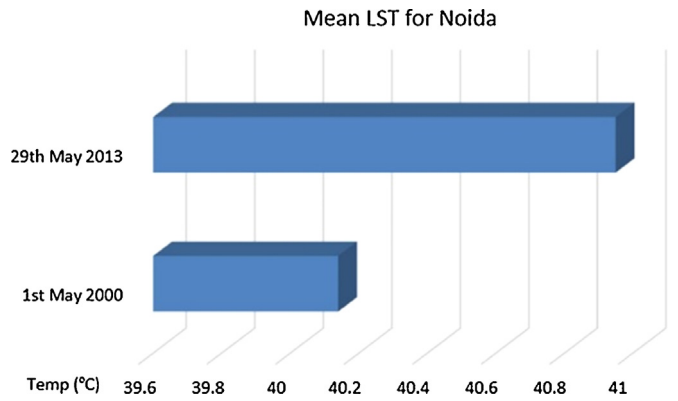


Fig. 7. Bar graph showing mean LST for Noida (temporal change) of May 2000 and May 2013.

4.3. Spatio-temporal analysis of LST

Due to the spatial variations in land cover, the soil representative meteorological conditions from the limited number of climate stations cannot always be obtained. In such cases the remote sensing data helps in procuring the consistent and frequent observation of land surface on both micro as well as macro scale (Southworth, 2004). The LST is calculated with the radiance value of thermal band from Landsat ETM and Landsat 8 data. Fig. 6 shows the land surface temperature maps of Noida (Fig. 7, Table 5).

It was observed that during 2000, the temperature ranged between 32.46 °C and 47.83 °C having a mean LST of 40.14 °C. The overall mean temperature showed an increasing trend during May 2013 with a mean LST of 40.95 °C and the temperature ranging between 33.89 °C and 48.01 °C. As Noida becoming one of the fastest developing cities in Delhi/NCR, urbanization is also increasing rapidly in which the natural land surface are getting replaced by roadways, buildings and other constructions which is contributing to rise in temperature thus increasing the urban heat island effect in a number of ways. In the built-up regions, the radiations are getting trapped because to the various building materials used nowadays and as observed closely from 2000 onwards it was seen that in the areas where built-up has increased, LST is also reportedly found to be increased. But in some regions during 2013, low LST is also reported. This is because of the increase in the green cover and the moisture trapping properties of the vegetation due to

Table 5
Noida mean LST (temporal change) Noida 2000.

Date	Minimum LST	Maximum LST	Mean LST (°C)
1st May 2000	32.46	47.83	40.14
29th May 2013	33.89	48.01	40.95

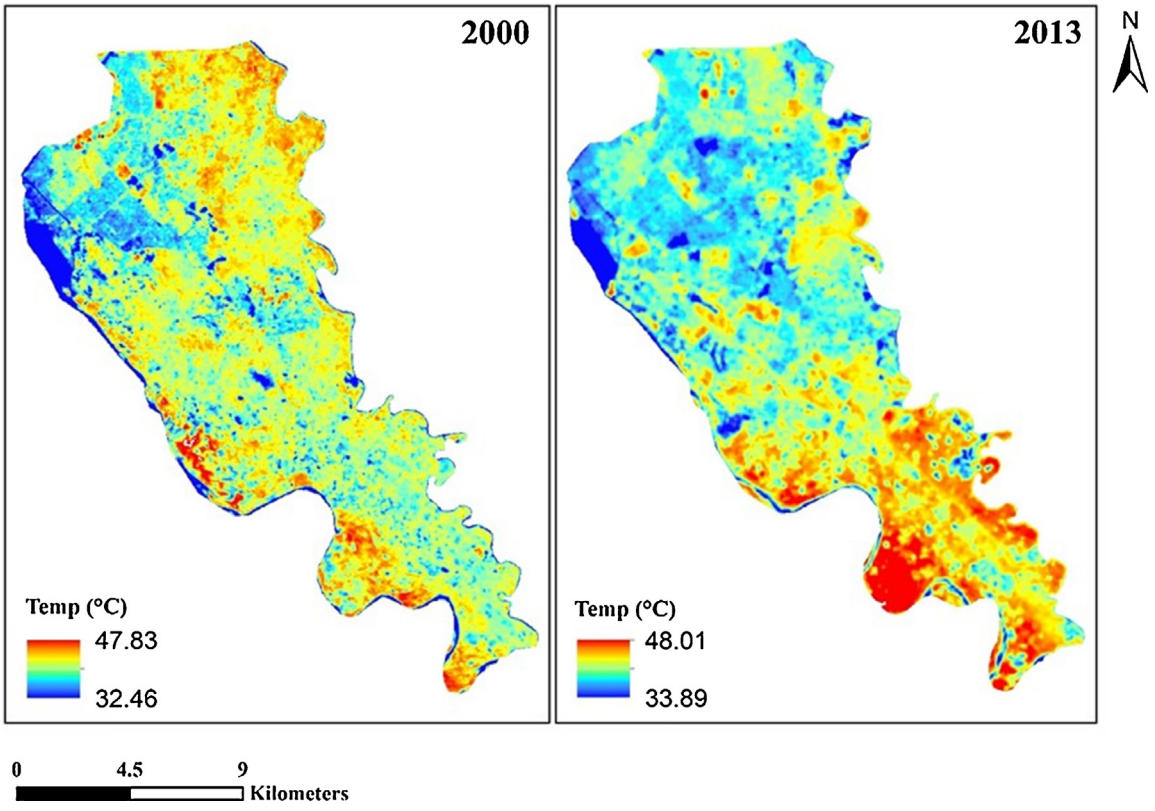


Fig. 6. LST map of Noida of May 2000 and May 2013.

Table 6i
Impact of LST on land use change of Noida of May 2000.

Noida 2000										
Grid number	Built up		Cultivation and others		Vegetation		Water bodies		LST	Mean LST
	Sq km	%	Sq km	%	Sq km	%	Sq km	%	°C	°C
0	0.19	2.32	7.01	82.08	0.95	11.12	0.38	4.46	45–47	46
1	2.74	1.71	15.08	94.02	0.64	3.99	0.04	0.26	42–44	43
2	0.31	1.97	14.71	92.44	0.85	5.38	0.03	0.19	45–47	46
3	0.83	5.27	14.12	88.73	0.91	5.72	0.04	0.26	44–45	44.5
4	1.41	8.86	11.91	74.83	2.58	16.22	0.01	0.07	44–45	44.5

Table 6ii
Impact of LST on land use change of Noida of May 2013.

Noida 2013										
Grid number	Built up		Cultivation and others		Vegetation		Water bodies		LST	Mean LST
	Sq km	%	Sq km	%	Sq km	%	Sq km	%	°C	°C
0	2.45	29.03	4.21	49.74	1.31	15.74	0.48	5.73	45–47	46
1	8.32	33.01	2.37	53.04	5.67	14.38	0.04	0.02	45–47	46
2	7.25	42.81	4.64	49.54	4.01	7.64	0.01	0	45–47	46
3	5.82	60.28	5.57	25.68	4.17	13.87	0.01	0.15	45–47	46
4	7.94	63.08	0.65	11.78	7.30	24.81	0.01	0.31	43–45	42

which the LST appears to be low. Vegetation has a high emissivity due to which the LST is low. NDVI plays a vital role in determination of the vegetation pixels and provides useful information as to understand the condition of the urban areas. Open lands are also reportedly found to have high temperatures. Water bodies exhibit minimum temperatures.

4.4. Grid level analysis of LST with LULC

Grid level analysis was carried out to estimate the land surface temperature for Noida urban area and the area was divided into 2/2 km^2 grid using the Arc GIS zonal statistical tool. The main objective of performing this analysis was to find out and correlate the major land use or land cover category which is responsible for the rising of land surface temperature. Grid level analysis of LST was performed by calculating the mean of land surface temperature within the area of 2/2 km^2 grid. The results observed from these analysis and their variations are shown in Fig. 8 (i and ii) and Tables 6i and 6ii.

During the years from May 2000 to May 2013, it was observed that out of the four land-use category, i.e., built-up, cultivation and others, vegetation and water bodies, grids having the major category of built-up greatly contributed to the rise in temperature. Grids having majority of built up near water bodies were found to have lower temperatures. Least temperature was observed in case of grids having majority of vegetation class and water bodies. Further, analysis has been carried out by selecting grids which was showing a major temperature deviation. The selected grids are numbered in the map in Fig. 8 (i and ii). It was observed that built up has a direct impact on the rising temperature. Fig. 9 (i and ii) showed some examples of images taken from Google Earth Historical Imagery of Grid numbers 3 and 4 which shows how urbanization has increased over the years.

4.4.1. Grid number 3 (Noida)

As Noida becoming a fast developing city, it can be seen from the image that over the period of year's urbanization has rapidly taken place in which the agricultural lands are getting replaced by pavements, highways, buildings and other infrastructures. The percentage of built up area in this grid increased tremendously with the percentage of built-up being 31.65% in May 2000 which increased to 60.28% during May 2013. Similarly, with the changing pattern in land use especially with the increase in the built up area the LST was also showing an increasing trend. The trend of land use change and temperature variation for the years 2000 and 2013 within this grid number 3 can be seen in Tables 6i and 6ii.

4.4.2. Grid number 4 (Noida)

This grid is showing one of the most important highways of Noida which is the Greater Noida Expressway. This expressway also connects to Yamuna expressway which is a new and shorter route to Taj Mahal in Agra, one of the important tourist destinations in India. This expressway connects many universities, workplaces, residential townships and independent settlements. Over the period years, it can be witnessed from the image on how development has taken place in this region. Built-up is replacing the agricultural lands and as a consequence the temperature was also found to increase. The trend of land use change and temperature variation for the years 2000, and 2013 within this grid number 4 can be seen in Tables 6i and 6ii.

4.5. Pearson's correlation

Correlation analysis between the LST and various indices, i.e. NDVI, NDBI, Emissivity and Albedo was done for finding out the relationships. The analysis showed that there is a strong positive correlation of LST with NDBI which indicated a direct relation of LST with NDBI. In other words, as NDBI increases the LST is also increasing. Similarly, a weak positive correlation was seen between LST and Albedo which showed that where there is high albedo, the temperature is also high (Table 7).

The results obtained through the correlation between LST and NDVI showed a negative correlation in which the areas with high NDVI values was found to have a lower temperature as compared to the areas with low values of NDVI. This is because plants are good absorbers as vegetation and moisture trapping soils utilize a relatively large proportion of the absorbed radiation in the evapotranspiration process and release water vapor that contributes to cool the air in their vicinity due to which the heat gets trapped and hence the emissivity in those regions are found to be high. Emissivity was found to be strongly negatively correlated because di-electric properties of a feature greatly impacts its ability to absorb or radiate heat. For example, all areas where water bodies were found to exist in both the study regions, lower temperature

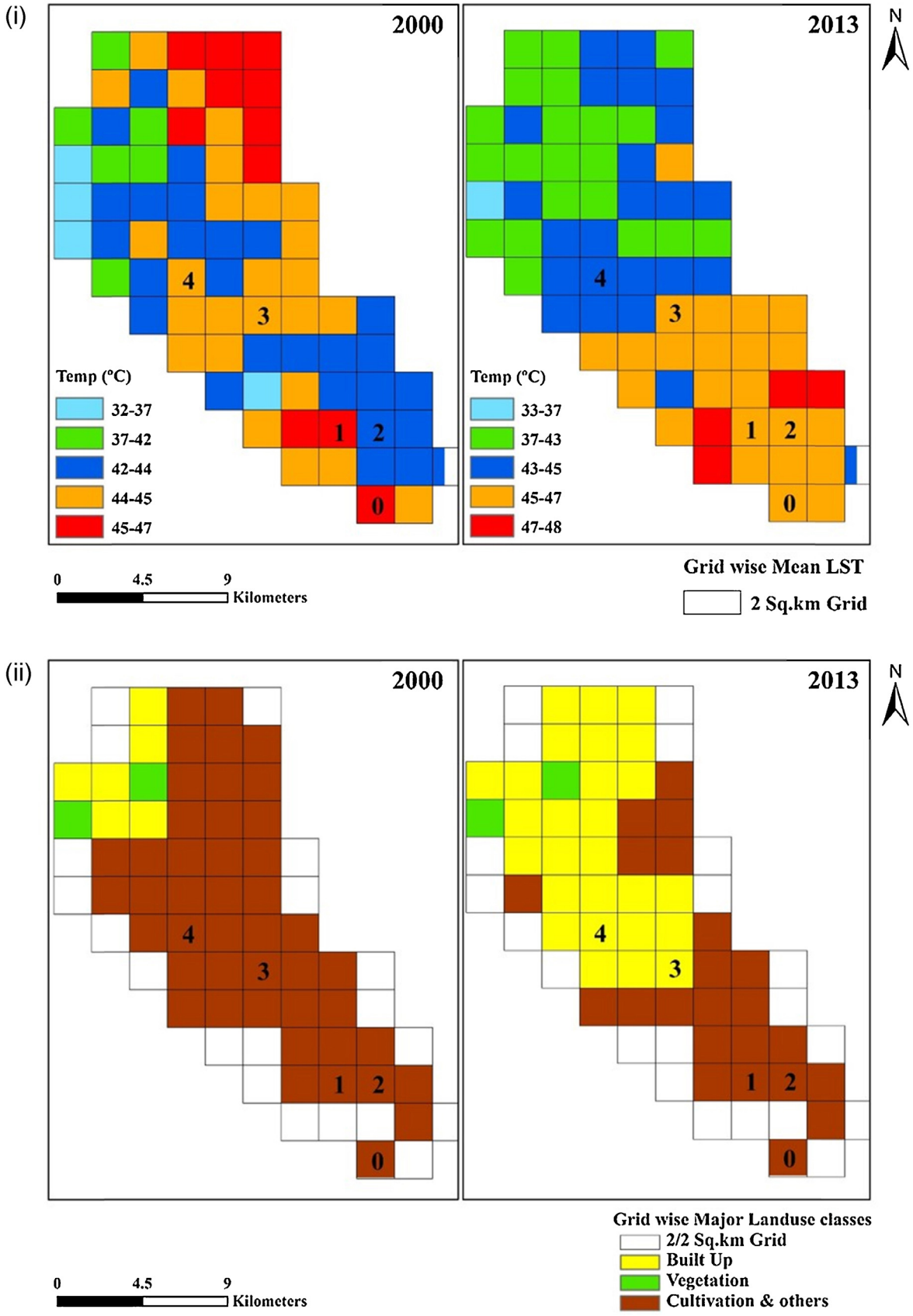


Fig. 8. (i) Map of grid wise LST of Noida of May 2000 and May 2013. *Note*: The meaning of Grid as 0, 1, 2, 3, and 4 are the numbering of grids as these grids are sum of the grids where major land use change and temperature change is observed both in positive and negative way and its tabulations of the grid wise major land use changes of these numbered grids are shown is Tables 6i and 6ii. Only some particular grids are selected for validation point of view. (ii) Map of grid wise major LULC category of Noida of May 2000 and May 2013.

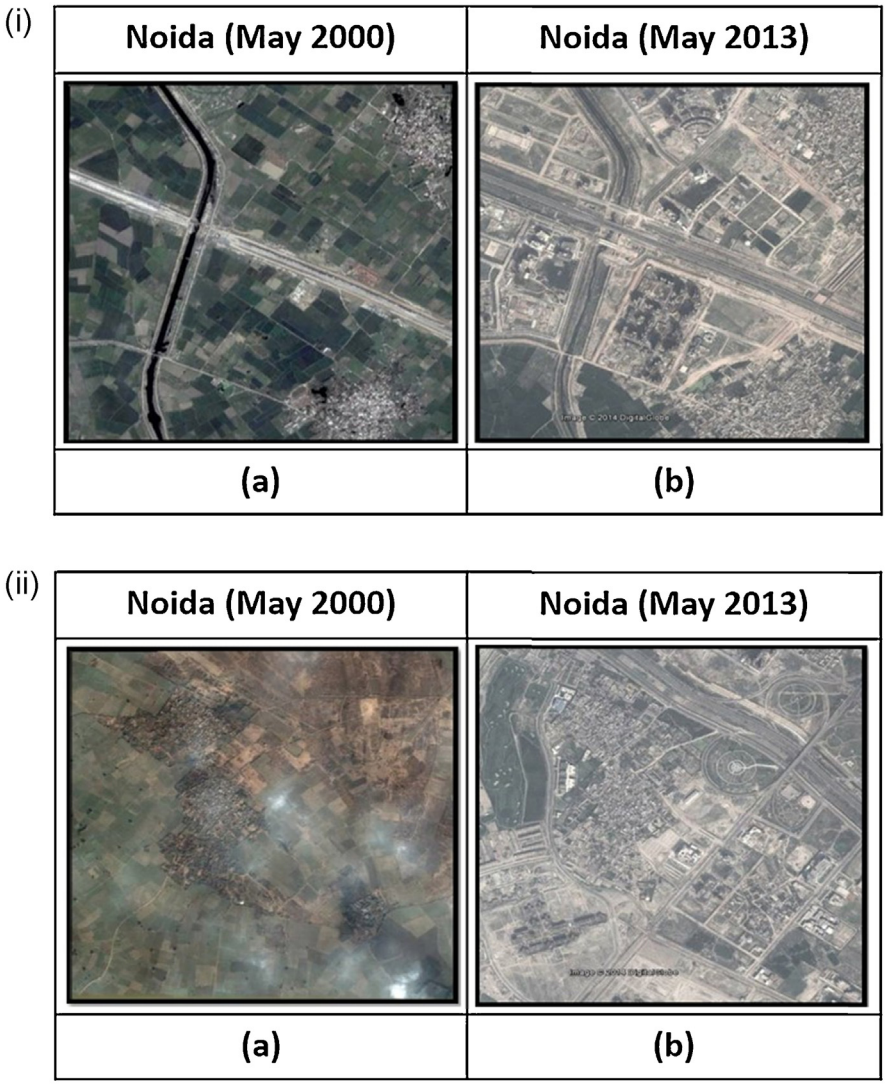


Fig. 9. (i) Google Earth Historical Imagery for Grid 3 (a) Noida 2000 and (b) Noida 2013 are showing the level of urbanization in the area. (ii) Google Earth Historical Imagery for Grid 4 (a) Noida 2000 and (b) Noida 2013 are showing the level of urbanization in the area.

Table 7
Correlation table of Noida.

Correlations		
		LST
LST	Pearson correlation	1
	Sig. (2-tailed)	
	N	10
NDVI	Pearson correlation	−547
	Sig. (2-tailed)	.083
	N	10
NDBI	Pearson correlation	.812
	Sig. (2-tailed)	.004
	N	10
Emissivity	Pearson correlation	−.574
	Sig. (2-tailed)	.083
	N	10
Albedo	Pearson correlation	.572
	Sig. (2-tailed)	.4
	N	10

were reported with its emissivity being the highest of about 0.993–0.998. On the contrary in Urban areas as as well as in open lands due to building material property and soil/sand di-electric constant, comparatively higher temperatures were reported.

5. Future implications for reducing the effect of urban heat island

The unbalanced temperature rise has adverse effects both on the human population of the city and the ecosystem of the surroundings. As urbanization is never ending process it is becoming mandatory to take necessary steps to create a balance between the environment and human settlements. So actions should be taken to minimize the urban heat island phenomenon. First and foremost steps to reduce the effects are to increase the vegetation cover in the city which would help in stimulating the rate of evapotranspiration. Planting trees around the settlements will help in shading the urban surfaces which reduces the temperature of roofs and walls. It leads to considerable decreases in energy usage for air conditioning. Secondly, other UHI reduction strategy is to increase surface reflectivity (i.e., high albedo) for reducing the radiation absorption properties of urban surfaces. So Building materials with high emissivity property should be used as it will store less heat and the roofs

tops, pavements etc. should be painted in light color like white as it will absorb less amount of solar radiation and keep the temperature low. Roof top Gardens or "Green roofs" which uses live vegetation on roofs are gaining popularity in order to reduce heat accumulation and helps in extending the lifespan of roofing materials as compared to traditional rooftops, reducing air pollutants and greenhouse gases, and insulation of buildings. Appropriate planning such as planting of trees and vegetation cover in urban areas, creation of green space such as parks will help in cooling of the atmosphere. Usage of renewable resources of energy like solar and wind should be promoted and fuels having low carbon emissions must be implemented. Carbon Credits or cap-and-trade markets are useful and an abrupt solutions for reducing Green House Gas (GHGs) emissions in the atmosphere. It is helpful in lowering the costs of renewable and low carbon technologies.

6. Conclusion

Temporal analysis was performed for the year 2000 and 2013 to study the trend of LST. LST was retrieved using mono-window algorithm using the Landsat ETM and Landsat 8 data. From the results obtained it was found that escalating trend of LST was observed in major parts of Noida city where built up area has increased. Through the correlation analysis, the relationship of LST with NDVI, NDBI, Albedo and Emissivity it was noticed that LST and NDBI share a positive relationship because in built up areas there is no type of restrictions such as sun radiations do not directly get in contact with the surface and hence the emissivity is comparatively lower. Albedo was also found to have a direct relationship with LST as the higher the albedo, the LST increases. A significant negative relationship was observed between LST and NDVI in which it was found that the areas where vegetation exists, the UHI effect was weak. Emissivity was also found to have a strong negative correlation with LST because di-electric properties of a feature greatly impact its ability to absorb or radiate heat and hence it was observed that the areas where emissivity was found to be high, low LST was reported.

Grid level analysis was also carried out to see which land use category had a major influence on the effect of LST. It was evident that built-up is one of the major land use category which is contributing to the formation of UHI.

Acknowledgments

The corresponding author expresses his gratefulness to the Vice Chancellor and Director, Amity Institute of Geoinformatics and Remote Sensing, Noida, for providing facility and constant encouragement for carried out this research work.

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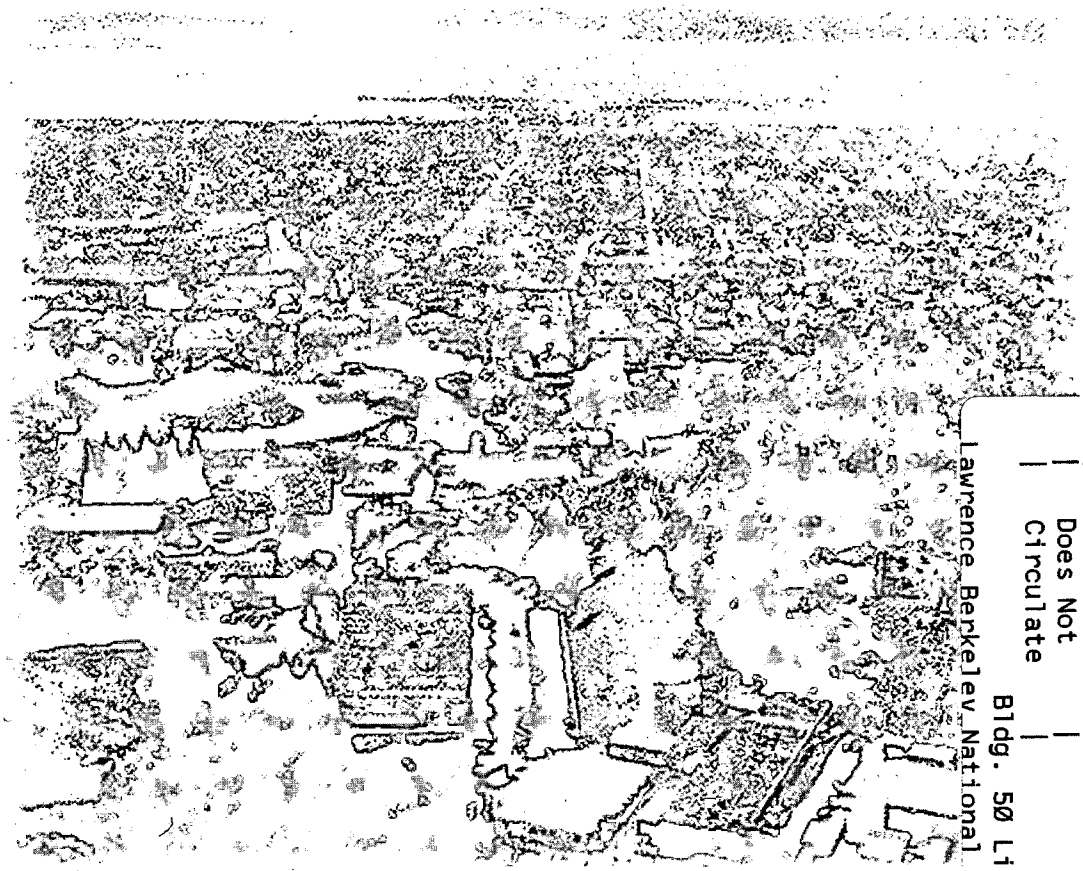
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Paving Materials for Heat Island Mitigation

M. Pomerantz, H. Akbari, A. Chen,
H. Taha, and A.H. Rosenfeld

Environmental Energy Technologies Division

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LBL-38074

Paving Materials for Heat Island Mitigation

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November 1997

This work was supported by the U.S. Environmental Protection Agency, and by the Office of Energy Efficiency and Renewable Energy, Office of Building Technologies, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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Paving Materials for Heat Island Mitigation

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Abstract

This report summarizes paving materials suitable for urban streets, driveways, parking lots and walkways. We evaluate materials for their abilities to reflect sunlight, which will reduce their temperatures. This in turn reduces the excess air temperature of cities (the "heat island" effect). The report presents the compositions of the materials, their suitability for particular applications, and their approximate costs (in 1996). Both new and resurfacing are described. We conclude that, although light-colored materials may be more expensive than conventional black materials, a thin layer of light-colored pavement may produce energy savings and smog reductions whose long-term worth is greater than the extra cost.

Key words: pavements, concrete, asphalt, grass, color, reflectivity, albedo, heat islands, safety.

Paving Materials for Heat Island Mitigation

M. Pomerantz, H. Akbari, A. Chen, H. Taha, and A. H. Rosenfeld

1. Introduction

The widespread paving of city streets with asphalt has happened only within the past hundred years. The advantages of this smooth and all-weather surface for the movement of bicycles and automobiles is obvious but some of the associated problems are perhaps not so well appreciated. One consequence of covering streets with dark asphalt surfaces is the increased heating of the city by sunlight. A surface is dark because it absorbs light; it gets warmer. The pavements in turn heat the air and help create the "urban heat island". If the urban surfaces were lighter in color, more of the incoming light would be reflected back into space and the surfaces and the air would be cooler. This tends to reduce the need for air-conditioning.

Cooler air, in turn, can reduce the amount of urban smog because the chemical reactions that produce smog slow down as the temperature is reduced. Avoided electricity generation also reduces air pollution. Recent simulations of smog production in Los Angeles(Taha, 1995) show that if a practical reflectivity [1] increase were effected it would lead to a decrease of the ozone exceedance by 12%. In some cases, a city that fails clean-air standards may thus be brought into compliance without drastic changes in lifestyle or infrastructure, such as restricted auto travel or electric cars. In addition to monetary savings, smog reduction improves the quality of life and health.

In addition to the heating caused by replacing cool vegetation by hot pavement, paved surfaces inhibit the entry of rainwater into the earth. This increases the danger of flooding and reduces the amount of water available for drinking or irrigation. We will discuss some porous and grass pavements which improve drainage.

We emphasize in this review those paving surfaces that ameliorate the heat island effect. We describe the chemical nature of the materials, their properties and most suitable applications, and their approximate costs (in 1996). The costs we state will be for the topmost paving material alone, because this is the layer that reflects the sunlight. This is only part of the total cost which may include preparation of the base on which the pavement is laid. We assume that the preparation costs are the same for all roads of the same class, regardless of the wearing surface. It is likely that light-colored surfaces will have higher initial costs than conventional dark materials. The crucial question is the marginal cost difference between dark and light surfaces. Even this marginal cost will decrease if lighter materials become widely used, and economies of scale set in. We cannot be precise about prices of materials because they depend on the size of the job, and the distance between the site and the sources of the materials. The relative costs of different materials may be the most useful information. In a future report we hope to address the important but more complicated issue of the life-time costs of the various surfaces. This is difficult because one needs, in addition to the initial costs, accurate data on the lifetime history of maintenance costs, down times, accident records, and disposal

[1] The reflectivity over the solar spectrum is also referred to as "albedo", which varies from 0, for perfect absorbers, to 1 for perfect reflectors. Taha's calculation assumes an albedo increase of 0.25.

costs of roads that perform comparable functions in comparable soil conditions and weather.

First we consider new pavements, which require grading of the terrain and a new base course of rock. The thickness of this base and its preparation will depend on the anticipated traffic. We focus therefore on the topmost (wearing) course which is relatively independent of the base and is the important part for the albedo of the pavement. Then we review resurfacing of pavements. The reasonable time to retrofit a street with a light surface is when routine maintenance is being performed. Then the total cost is increased by the marginal difference between light and dark materials; the extra labor and shut-down times are minimized. An analysis of cost vs savings completes the paper. A glossary of terms and a list of units are appended. We also include a list of sources of information.

2. New Pavements

We first consider new pavements that are sufficiently thick that they can support automobile traffic. We assume that the base is the same for each type of pavement and thus focus on the outer wearing course only. There are three main types of new pavements: asphalt concrete, cement concrete and porous paver. In general, a pavement consists of a binder (asphalt, tar, or Portland cement) and aggregate (stones of various sizes down to sand). The function of the binder is to glue the aggregate together. The aggregate provides the strength, friction and resistance to wear, and the binder keeps the stones from dispersing under the forces of the traffic and weather.

a) *Asphalt concrete in new pavements*

Asphalt or bituminous materials are the most common binders of road surfaces(Asphalt-Institute, 1989). The relative amount of asphalt and aggregate is about 1 part in 10 (typically about 7% asphalt by weight, or 17% by volume). This type of pavement is properly called "asphalt concrete", suggestive of its composite nature. The fact that about 80% of roads now in service are made of asphalt concrete is a result of its relatively low initial cost and ease of repair.

Asphalt is derived from petroleum. It is often the residue after lighter components, such as gasoline and kerosene, are fractionated from crude oil. As such, it varies in composition depending on the reservoir of origin and on the fractionating process to which it is subjected. Compared to the Portland cement concrete, bituminous concrete is more flexible. This has the advantage that the wearing surface tends to conform to any movements of the subgrade with less cracking, but too much softness can lead to spreading or rutting of the road. In particular, asphalt concrete softens more than Portland cement concrete at temperatures which roads may attain.

The cost of the bitumen itself is about $120 per ton (**Table 1**) (or $0.15 per liter or $0.50 per gallon). The cost of typical rock aggregate is about $16 per ton delivered within 25 miles of the quarry, and additional shipping costs about $0.10 per mile per ton(NSA, 1996). Asphalt concrete (with about 7% bitumen and 93% aggregate by weight) costs about $25/ton or $50/yd^3(Means, 1996). (The density of finished mixed asphalt concrete is 1.8 ton/yd^3 = 2.1 Mg/m^3). Thus for a surface 4 in thick, the cost is about $0.60/ft^2 (**Table 2**). The cost of the bitumen alone in a 4" pavement is about $0.25/ft^2.

Table 1. Approximate costs and densities of asphalt, asphalt concrete, cement and cement concrete.

Property		Asphalt Concrete		Cement Concrete	
		Asphalt	Concrete	Cement	Concrete
Cost	$/m^3	130	65	250	72
	$/Mg	130	31	83	30
	$/yd^3	100	50	190	55
	$/ton	120	28	75	28
Density	Mg/m^3	1	2.1	3	2.4
	ton/yd^3	0.84	1.8	2.5	2

b) *Cement concrete in new pavements*

Cement concrete consists of an inorganic binder, or *cement*, which, after being mixed with water, can harden and hold together stony aggregate. The raw material of the cement contains *lime* (CaO), which is derived from *limestone* (calcium carbonates, $CaCO_3$) or oyster shells. Portland cement contains *clay,* which has iron oxides, silica, and alumina in it. The approximate composition (by weight %) of Portland cements is(Leighou, 1942)lime (60), silica (20), alumina (5), iron oxide (3), magnesia (2), and other (10). Depending on the composition of the starting materials, a suitable mixture of them is ground together. (E.g., limestone contains 52% lime and 3% silica, but slag contains 42% lime and 34% silica, so the amount of clay (57% silica) to be added would differ between limestone and slag based cements to get a final silica content of 20%.)

Concrete pavings are the choice for very heavy traffic loads because the material does not deform as much as asphalt. In dry climates in Texas, for example, concrete is chosen when the traffic exceeds 70,000 cars per day. In wet climates, where the softer undersurface requires a stiffer road, concrete is preferred for traffic of 40,000 per day(Smart, 1994). However, the higher initial cost of concrete and the difficulty of modifying the surface favors asphalt in applications to roads that carry traffic in low volume and low weight, such as in residential areas and parking lots. The initial cost of ready mixed concrete is about $50 - $60 per cubic yard(Means, 1996), or about $30 per ton. Thus the cost is about $1/ft^2 for a 4" thickness.

Cement is darkened by the presence of iron oxide, which can be reduced to get a whiter cement by using kaolin, instead of ordinary clays. Added titanium dioxide makes it whiter, but manganese oxide, present in slag, makes it browner. Measurements and literature searches(Taha, Sailor et al., 1992), give an albedo, a , of fresh cement concrete of 0.35 - 0.40. As cement concrete ages it tends to get darker, because of dirt, and the a tends toward 0.25 - 0.30. Contrarily, asphalt concrete tends to get lighter as it ages, because the black asphalt wears away to reveal the lighter aggregate. We have measured $a = 0.15$ for an old asphalt pavement.

It is possible to produce concrete with visible reflectivity approaching 68 % by using whiter cements and aggregates(Lehigh-Cement, 1994)[2]. The cement is white because the starting materials are selected to have low concentrations of colored minerals, such as iron oxides. White aggregates, such as white sand, and some limestones are available, but

[2]White cement is available, for example, from Lehigh Portland Cement Co., Allentown, PA 18195

Table 2.
Representative materials for new pavements. Entries refer to the topmost layer; the grading and bases are assumed the same for all the pavements. Prices are merely indicative and average; they will vary with job size, location and time.

Name	Composition	base	thickness cm (in)	cost for thickness given $/m2 ($/ft2)	albedo*/color
Impermeable					
asphalt concrete	7 % asphalt + 93 % aggregate by weight	graded rock	10 cm (4 in)	$7/m2 ($0.60/ft2)	Albedo (new) 0.05 - 0.1, (weathered) 0.15 - 0.2
Portland cement concrete	portland cement/sand/stones (about 1/3/5 by weight)	graded rock	10 (4)	10 (0.9)	a (new) = 0.35 - 0.40, (weathered) 0.25 - 0.30
white cement concrete (Lehigh)	white aggregate + cement which is low in Fe oxides	graded rock	10 (4)	22 (2)	a (new) = 0.70 - 0.80, (weathered) 0.40 - 0.60
Road Oyl (Road Products Corp.,	resin modified emulsion	graded rock	10 (4)	11 (1)	Binder is tan colored
Permeable					
Grasscrete (Bomanite Co.)	concrete lattice, filled with soil.	soil, sand/ gravel	15 (6)	60 (5.5)	a(grass) ≈ 0.2
Grasspave2 (Invisible Structures, Inc.)	lattice of100% recycled rigid polyethylene cylinders, filled with soil	soil, sand/ gravel	3 (1)	$1.5/ft2 for < 10 kft2; $0.50/ft2 for M ft2.	a(grass) ≈ 0.2
Gravelpave (Invisible Structures Inc.)	Same as grasspave, except filled with gravel only.	soil, sand/ gravel	3 (1)	$1.5/ft2	a(gravel) ≈ 0.5
Geoblock (Presto Products)	lattice of 50% recycled, rigid fiber-reinforced polyethylene rectangles, filled with soil	soil, sand/ gravel	3 (1) or 5 (2)	$2/ft2 for more than 40,000 ft2	a(grass) ≈ 0.2
Geoweb (Presto Products)	Flexible polyethylene sheets formed into lattice, filled with soil and grass.	soil, sand/ gravel	>13 (> 5)	$0.95 /ft2 for more than 40, 000 ft2	a(grass) ≈ 0.2

*Albedo data from Taha, et al., 1992.

usually cost more. The price of white dolomite rock is about $30 per ton at the quarry, compared to usual rock at about $4 - 9 per ton at the quarry. Because the quarries for white rock are fewer, they are likely to be further from the final destination, and thus transportation costs may be higher than the usual $6/ton within 25 miles(Filapeck, 1994). Because of the higher costs of both the cement and the aggregates, the cost of white concrete is about $110 - $150/yd^3, or about $ 2 /ft^2 for a 4" thickness.

c) *Tree-resin modified emulsions*

"Road Oyl", a relatively new binder, is tan colored because it is derived from pine tree pitch and resin. When it is mixed with stone or sand, it produces a light colored pavement. In the emulsified form it is water soluble, applied without heating and thus is particularly convenient to apply where access of large equipment is a problem. After drying and setting it is insoluble in water. It is comparable in strength to asphalt concrete in laboratory tests, but has not yet been extensively tested on city streets. RoadOyl costs about $2 per gallon, and comprises about 6% by weight of the finished pavement. It is manufactured by Road Products Corp. of Knoxville, TN.

d) *Coal-tar resins*

In the South Eastern U. S., near coal mining regions, coal - tar resins are used in a manner similar to asphalt binder. Because it is not applied much nation-wide, and it is black, we shall not discuss it any further here.

e) *Porous pavers for new pavements*

Porous pavements are defined in this paper as pavements that deliberately allow water to pass through them. Permeability has the advantages of permitting rain water to be stored in the earth and reducing the problems of flooding. A road surface made of grass has the added desirable qualities that the grass evapotranspires and thus cools the air above it, and it is decorative. However, a grassy field as a parking lot or access road is soft when it is wet and is easily rutted permanently. These defects can be alleviated by enclosing the soil in a lattice structure that provides lateral containment. The lattice structure thus serves as a binder for the soil or gravel. We refer to such porous pavements as "grass pavement". All grass pavements must have sufficient water year round, which, depending on the location, may entail a cost. In Los Angeles, e. g., watering may cost $0.01/ft^2-yr. Grass pavers are best suited for occasional use where perhaps one or two cars a day traverse it (e.g., parking for employees, sports facilities, overflow), or as fire lanes, because grass cannot survive frequent traffic. Also, it is advisable to minimize walking on the surface for safety reasons because the footing may be somewhat irregular. The lattices supporting the grass pavers are made either of concrete or plastic.

Another type of porous pavement is formed of concrete (asphalt(Brown, 1996) or cement) which is loosely packed so that water can percolate through it. We now present some examples of these permeable pavements.

(i) Concrete-lattice grass pavement: The lattice of cement concrete can be either prefabricated or poured in place. Typical prefabricated units are 2 ft x 2 ft and 6" thick, with 3" or 4" diameter through-holes. The prefabricated pavers suffer from possible differential settling of one unit with respect to another, particularly in rainy conditions. At a greater cost per area, a large area can be covered with a poured-in-place type. For example, "Grasscrete", (Bomanite Corp., Madera, CA) is made of a grid of steel-reinforcing bars about which concrete is poured into forms to a thickness of at least 5". The bars are 6" apart, and when the concrete is in place it forms a pattern of roughly square blocks. There is space for soil between the blocks so that about half the area is filled with soil. When the grass is fully grown, from a distance it looks like a continuous lawn. The installation of Grasscrete requires more labor than does a simple concrete

pavement. Thus in addition to a materials cost of about \$2.50 per ft^2, there is an extra labor cost of about \$2.00 per ft^2, which gives a total cost of about \$ 5.50 per ft^2.

(ii) Plastic-lattice grass pavement: A lattice can be made of hard or soft plastic. A typical panel of the hard type is about 2 x 2 ft^2. The units can be connected together to inhibit differential movement, and cover large areas. The vertical walls of the cells of the lattice are about 1" tall, 0.25" thick, and spaced about 3" apart. Thus, most of the area is soil. In one product, "Geoblock®", (Presto Products Co., Appleton, WI) the areas of the cells are rectangles 6.9 cm x 7.1 cm (2.7 in x 2.8 in); in another, "Grassspave^2" (Invisible Structures, Inc., Aurora, CO) the cells are 6 cm (2.4") diameter cylinders connected on 10 cm (3") centers by spokes. The costs of these products (including the soil, grass, and the rigid forms) range upward from approximately \$1.5/ft^2 for areas about an acre. For areas approaching 100 acres (4 million ft^2) the price may decrease to about \$0.5/ft^2. Asphalt concrete prices, by comparison, seem not to depend as much on the scale of the job; they may decrease by about 20% for jobs over 1 acre. Thus for areas approaching 100 acres the prices of grass pavements are similar in cost to new asphalt concrete.

There is also a flexible plastic form, called "Geoweb®" (Presto Products Co., Appleton, WI). It is thin strips of plastic many feet long and about 8" tall, bonded together to form a lattice. When filled with earth it is strong enough to support an automobile.

Instead of filling the lattices with grass, one may substitute gravel or crushed stones. This will lead to lower maintenance costs and yet is still environmentally beneficial by allowing a path for rain water entry and having potentially light color, if the stones are chosen with this in mind. A possible combination might be access roads and lanes finished with white stones (which can withstand repeated traffic), and parking spaces finished with grass.

(iii) Porous pavement of asphalt or cement concrete: To construct a permeable pavement entirely of asphalt or cement concrete, the aggregate is chosen to be a single size, usually about 3/8 in. (so-called "open-graded" aggregates.) In the absence of fine aggregates and sand, the stones pack so loosely that there are channels through which moderate flows of water can filter(Asphalt-Institute, 1974). This porous pavement is usually placed over a solid pavement for strength, and is domed such that the water leaks out the sides of the roadway. Blockage of the pores by dirt, and fracture by freeze-thaw cycles may be problems. The porous surface has a safety advantage of avoiding standing water that can lead to aquaplaning by fast autos. Another benefit that is welcome in cities is that these surfaces tend to suppress tire noise(Hugues, *et al.*, 1995; Lefebvre, *et al.*, 1995).

3. Resurfacing of pavements

a) *Asphaltic coatings*

Asphalt and asphalt based materials are the most common for repair and resurfacing roads(Raza, 1995). Asphalt adheres well to both older asphalt and to cement concrete. For large jobs, conventional hot-mix asphalt concrete at least an inch thick is commonly used. The price of hot ready-mix asphalt concrete is indicated in Table 1. The prices of resurfacing are shown in **Table 3**.

Keeping asphalt in a fluid state is accomplished by having oil-fired heaters onboard the spreaders. For small repair jobs, room temperature bituminous binders have been developed. One such binder is asphalt dissolved in kerosene or creosote. This is called a

Table 3.
Materials for resurfacing pavements. Costs are for the materials only for the given thicknesses. They are merely indicative as they vary with location, time and size of the job.

Name	Composition	Base	Thickness cm (in)	Cost ($/m2)	Albedo or Color
Chip seal/Seal coat Surface treatment	aggregate pressed into emulsified asphalt	previous pavement stony or soil subbase	1 (0.4")	0.8	depends on aggregate
Sand seal	sand pressed into asphalt emulsion, cement	previous pavement	0.2 (0.08")	0.6	depends on aggregate
Hot-mix overlay (Blacktop)	hot asphalt, various aggregates mixed before spreading	previous pavement	1.3 (0.5")	1	*0.1 (new); 0.2 (weathered)
Slurry	asphalt emulsion, cellulose fibers, color agents, aggregate (3/8 in.)	previous pavement	0.7 (0.3")	0.7	*0.1
Microsurfacing	polymer-modified asphalt emulsion, crushed mineral aggregate, mineral filler, water, and field additives as needed.	previous pavement	0.7 (0.3 ")	1.4	*0.1
Fog coat, or tack coat	asphalt emulsion	previous pavement	0.013 (0.005")	0.01	*0.1
Petroleum resin (Pavebrite)	petroleum resin + white fine aggregate + pigment	rock, previous asphalt or concrete + pavebrite tack coat	1.3 (0.5")	10	add TiO2 for whiteness
Pine resin (Road Oyl)	tree resin modified emulsion	graded rock	>10.2 (> 4")	10	Binder is tan colored
Cement concrete	portland cement and aggregates	pavement	>5.1 (> 2")	6.5	*0.4 (new); 0.3 (weathered)
Acrylic	acrylics, dyes, fillers	previous pavement	0.2 (0.06)	3.4	^0.5 (new)

*Albedo data from Taha, et al., (1992).
^Unpublished measurements by Berdahl and Wang, LBNL (1996).

"cutback" asphalt. The solvent evaporates over a "curing" time, after which the asphalt is hard. The emission of the organic solvents, however, has adverse effects on the environment, so the cutback asphalts have been superceded by water-soluble asphalt emulsions(AEMA 1995). Here the bitumen is ground to small particles and chemically treated with an emulsifier so that it remains in suspension in water. The emulsifier is chosen anionic or cationic to facilitate the wetting of the particular mineral aggregates that are mixed with the emulsion. After the spreading of the emulsion and aggregate, the water separates ("breaks") and evaporates harmlessly. The asphalt coats and binds the aggregate to form an asphalt concrete. Asphalt emulsions cost from 15% to 100% more than bulk asphalt; costs of more than $1/gal(Reed 1997), and an average of about $1.50 per gal are quoted(Raza 1995; Means 1996). Emulsions have drying times of as little as a few hours, resulting in minimal disruption of traffic. A newer type of binder is formed by adding polymers to asphalt emulsions; this is called "micro-surfacing". We emphasize in Table 3 the costs of the materials alone, but it should be borne in mind that as the repaving gets thinner, the relative costs of the material, compared to costs of labor and equipment gets smaller. For example, the costs (¢ per square yard) of the thinnest layer of asphalt emulsion, a "tack coat", are broken down(Means 1996) to 8 (¢/yd^2) for the material, 15 for the labor and 28 for equipment, for jobs of 1000 square yards. For thicker resurfacing, such as "slurry seals", the costs for small jobs breaks down to 57 (¢/yd^2) for material, 46 for labor and 43 for equipment; material is a more significant component. For larger jobs, however, economies of scale set in for labor and equipment, but less so for material. Thus, materials are a larger component for large jobs. For example, for tack coats of 10,000 square yd, the labor and equipment costs decrease from 15 and 28 (¢/yd^2) to 4 and 7 (¢/yd^2) respectively, but the material cost remains the same at 8 (¢/yd^2).

There are two general approaches to the repair or resurfacing of an existing pavement(Hunter 1994). In both cases the new surface is a composite of binder and aggregate; the difference is whether these components are mixed after or before the binder is spread on the old surface. If the binder is spread first and then the aggregate is dropped on top of it and then pressed into the binder, it is called a "chip" seal or a "sand" seal. Otherwise, the aggregate and binder are premixed and then spread. The mixing is often done onboard the spreader vehicle just before the mixture is applied to the pavement. The premixed pavements are known as "overlays", "slurry coats", "microsurfaces", and "fog coats" depending on the binder and the size of aggregate; they have different suitabilities.

(i) Chip seal: The binder in a chip seal is usually a fast-drying emulsified asphalt. As soon as possible after the binder is spread, uniform aggregate is dropped and rolled into the binder. The typical surface is about 1/4" thick. When the chip seal is used to resurface an existing pavement it is sometimes(AEMA 1995) referred to as a "seal coat", which may be confused with the same word applied to a slurry coat containing fine aggregate. (Cf. below). When the chip seal is applied to a stony or soil surface it may be referred to as a "surface treatment"(AEMA 1995).

Chip seals are usually applied to low-use roads, such as in rural areas. The rough aggregate on the surface is problematic in residential areas where children play and fall, and loose aggregate thrown by car tires may be more dangerous. The color of the surface is strongly influenced by the color of the aggregate. When white limestone is used, as in Texas where it is abundant, a quite white surface results. The average cost of chip seals is about $0.75/m^2 (Raza 1995).

(ii) Sand seal: This provides a thin coating for surfaces which have small need of repair. It consists of a emulsified asphalt onto which sand is spread. Sometimes cement

and other materials are added to the mix, but the aggregate particles must be smaller in diameter than about 0.04". The preliminary preparation of the surface is relatively simple. Deposits of grease and oil must be removed or sealed over. Otherwise, the surface must be thoroughly cleaned of loose dirt or paving particles. The surface is then dampened with water, and the slurry is applied in a smooth coat. For one coat, the amount of asphalt applied(Asphalt-Institute 1989) is about 0.6 liter/m^2, and about 4 kg/m^2 of sand, which produces a layer about 1mm (0.05") thick. The thickness of the binder is about 0.6 mm (0.03"). Sand seals cost about $ 0.50/m^2 ($0.06/$ft^2$)(Means 1996). (Note that the term "seal coat" is sometimes applied to chip seals on pre-existing pavements.)

The color of the binder is basically gray, and is normally made darker by the addition of carbon black. Even when the carbon black is omitted, the gray surface has an albedo of 0.05, as measured by P. Berdahl at LBNL. To lighten the color, rutile (titanium dioxide, TiO_2) powder can be added. This increases albedo to 0.10 with no loss of structural quality. An emulsion designed to rejuvenate asphalt, Reclamite(Erickson 1989), is often followed by a coating with sand. Thus a lighter color is achievable if white sand is used.

The more common pre-mixed asphaltic resurfacing methods, in the order of decreasing thickness are:

(iii) Hot-mix overlays: For roads needing considerable repair or that must support large stresses, such as near stop signs where acceleration and turning are frequent, a sturdy repair can be done with a hot mix containing aggregate from 3/8" to 1/2" in maximum diameters. Typical(Raza 1995) dense hot-mix applications are about 35 kg/m^2 for each layer. At 2 ton/yd^3 (2.3 Mg/m^3), this is about 0.5" thick. At a cost of $30/Mg ($25/ton), the unit price is about $1/$m^2$ ($0.1/$ft^2$) for a 5,000 ft^2 job.

(iv) Slurries: For surfaces with medium need of repair and that carry considerable traffic, resurfacing may be done with a mixture of asphalt emulsion and aggregate. The size of the aggregate and the formulation of the emulsion are determined by the expected traffic and the climate. The typical aggregate is about 1/4" maximum diameter (ISSA 1991). The slurry is spread at about 7 kg per m^2 (1.4 lb/ft^2). At a density of about 2.1 Mg/m^3 (specific gravity of 2.1) this gives a thickness of about 0.4 cm or 0.2 in. (one rock thick). The cost of materials is about $ 0.70 per m^2 for large jobs(Means 1996).

(v) Microsurfacing: When polymers are added to slurry binders the product is called "microsurfacing"(Raza 1994). The polymer confers greater resistance to wear. In addition, it becomes possible to apply a layer in multistone thicknesses; it can be more than 1.5 times thicker than the largest aggregate. It can be used for layers down to 0.3". At a cost of about $110/Mg or tonne ($100/ton) and a material application rate(Raza 1994) of 13 kg/m^2, the cost of materials is about $1.40/$m^2$ ($0.13/$ft^2$).

(vi) Fog coat: A thin layer of diluted asphalt emulsion is spread on an existing pavement. It can be used as a protective layer, but also to change color. The typical amount of asphalt applied is about 0.06L /m^2 (0.03 gal/yd^2)(AEMA 1995). This results in a coating about 0.005" thick. The cost of the labor would dominate the total cost because the amount of material is so small.

b. Petroleum resin coatings

A petroleum product that is not an asphalt is manufactured by Neville Chemical Co., Pittsburgh, PA, and sold as "Pavebrite®"(Willockl 1995). Similar products are distributed in Europe by the French Shell Oil, as "Mexphalte C" and by Total as "LSC",

(Liants Synthetiques Clairs). These are synthetic resins derived from lighter fractions of petroleum, and chemically modified. The pure material is tan in color, but coloring additives can achieve bright colors. The color of the aggregates must be chosen to not interfere with the desired color, as well as to provide the required mechanical strength. The aggregates are fine graded, meaning they all pass a # 8 mesh (about 0.1") screen. This is necessary in order to prevent the color of the aggregate from becoming significant as the pavement wears, if one desires that the color pavement stay the color of the binder. For the purposes of a whiter road, a white binder could be mixed with white rock of any desired sizes. The mechanical properties of the paving is reported to be at least as good as comparable asphaltic pavings.

The typical use in the U. S. has been for pavements at least 1/2" thick. In Holland there is some experience in using the binder in slurries. The cost of this product is currently about $8/gal. and the complete mixture with aggregate and pigments is about $350/ton. A ton occupies about 15 ft^3. When used for a 1/2" pavement, it requires one ton to make 36 yd^2 and thus cost about $1/$ft^2$.

c. *Tree resin coatings*

A resinous material derived from pine trees, known as RoadOyl®, is used for roads and dust-suppression. In Marshall stability tests, it is reported to perform at least as well as asphalt(SSC, 1995). It has not yet been completely evaluated as a slurry binder. Its cost is about $2/gal.

d. *Cement concrete coatings ("white-topping")*

Layers of concrete as thin as 2" have been used for resurfacing roads. The procedure is still somewhat experimental and the long-term behavior and proper practice are still under study.

e. *Acrylics*

These are synthetic polymers which can be highly colored. They are expensive, and are thus far have been used mostly for special applications such as tennis courts. Recently, Reed and Graham, Inc., San Jose CA, produced experimental materials based on acrylics mixed with pigments, that proved to have acceptable structural strength(Lungren, *et al.*, 1996) as a roadway, and solar reflectivities of about 50%(Berdahl, *et al.*, 1996). The effect of the high albedo on the temperature of the pavement was measured(Pomerantz, *et al.*, 1997) by comparison of a new asphalt concrete pavement, of albedo 0.05, an old asphalt pavement, a = 0.15, and an old asphalt pavement coated with the white overcoat, a = 0.50. On a sunny September afternoon in Berkeley, CA, the measured pavement temperatures were as shown in Fig. 1. A considerable effect of albedo on temperature is evident.

The cost is estimated at $8 per gallon. At the recommended coverage of 25 ft^2 per gallon, the cost is about $0.3 per ft^2, or $3.4/$m^2$.

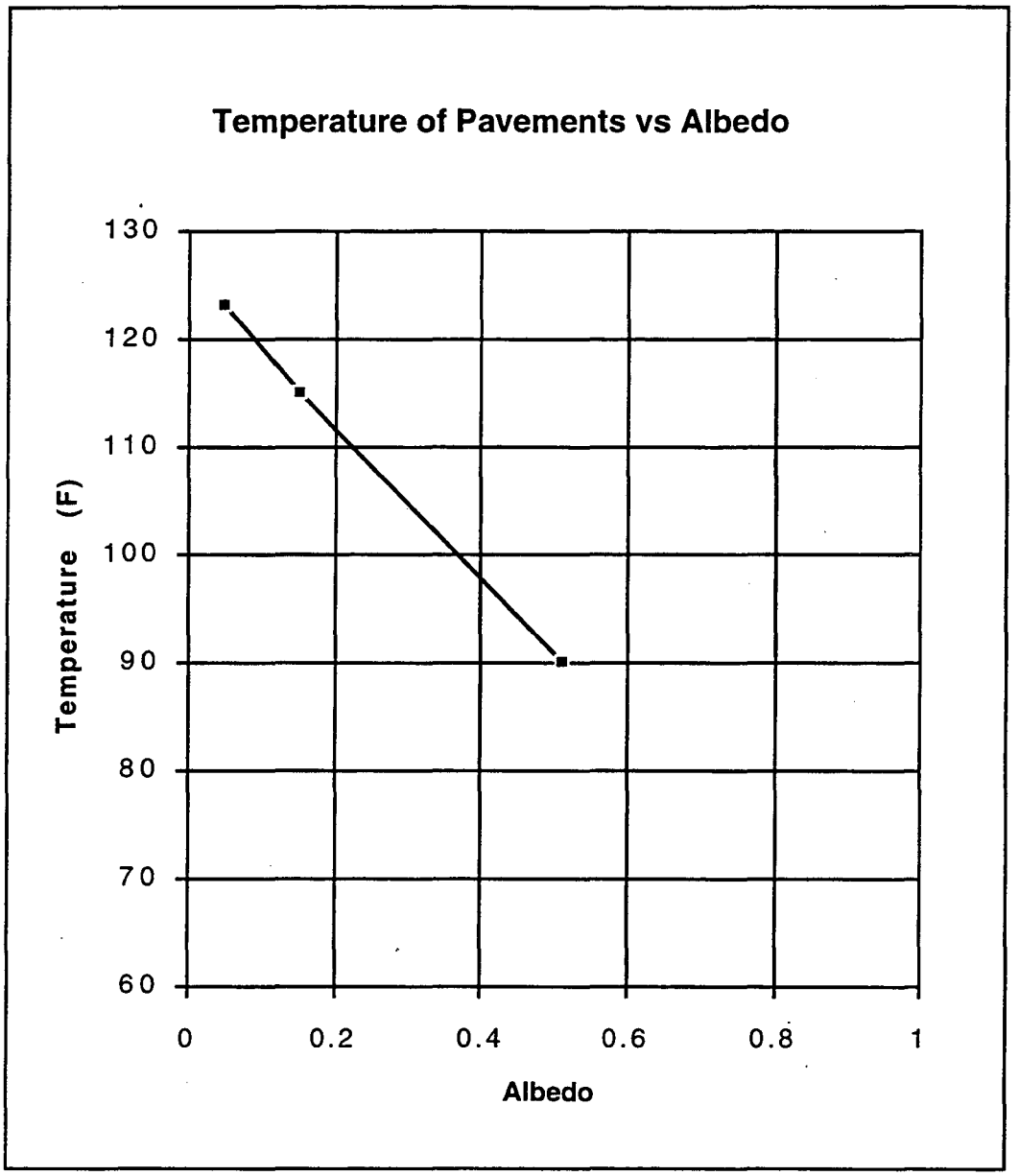


Fig. 1. Dependence of pavement temperature on albedo, on an afternoon in September, in Berkeley, CA.

4. Costs and savings of reflective pavements

We now address the question of whether the higher cost of high albedo pavements can be compensated by the savings produced by cooler surfaces. An estimate of the cost savings to society can be deduced by finding the temperature decrease that would result if a city were resurfaced with more reflective materials. Lower temperature has two effects: reduced demand for electricity for air conditioning and decreased production of smog (ozone). We sketch now the cost savings of both reduced demand for electricity and the externalities of lower ozone concentrations. The details are published elsewhere (Rosenfeld, Romm et al., 1996).

a. *Electric power savings in Los Angeles*

Simulations of Los Angeles show that for a practical change in albedo a noticeable decrease in temperature can be achieved. A simulation of Los Angeles predicted a 1.5 °C (2.7 °F) decrease in temperature of the downtown area(Taha, 1995). (The model assumes that all roofs (1250 $km^{2)}$ have albedo increased by 0.35 and all pavements (1250 km^2) have albedo increased by 0.25.) From simulations of the temperature changes on one day in each season, the temperature changes for every day in a typical year were estimated for Burbank, typical of the hottest 1/3 of LA. The energy consumptions of typical buildings were then simulated for the original weather and also for the modified weather. The differences are the energy-demand changes due to the ambient temperature decrease. The result is a city-wide annual saving of about $71 M, due to combined albedo and vegetation changes. The temperature changes due to albedo came out to be the same as due to trees. Pavements give rise to about 21% of the total saving since their area is the same as the roof area, but their albedo change is assumed to be 0.25 compared to roof-albedo change of 0.35. Thus the savings attributable to the pavement is $15 M/yr, or $0.012/$m^2$-yr ($0.001 per ft^2-yr). Analysis of the hourly demand indicates that cooler pavements could save an estimated 100 MW of *peak* power in LA. The power plants required to handle this peak load need not then be built, which saves money, resources, and pollution.

We can estimate the savings due to grass parking lots from the result for trees. Planting 11 million trees reduces the temperature by about 2.7 F (1.5 C), similar in magnitude as albedo changes(Taha, 1996). Thus trees cause about half of the total saving of $71 M per year, or $35 M per year. Each of the 11 million trees thus saves about $3 per year, or $23 present value. (The present value multiplier is 7.5 because it takes about 10 years for the tree to reach full size(Rosenfeld, *et al.*, 1997). A mature tree has an area of about 50 m^2 or 538 ft^2. A typical parking stall has an area of 300 ft^2, included lanes. If it is assumed that the area of grass is as effective at cooling the air as the same area of tree, a grass parking stall will save 0.56 as much as a tree, or about $1.7/stall -yr. Unlike a tree, grass is effective in its first year. Thus its present-value multiplier for a 10 year life is 8.5, giving a present value of $14.5/stall.

b.*Smog savings in Los Angeles*

The production of ozone (O_3) in smog requires precursors (nitrous oxides (NO_x) and volatile organic hydrocarbon gases), sunlight and heat to drive the reactions. These reactions occur more rapidly as the temperature is increased, known as "cooking the smog". The influence of temperature is demonstrated by the dramatic dependence of smog incidents on the daily maximum temperature in Los Angeles. In 1985, there were no violations of the National Air Quality Standards of 120 parts per billion of ozone when the maximum temperature was below 72 °F. Above that temperature the number of days with violations increased steadily, until for peak temperatures of 95 °F the ozone concentrations can be almost double the allowable level(Taha, 1995). The simulations of the effects of higher albedo on smog formation indicate that an albedo change of 0.3 over the developed 25% of the city would yield a 12% decrease in the exceedance above the California standards(Taha, 1995). It has been estimated(Hall, *et al.*, 1992) that people would pay about $10 billion per year to avoid the medical costs and lost work due to air pollution in LA. The bigger part of pollution is particulates, but the ozone contribution is about $3 billion/yr. Assuming a proportional relationship of the cost with the amount of smog exceedance, the cooler-surfaced city would save 12% of $3 billion/yr, or $360 M/yr. As above, we attribute about 21% of the saving to pavements. Thus the smog

improvement from changing the albedo of all 1250 km^2 of pavements by 0.25 saves about \$76M/yr. Per unit area, this is worth about \$0.06/m^2-yr, (\$0.0056/ft^2-yr).

It was estimated(Rosenfeld , *et al.*, 1997) that the cooling by trees can lower the air temperature in Los Angeles sufficient to reduce smog and save \$180 M. The savings of grass parking areas, by analogy with trees, as in the previous section, has a present values of about \$75/stall. Thus a grass stall in LA can cost an extra \$89 and be economical. These estimates depend on the simulations of LA. For other cities a similar analysis needs to be performed.

c. Comparison of cost vs savings of cooler pavements

The economic question is whether the savings generated by a cool pavement over its lifetime are greater than its extra cost. Properly, one should distinguish between initial cost and lifetime costs (including maintenance, repair time, and length of service of the road). Often the initial cost is decisive, so, again, we will consider only that here. Consider first a new asphalt pavement; its lifetime is about 20 years. If it were made with a reflective aggregate it would generate a stream of savings (\$0.07/m^2-year or \$0.007/ft^2-year in LA) for this length of time. At a real interest rate of 3% per year, this has a present value about 15 times the current saving(Rosenfeld , *et al.*, 1997). Thus, the potential savings are worth \$1.08/m^2 (\$0.10/ft^2) at present. Table 2 indicates that all *new* light-colored pavements cost more than \$1.08/m^2 (\$0.10/ft^2) more than black asphalt, and are thus too expensive.

However, to improve the reflectivity of a road it is sufficient that only the outer layer be reflective. The possibility that *resurfaced* layers may be competitively priced will now be estimated. The lifetime of resurfacing is only about 5 years, so that the present value is 5 times greater than the annual savings[3]. Thus the present value is about \$0.36 /m^2 (\$0.03/ft^2). Can a pavement be resurfaced with a light color at an added cost less than this saving?

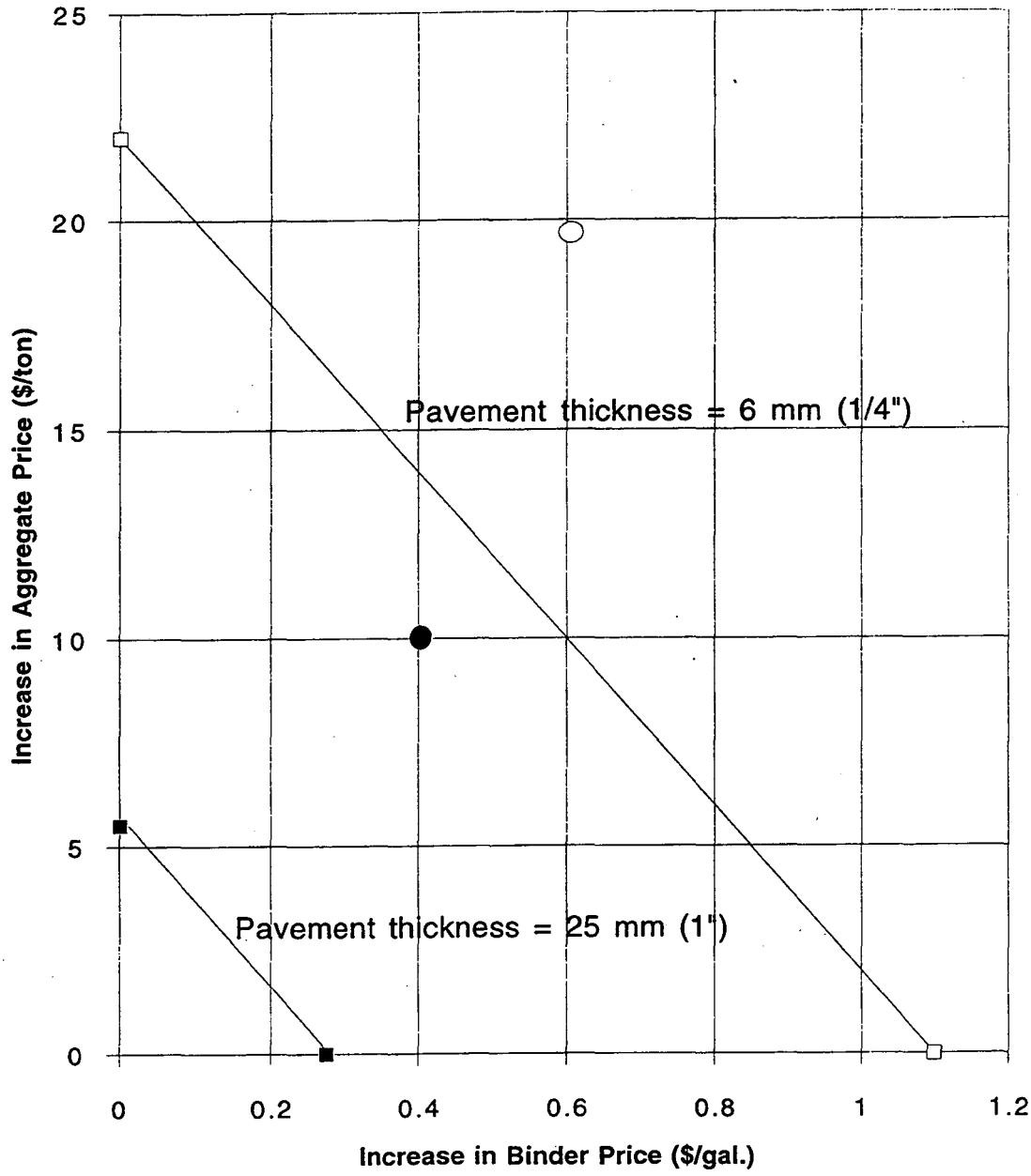
From our survey of asphalt-based pavements, we observe that, within ± 2 %, all of them are composed of about 93% aggregate and 7% binder, by weight (Asphalt-Institute, 1989). We can thus express the cost of the *materials* of all asphalt-based layers as the sum of the costs of the aggregate and the binder. (We assume that there is no difference in cost between the laying of different kinds of pavements.) In what follows we give numbers in metric units. For *6 mm thick resurfacing,* 1 m^3 of paving has a volume of 0.006 m^3 , of which 17.5% by volume is binder (the density of aggregate is about 2.5 times greater than asphalt). Thus, in this volume, 0.00495 m3 (0.0172 ft^3) is aggregate and 0.00105 m^3 (0.00364 ft^3) is binder. Other units for the amount of aggregate are 0.00495 m^3 <=> *12.4 kg*. Other units for the amount of binder are 0.00105 m^3 <=> 1.05 kg <=> *1.05 liters* . Thus, using units of \$/kg for the cost of aggregate, A, and \$/liter for the cost of binder, B, the price, P, of material for 1 m^2 of 6mm thick pavement is P (6 mm) = 12.4A + 1.05B. Note that the costs of pavements are proportional to their thicknesses in this approximation of constant cost of application[4].

---

[3]This ignores the possibility that the light-colored aggregate may be recycled in subsequent resurfacings. In that case the effective lifetime of the material is greater, the present value multiplier will be larger than 5, and the savings will be larger than calculated here.

[4] In English units, the price of the one square foot of same thickness (6 mm or 1/4 in.) is given by P= 0.00135A + 0.0273B, where A is the cost of aggregate in \$/ton and B is the

Fig. 2. Increase in the binder and aggregate prices at a cost of $0.36 per square meter ($0.03 per square foot).



If one buys more expensive aggregate, at a cost change of ΔA, and binder at a cost change of ΔB, the price *changes* of the pavement, ΔP, can similarly be written:

$$\Delta P\,(6\text{ mm}) = 12.4\Delta A + 1.05\Delta B, \quad (\$/m^2) \qquad (1)$$

From Eq. 1 we can determine the maximum price *increases* of aggregate and binder for a 1/4 " thick pavement that are paid for by the cooling savings, ΔP. This is shown in **Fig. 2.** The increases in aggregate prices and binder prices below the line that passes through the open squares result in cost increases less than the savings of $\$0.36/m^2$ ($\$0.03/ft^2$). For example, a binder more costly by as much as \$1.10/gal is affordable (if the aggregate is unchanged). Or, aggregate costing up to \$22/ton more can be used (and the binder stays the same). It is likely that very white aggregate can be bought at this price. Of course, intermediate choices between these extremes are possible. One needs only to stay below the line drawn through the open squares in Fig. 2. For example, an increase in cost of aggregate by \$10 and an increase of binder by \$0.40 per gallon, indicated by the full circle in Fig. 2, would be an economical choice for a 6 mm thick resurfacing. But increases of \$20/ton for aggregate and \$0.60/gal for binder would not be paid for by the benefits (the empty circle lies above the line).

To demonstrate the effect of the layer thickness, we repeat this analysis for a thicker layer, say 25 mm (1") thick. Since four times as much material is used than for the 1/4" pavement, Eq. 1 becomes

$$\Delta P(25\text{ mm}) = 49.6\Delta A(\$/kg) + 4.2\Delta B(\$/liter) \qquad (\$/m^2) \quad (2)$$

or in English units:

$$\Delta P(1\text{" thick}) = 0.00540\Delta A(\$/ton) + 0.109\Delta B(\$/gal) \qquad (\$/ft^2)$$

The affordable price increases of aggregates and binders (that cause a price increase equal to the cooling saving of $\$0.36/m^2$ or $\$0.03/ft^2$) are shown by the line through the filled squares of Fig. 2. In this case, one could afford an increase of up to \$0.27/gal in binder price, or an increase of \$5.5/ton in the aggregate price. Clearly, a thinner layer is more likely to be economical.

5. Conclusions and future work

The first conclusion is that one should consider the thinnest layers possible. As the layers get thinner their costs decrease, and the extra costs of the lighter material also decrease. The benefit from higher albedo does not decrease with the thinness until the base shows through. Thus, one should use only enough of the more expensive coating to achieve the maximum albedo and sufficient mechanical strength. Significantly, with thin enough layers, quite white surfaces may be affordable. In LA, for example, the savings in air conditioning costs and smog abatement repay an extra cost of as much as \$22/ton for aggregate; the whiter aggregate available at this additional price pays for itself.

---

cost of binder in \$/gal. To check the accuracy of this equation, recall from Tables 2 and 3 that the least expensive materials for pavement are aggregate at about \$15/ton (delivered) and asphalt at about \$0.50/gal. We find the cost P to be about $\$0.04/ft^2$ for a 1/4" thick pavement. Scaled up to a 4" thick asphalt pavement, this predicts a 16 fold greater cost of $\$0.64/ft^2$. This agrees with a 4" thickness costing $\$0.60/ft^2$ (Dalmaso, 1995). Asphalt slurry coats use binder costing about \$1/gal, and aggregate at about \$15/ton. They give a coating about 1/4" thick and Eq. 1 predicts a cost of about $\$0.06/ft^2$. This is close to the value of $\$0.63/ft^2$ ($\$0.57/yd^2$), reported by Means(Means, 1996). The equation for the cost of materials thus gives reasonable estimates of actual costs for thick pavements. For thin pavements the estimate is lower than what contractors quote, probably because installation is a relatively larger fraction of the cost compared to the materials.

There are other benefits of higher albedo beyond electricity costs and smog which need to be investigated in the future.

1. Because the surface stays cooler there is less softening of the asphalt, and thus there is less rutting due to traffic(Loustalot, *et al.*, 1995). The lifetime of the road is thereby extended. There are some preliminary laboratory tests of the relationship of durability and temperature of the asphalt-aggregate sample(Monismith, *et al.*, 1994). If the asphalt road is cooler, the chemical reactions that make the asphalt more brittle proceed at a slower rate and thus the desired flexibility is maintained for longer times. Longer lifetimes save on maintenance and replacement costs, including the disposal of old roads.

2. If fewer resurfacings are made there is less emission of the volatile asphalt fumes which feed smog.

3. If roads are cooler, softer (presumably cheaper) grades of asphalt may be used.

4. Whiter road surfaces require less night-time artificial lighting while maintaining visibility of pedestrians. Thus, safety and crime prevention will cost less.

The quantification of these effects requires further research.

Possible problems with light-colored pavements are that there may be excessive glare with extremely reflective pavements, which may make some people uncomfortable or unable to see well. The reflectivity of fresh cement concrete (about 35%) seems to be no problem, however. Also, in locales where there is thin snow on the pavements for part of the year, the snow may melt slower on a whiter road. This disadvantage may be compensated by the longer lifetime of the road due to less frequent freezing and thawing, which is a major cause of deterioration of roads. These factors need to be checked in controlled field situations in order to be quantified.

Disclaimer

The mention in this report of specific suppliers of materials does not represent an endorsement of the company or the product by the authors or by the DoE. It is only meant to indicate the commercial availability of the kind of product discussed.

Acknowledgements

We wish to thank those who provided us with information: Alan Dalmaso of Dryco Pavings, Berkeley, CA; Lance Boyer and Shawn Devine, Sullivan Concrete, Costa Mesa, CA; Bill Bohnhoff, Invisible Structures, Aurora, CO; Carol Goldman and Bart Lungren of Reed and Graham Co., San Jose, CA; Marsh Pitman, Soil Stabilization Co., Merced, CA; Roger Smith, formerly of the Asphalt Institute, Auburn, CA; D. Filapeck, Rock Transport Co., Oakland, CA; Steve Konopacki provided timely DOE-2 simulations. This work was supported by the U. S. Environmental Protection Agency and the U. S. Department of Energy under contract N0. DE- AC03-76SF00098.

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Appendix A. Glossary of some pavement terms:

Aggregate: A hard material used in pavements to bear the weight and provide skid resistance. It can be sand, rock, gravel, ceramics, etc.
Asphalt: A petroleum product used as a binder in asphalt concrete pavements and coatings. It is solid at room temperature. It is often the remainder after the refinement of crude oil has removed other liquids such as gasoline and kerosene.
Binder: A general term for the component of a pavement that adheres to aggregate, holding it together to prevent its spreading under the action of traffic. Common forms of binder are cements (such as Portland cement) and asphalt.
Cement: The inorganic binding material used to hold together sand (in mortar) or sand and rocks (in concrete). Cement is distinguished from asphalt which is an organic (hydrocarbon) binder.
Chip seal: A method of resurfacing a pavement that involves covering the pavement with a binder, such as asphalt, and then spreading aggregate ("chips") such as rocks or sea shells, and pressing the aggregate into the binder and the older surface.
Concrete: The general term applied to a composite of binder and aggregate to form a pavement. The major distinction among concretes is the binder used; the aggregates are often similar. Common examples are Portland-cement concrete and asphalt concrete.
Cut - back bitumen: Bitumen to which a volatile solvent, such as kerosene or creosote has been added. These are used when small amounts of binder are needed and it is inconvenient to heat the viscous bitumen.
Emulsion: A material in which an oily substance is mixed with an ionic substance such that they do not segregate. In the case of an asphalt emulsion, the asphalt is ground to a size less than 50 micrometers. It is then treated with an emulsifier, a molecule that has an oily end, which attaches to the asphalt. The other end is ionic and is repelled by the asphalt but is attractive to water. Thus the asphalt particles present a water-seeking coating which allows them to remain in suspension in water.
Hot mix: Asphalt that is melted and mixed with aggregate before being spread for pavement.
Macadam: Type of road construction in which the base (under the wearing surface) is of compacted rock. The surface is contoured for drainage .
Marshall stability test: The maximum compressive force that a sample 102 mm (4 in.) in diameter and 64 mm (2 1/2 in.) in height can support before rupturing, under specified conditions of compaction, temperature, rate of deformation, and direction of force(Asphalt-Institute, 1989).
Microsurfacing: Resurfacing method employing an polymer-modified emulsion binder that also contains crushed stone aggregate, and mineral filler (e.g., Portland cement), and water.
Overlay: A resurfacing material which is a hot mix, containing aggregate of about 3/8 or 1/2 in. diameter.
Portland cement: A mixture of calcium-bearing minerals, clay and water which is a binder when it solidifies.
Seal coat: A mixture of emulsified bitumen, water and a fine aggregate, used to resurface a pavement with a thin (less than 1/32 in) layer. Sometimes the term is used to refer to a chip-seal placed on an existing pavement.
Slurry coat: A mixture of emulsified bitumen, water and a gritty aggregate, used to resurface a pavement with a layer about 1/8 to 1/4 in. thick.

Appendix B. Units and conversions

The units used in this report are abbreviated as follows : inch = " or in., foot = ft, square foot = ft^2, cubic foot = ft^3, yard = yd, square yard = yd^2 , cubic yard = yd^3, square meter = m^2, cubic meter = m^3. Because this review is intended for people in the United States pavement industry as well as the research community, we use both the common U. S. units of length, weight and temperature, as well as metric units. The conversions we use are:

1 yd = 3 ft = 0.914 m

1 yd^2 (square yard) = 9 ft^2 = 0.836 m^2; 1 m^2= 10.76 ft^2

1 yd^3 (cubic yard) = 27 ft^3= 0.765 m^3

1°F = 5/9 °C. Temperature of 65 °F corresponds to 18 °C

1 lb <-> 0.454 kg <-> 0.12 gallons of water (or asphalt)

1 ton (short - 2000 lb) <-> 907 kg = 0.907 Mg

To convert kg/m^3 to lb/yd^3 , multiply it by 1.69.

Appendix C. Trade associations and sources of information

American Portland Cement Association (APCA), Suite 300, 1225 Eye Street N.W., Washington, D.C. 20005 (202) 408-9494 - fax- 0877

American Concrete Pavement Assoc, 3800 N. Wilke Rd, Suite 490, Arlington Heights, Ill 60004-1268, (708) 966-2272, fax- 394-5610

Asphalt Emulsion Manufacturers Association, #3 Church Circle, Suite 250, Annapolis, MD 21401, (410) 267-0023, fax-7546 - manufacturers of various emulsions, microsurface.

Asphalt Institute, Research Park Drive, P. O. Box 14052, Lexington, KY 40512-4052, (606)288-4960 - fax -4999

Asphalt Sealcoat Manufacturers Assoc., P. O. Box 511, Elk Grove, CA 95759-0511

International Slurry Surfacing Assoc. 1200 19th Street, N. W., Suite 300, Washington, D. C. 20036-2401 (202) 857-1160, fax 223-4579. Represents contractors who apply slurry seals.

Federal Highway Research Report Information System, R &T Report Center (703) 285-2144, fax-2919

National Asphalt Pavement Assoc., 5100 Forbes Blvd., Lantham, MD 20706 - 4413 (301) 731-4748, fax-4621 (Gary Fore)

National Ready Mixed Concrete Assoc., 900 Spring Street, Silver Spring, MD 20910, (301) 587-1400, fax 585-4219

National Stone Association, Washington, D.C. 800/342-1415. Represents suppliers of aggregate.

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Prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098

FEASIBILITY ASSESSMENT

REPLACING DIESEL-BASED WITH GAS-BASED GENERATORS

FARIDABAD INDUSTRIAL AREAS



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This report has been supported by Bloomberg Philanthropies and Shakti Sustainable Energy Foundation.

The opinions expressed do not necessarily reflect those of Bloomberg Philanthropies nor should they be attributed to the organization.

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Material from this publication can be used, but with acknowledgement.

Citation: Ishita Garg 2021, *Replacing Diesel-Based with Gas-Based Generators: Faridabad Industrial Areas*, Centre for Science and Environment , New Delhi

Published by
Centre for Science and Environment
41, Tughlakabad Institutional Area
New Delhi 110 062
Phones: 91-11-40616000
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E-mail: sales@cseinida.org
Website: www.cseindia.org

FEASIBILITY ASSESSMENT

REPLACING DIESEL-BASED WITH GAS-BASED GENERATORS

FARIDABAD INDUSTRIAL AREAS

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1. Background

Centre for Science and Environment (CSE) recently published a report titled *Assessment of Industrial Air Pollution in Delhi-NCR*. The report surveyed seven districts surrounding the national capital—namely Alwar, Bhiwadi, Gurugram, Sonipat, Panipat, Faridabad and Ghaziabad—and assessed the sources from industrial areas that contributed to the overall air pollution of the area. The presence of large numbers of diesel generator (DG) sets in industrial areas stood out.

Diesel generator sets are used in industry as a source of backup in case of power cuts. As the name suggests, these gensets use diesel as fuel. On burning, diesel emits oxides of nitrogen, carbon monoxide and particulate matter, which are major contributors to air pollution. According to a study, a standard DG set of 250 kVA capacity running at an average of three hours per day emits 0.183 kg/day of PM 10, 3.08 kg/day of NOx and 1.50 kg/day of CO.[1]

According to media reports, Faridabad was ranked as the second most polluted city in the world by a 2018 WHO report.[2] Of the areas assessed in CSE's report, Faridabad's industrial areas use the highest number of diesel-based gensets. The widespread use of DG sets can be considered a major contributor to the city's pollution.

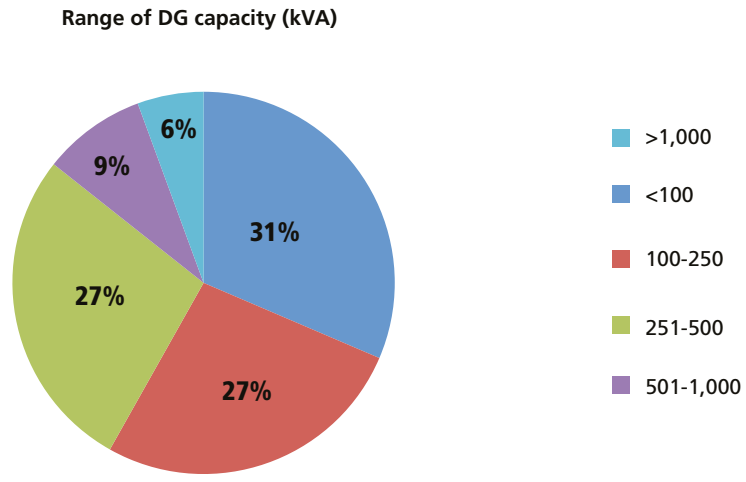
This report explores an alternative to the use of diesel gensets in Faridabad industrial areas and assesses the feasibility of replacing the standard DG by natural gas gensets (NG-GS). It takes into account technological, economic and environmental aspects of converting the DGs currently in use to NG-GS.

Status of DG sets in Faridabad

Faridabad has two industrial clusters, Faridabad and Ballabgarh. These clusters together house approximately 950 air-polluting industries, the largest number among the seven districts surveyed by CSE. The industries in the area use coal, agro, liquid fuel and biomass as fuel, mainly in boilers for steam generation or thermo pack for heating. However, according to data provided by HSPCB, a large number of industries—approximately 780—also use liquid fuel in DG sets installed in their premises. Over 1,000 DG sets of varying capacity ranging from as small as 10 kVA to as high as even 8,000 kVA are installed in these industries (see *Figure 1: Range of DG capacity in industrial areas of Faridabad*).

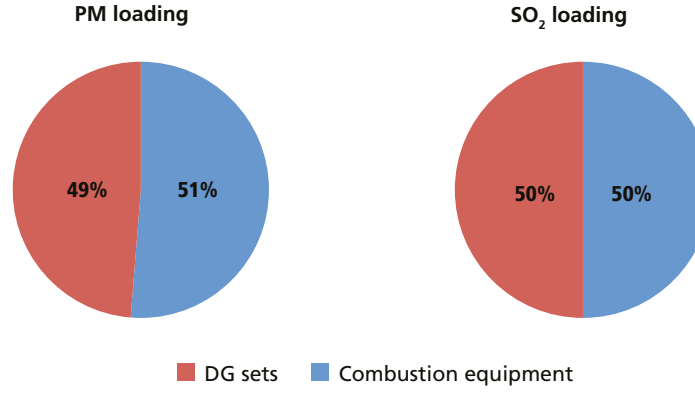
These DG sets together consume around 1.41 lakh tonnes of diesel annually, which is about 60–70 per cent of the total annual consumption of liquid fuel by industries in the region. This extensive use of DG fuel results in a high degree of pollution in the area. A rough estimate indicates that the annual contribution of DG sets in the overall pollution load of Faridabad is almost 50 per cent for both PM and SO_2, assuming daily operation of DG sets for four hours (see *Figure 2: Pollution loading from DG sets [four hours of operation]*).

Figure 1: Range of DG capacity in industrial areas of Faridabad



Source: CSE

Figure 2: Pollution loading from DG sets (four hours of operation)



Source: CSE

DG sets have several drawbacks. Their operation generates high noise levels, contributing to noise pollution. In addition, the operating cost of DG sets fluctuates with diesel prices, making it financially unstable. Also, diesel fuel needs to be procured and stored in bulk, which necessitates additional storage area in industries.

But the most deleterious effect of the use of DG sets is high emissions of PM, NO_X, unburned hydrocarbons and other toxic pollutants that along with causing air pollution have negative impacts on human health.

In view of the pollution scenario in Delhi-NCR—and to reduce the impacts—a major objective of the government is to adopt cleaner fuel. This study aligns with this objective and assesses an alternative to diesel-based gensets.

Gas-based DG sets—an alternative

A natural-gas generator works similarly to diesel generators, the only difference being the fuel used to power the units. Natural gas can be used to power both emergency and portable generators and is regarded as one of the most affordable and effective fuels among non-renewable resources for power generation.

The general impression is that diesel engines are cost-effective and energy-efficient while natural gas engines are more environmentally friendly. However, in the current scenario the price of diesel is far more than that of natural gas, which makes the operational cost of a diesel genset higher than its gas counterpart.

In terms of providing high power, response and longevity, diesel is no longer a clear winner in terms of power and response. Spark-ignited (natural gas) industrial engines are available that can optimize the RPM of these engines to make the transient response similar to that of diesel. Natural gas units that can meet the 10-second startup requirement for backup systems are also being produced—these have traditionally been associated only with diesel engines.

Advantages of gas-based gensets:

- Operating cost is 45–50 per cent lower than for diesel-powered generators;
- Natural gas is generally cheaper than liquid fuels like light diesel oil (LDO) and diesel;
- Zero emission of harmful particulate matter and smoke;
- 35–40 per cent less emission of pollutants such as NOx and CO_2;
- No scaling or sooting takes place in use of natural gas and hence maintenance cost is less than that of other fuels;
- Piped natural gas (PNG) does not require any storage tank or storage space since it is supplied through pipelines;
- Noise level generated is 4 dbA lower than noise generated by a conventional genset; and
- Natural gas does not produce a pungent odour, which is fairly common in generators powered by diesel.

Feasibility assessment

a. Technical aspects

Specific fuel consumption: Fuel efficiency is a metric of expressing the efficiency performance of a generator set. Specific fuel consumption (SFC) expressed in litre/hour or gram/kWh is an indication of the quantity of fuel required to generate one unit of electricity. This parameter is of direct relevance as it relates to the operating costs of generating electricity from generator sets.

The SFC of natural gas is 34 standard cubic metres (SCM)/hour (0.026 tonnes/hour) while that of diesel is 28 litres/hour (0.024 tonnes/hour). Although the SFC of natural gas is slightly higher, the difference in market cost of diesel (Rs 80) and natural gas (Rs 35) completely eclipses this factor as the overall operational cost of NG-GS is much lower than that of diesel gensets.

b. Economic aspects

The one-time cost of setting up a diesel generator is less than that of a natural gas generator. As previously discussed, however, due to the low operational costs, natural-gas-based gensets are more economical than their diesel counterparts.

A 100 kW gas generator costs about Rs 12 lakh as compared to Rs 6.5 lakh for a diesel set. A comparative analysis of the operational cost, however, indicates that the additional cost incurred in purchasing a gas generator can be recovered in about four months (assuming that the genset is used for four hours of power backup and given the fact that gas is cheaper than diesel) (see *Table 1: Estimated cost for diesel gensets and natural gas gensets for 100 kW rating*).

Table 1: Estimated cost for diesel and natural gas gensets for 100 kW rating

Particular	Diesel genset	Natural gas genset
Genset cost (Rs)	6.5 lakh	12 lakh
Daily hours of operation (assumption)	4	4
Units generated (kWH)	400	400
Diesel cost/PNG cost (Rs)	80	35
Fuel consumption at 100% load (litres/hour)	28	34 (SCM/hour)
Total cost of fuel (Rs/hour)	2,240	1,190
Per unit cost	22.40	11.90
Daily cost for four hours running (Rs)	8960	4200
Monthly cost (Rs)	2,68,800	1,26,000
Monthly cost saved (Rs)		1,42,800
Cost saved in four months	Rs 5,71,200	

Source: Technical details provided by Mahindra Powerol, analysis by CSE.

c. Environmental aspects

The operation of diesel generators emits high amounts of oxides of nitrogen (NOx), sulphur dioxide (SO_2) and soot particles (particulate matter or PM) and also contributes to CO_2 emissions. The use of NG-GS results in considerable reduction of NOx and CO_2 emissions while almost eliminating PM and SOx emissions.

Reduction in pollution loading

The pollution loading from operating gensets has been calculated for three scenarios: theoretical DG fuel consumption, theoretical NG-GS fuel consumption and the actual fuel consumption in diesel generators in the Faridabad region (data provided by HSPCB). The theoretical fuel consumption for both diesel and natural gas is calculated in tonnes/annum, assuming four hours of daily operation. The loading is calculated for PM, SO_2, NOx and CO_2 emissions in tonnes/annum for different capacity of gensets (see *Table 2: Pollution loading from generators—comparative analysis*).

The percentage reduction in pollution loading by replacing existing diesel generators with NG-GS works out to **100 per cent for PM and SO_2 while it is 43 per cent and 34 per cent for NOx and CO_2** respectively.

Table 2: Pollution loading from generators—comparative analysis[3, 4]

Capacity	Fuel consumption	PM (T/A)	SO_2 (T/A)	NO_X (T/A)	CO_2 (T/A)	Reduction in NO_X (%)	Reduction in CO_2 (%)
20 kW	Diesel (theoretical)	0.11	0.18	1.49	55.45	–	–
	NG (theoretical)	ND	ND	1.0	44.8	37	27
	Diesel (actual)	0.12	0.20	1.66	61.53	–	–
100 kW	Diesel (theoretical)	0.5	0.8	6.9	256.5	–	–
	NG (theoretical)	ND	ND	4.7	202.9	43	34
	Diesel (actual)	0.59	0.99	8.30	307.81	–	–
150 kW	Diesel (theoretical)	0.7	1.2	10.2	377.8	–	–
	NG (theoretical)	ND	ND	7.0	301.8	43	34
	Diesel (actual)	0.88	1.48	12.42	460.65	–	–
200 kW	Diesel (theoretical)	1.0	1.6	13.5	499.1	–	–
	NG (theoretical)	ND	ND	9.3	400.7	44	35
	Diesel (actual)	1.2	2.0	16.6	615.3	–	–
250 kW	Diesel (theoretical)	1.2	2.0	16.8	623.9	–	–
	NG (theoretical)	ND	ND	11.6	499.5	44	35
	Diesel (actual)	1.5	2.5	20.8	773.2	–	–
300 kW	Diesel (theoretical)	1.4	2.4	20.1	745.2	–	–
	NG (theoretical)	ND	ND	13.9	598.3	44	35
	Diesel (actual)	1.8	3.0	24.8	921.3	–	–
350 kW	Diesel (theoretical)	1.7	2.8	23.5	869.9	–	–
	NG (theoretical)	ND	ND	16.3	697.2	44	36
	Diesel (actual)	2.1	3.5	29.3	1,085.8	–	–
400 kW	Diesel (theoretical)	1.9	3.2	26.7	991.3	–	–
	NG (theoretical)	ND	ND	18.6	796.0	44	35
	Diesel (actual)	2.4	4.0	33.3	1,233.9	–	–
500 kW	Diesel (theoretical)	2.4	4.0	33.4	1,237.3	–	–
	NG (theoretical)	ND	ND	23.2	993.8	44	35
	Diesel (actual)	2.9	4.9	41.5	1,538.2	–	–
750 kW	Diesel (theoretical)	3.5	5.9	49.9	1,850.8	–	–
	NG (theoretical)	ND	ND	34.7	1,488.0	43	34
	Diesel (actual)	4.34	7.28	61.20	2,270.34	–	–
1,000 kW	Diesel (theoretical)	5	8	66	2,464	–	–
	NG (theoretical)	ND	ND	46	1,982	44	36
	Diesel (actual)	5.89	9.871488	82.9312	3,076.48	–	–

* Percentage reduction for NO_X and CO_2 is calculated between diesel (actual) and NG (theoretical)
Source: CSE.

STANDARDS AND NORMS FOR EMISSIONS FROM DIESEL GENERATORS IN INDIA[5]

The Central Pollution Control Board (CPCB) has been regulating emissions from diesel generators at the manufacturing stage (through product certification) since 2005. The emission norms in India cover CO, NOx, PM, and HC and are specified based on the number of grams of these compounds present in diesel exhaust when one kilowatt-hour of electricity is generated. These norms were revised in December 2013 (G.S.R. 771 (E)/11 December 2013 notification) and have been enacted from April 2014 (CPCB II) (see *Table 3: CPCB's revised emission norms for diesel engines*).

Table 3: CPCB's revised emission norms for diesel engines

Capacity of diesel engines	Old emission limits (g/kWh)				Capacity of diesel engines	Revised emission limits with effect from April 2014 (g/kWh)		
	NOx	HC	CO	PM		NOx + HC	CO	PM
Up to 19 kW	9.2	1.3	3.5	0.3	Up to 19 kW	<=7.5	<=3.5	<=0.3
>19 kW up to and 176 kW	9.2	1.3	3.5	0.3	> 19 kW and up to 75 kW	<=4.7	<=3.5	<=0.3
>176 kW and up to 800 kW	9.2	1.3	3.5	0.3	> 75 kW and up to 800 kW	<=4.0	<=3.5	<=0.2

The revised norms have a combined cap on NOx and HC that is in line with the practice followed in USA and Europe. At the time of monitoring and verification, the two pollutants are measured separately and then added to check compliance to the norms. CPCB had also notified emission limits for diesel generators greater than 800 kW in 2002. Discussion with stakeholders revealed that diesel generator sets of size 800 kW and above are generally regulated by the State Pollution Control Boards or Pollution Control Committees at the site of installation.

With revised norms in place, India's emission standard for diesel generators has moved closer to world benchmarks (see *Table 4: Emission norms for diesel gensets in different countries*). It is important to note that quality of diesel (in terms of sulphur content in ppm) is an important consideration during setting of emission norms for diesel engines.

Table 4: Emission norms for diesel gensets in different countries

Emission norms	Sulphur content in diesel (ppm)
India CPCB II (April 2014 onwards)	350/50
India CPCB I (2004–13)	500/350
Japan Tier III (2011–13)	50
Japan Tier IV (2014–16)	10
Europe Stage IIIA (current for 18–36 kW)	50
Europe Stage IIIB (current for 37–129 kW)	10
Europe Stage IV (current for 130–560 kW)	10
US EPA-Tier 4 (2008–14)	15

DEVELOPMENT IN THE FIELD OF NATURAL GAS GENERATORS

Indraprastha Gas Ltd aims to replace diesel generators by gas generators—which it has pitched as a cheaper and an environment-friendly option—in housing complexes and factories in the National Capital Region. The company is about to launch its services in Rewari and aims to supply 1 lakh cubic metres per day to the factories of the region. The company also plans to install gas-based generators in two or three housing complexes in Indirapuram on the outskirts of Delhi, which will serve as a model for other areas.[6]

Mahindra Powerol launched India's first CPCB-II-approved gas genset of 125 kVA capacity in Delhi on 11 April 2018. As per the claims by the company, this gas-based genset will reduce the operating cost by 45 per cent as compared to diesel gensets.[7]

Table 5: Overall comparison between diesel and natural gas gensets

Parameter	Diesel genset	Natural gas genset
Purchase cost	Low	High
Fuel price	High	Low
Fuel supply	Intermittent (storage required)	Continuous
O&M cost	High	Low
Noise generation	High	Low
PM and smoke emissions	High	Nil
NOx and CO_2 emissions	High	Low

Source: CSE.

CASE STUDY

To strengthen the findings of this research, CSE's team visited an industrial facility that had shifted its operation from a diesel to a gas generator. The objective of the visit was to understand and document the experience of using a gas generator and compare it with that of using a diesel generator.

The team visited Hamdard Laboratories based in Okhla, Delhi. This industry previously used a 100 kVA diesel generator which they replaced by a 125 kVA gas generator. The cost of their new gas-based generator was in the range of Rs 10–11 lakh while the diesel generator of a similar capacity cost Rs 7–8 lakh. Although the initial cost of a gas-based genset was higher than that of its diesel counterpart, there are advantages in the long run.



Natural gas generator installed at Hamdard Laboratories

Industries consuming less than 500 standard cubic metres (SCM) per day and switching to gas as fuel in the state of Delhi receive a one-time subsidy of Rs 50,000; industries consuming more than 500 SCM per day get a one-time subsidy of Rs 1 lakh.

The Hamdard factory received an initial subsidy of Rs 50,000. The annual maintenance cost of their gas genset is approximately Rs 15,000 while for their older diesel generator the annual maintenance cost was around Rs 30,000. This indicates the low requirement and cost of maintenance for gas gensets. Fuel-cost economics based on data shared by the industry shows that the fuel for diesel gensets costs around Rs 12.6 kVA/hour while the cost of fuel of a gas genset is around Rs 6.06 kVA/hour. This shows that although gas gensets need more initial investment, the price of fuel for operating them is almost 50 per cent less than that of diesel-based gensets. Also, the use of gas gensets forestalls regulatory actions and penalties on industries (see *Table 6: Comparison between gas and diesel gensets by an industry*).

Table 6: Comparison between gas and diesel gensets by an industry

S. no.	Aspect	Diesel genset	Gas genset
1.	Initial cost (Rs)	7 lakhs	10–11 lakhs
2.	Maintenance cost (Rs/year)	15,000	30,000
3.	Regulatory measures	Subjected to them from time to time	No regulatory measures shall be possible
4.	Fuel cost (Rs/kVA)	12.6	6.06
5.	Subsidy	No subsidy	Subsidy in Delhi
6.	Noise	Very high	Negligible

Source: CSE

2. Proposed model for Faridabad

Faridabad's industrial areas face frequent power cuts due to which use of diesel generator sets in industries as a source of power back up is common. These industrial areas comprise approximately 1,200 DG sets of total capacity of 378 MW and consume around 1.41 lakh tonnes of fuel annually. Their contribution in the overall pollution load is significantly high, in the range of 15–50 per cent, depending on the hours of operation (see *Table 7: Estimated pollution load from gensets, combustion equipment and overall loading in Faridabad*).

Table 7: Estimated pollution load from gensets, combustion equipment and overall loading in Faridabad

Parameters	Loading from combustion equipment (tonnes/ annum)	Loading from DG sets (tonnes/ annum)	Total (tonnes/ annum)	Contribution of DG sets (%)
DG operation: four hours				
PM	2,344	2,228	4,572	49
SO_2	3,156	3,736	6,893	54
DG operation: two hours				
PM	2,685	1,114	3,799	29
SO_2	5,704	1,868	7,572	25
DG operation: one hour				
PM	2,856	557	3,413	16
SO_2	6,978	934	7,912	12%

Source: CSE

The following section discusses a proposal for replacing DG sets with natural gas gensets to combat the issue of pollution in Faridabad industrial areas.

Availability of infrastructure for gas pipeline

Adani Gas Ltd is a prime supplier of natural gas in Faridabad industrial areas and for laying down the pipeline network in the area. As per data provided by Adani Ltd, Adani has a well laid out pipeline infrastructure for natural gas supply in nine out of a total of thirteen areas industrial areas in Faridabad (see *Table 8: Distribution of gas line infrastructure in different industrial areas of Faridabad*). This implies that these nine areas can immediately switch to natural gas gensets. Areas that do not have a gas pipeline can switch to NG-GS in a phased manner.

Table 8: Distribution of gas line infrastructure in different industrial areas of Faridabad

Industrial areas of Faridabad	Availability of gas pipeline
DLF Industrial Area	Yes
Sector 27 (A, B, C, D)	No
Sector 4	Yes
Sector 6	Yes
Sector 24	Yes
Sector 25	Yes
Sector 58	Yes
Sector 59	Yes
IMT	Yes
NIT	Yes

Source: Adani Ltd

Reduction in pollution load

The economic feasibility of natural gas gensets (NG-GS) has been discussed in the previous section from the point of view of industries. With regard to pollutant emissions, Faridabad industrial areas will be able to reduce overall NOx and CO_2 loading by 37 and 27 per cent respectively while PM and SOx loading will be nil with a 100 per cent switch to NG-GSs (see *Table 9: Percentage reduction in pollution loading by converting from DGs to NG-GSs in Faridabad industrial areas*).

Table 9: Percentage reduction in pollution loading by converting from DGs to NG-GSs in Faridabad industrial areas

	Total DG capacity (MW)	Fuel consumption (tonnes/ annum)	PM loading (tonnes/ annum)	SO_2 loading (tonnes/ annum)	NOx loading (tonnes/ annum)	CO_2 loading (tonnes/ annum)
Diesel gensets	378	1.41 lakh	2,227.56	3,736.23	31,388	1,164,406
Natural gas gensets		1.53 lakh	0	0	19,773	848,052
Percentage reduction		–	100	100	37	27

Source: CSE

Conclusion

Replacing the use of diesel generators with natural gas generators shows substantial reduction in emission of pollutants, thereby improving the environment along with monetary benefits to users—a win-win situation.

The following steps are needed to replace existing DG sets with gas generators:

- **Policy roadmap for power in Faridabad:** Use of a large number of generators in the industrial areas of Faridabad points to the inadequacy of power

supply in the region. To discourage use of generators as power backup, improvement of power supply in the region must be the prime focus. The policy for the city should be either continuous electricity supply or use of gas generators. Use of diesel-based gensets should be strictly prohibited.

- **Transition to gas gensets:** For new installations, only natural gas generators must be allowed. Existing generators should be converted into gas-based ones within one year.

- **Ensure uninterrupted supply of gas**: Many areas that have gas pipelines often face issues with non-continuity of supply. Continuous supply of gas must be be ensured as an interrupted supply could act as an argument for continued use of diesel generators.

- **Handholding support:** Regulators should inventorize DG sets installed in each industrial region and provide handholding for the switchover. More stakeholder interaction is required to understand the cost economics and benefits of installing natural gas gensets.

- **Monitoring for compliance:** Random monitoring of DG set needs to be conducted to ensure compliance.

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A 2018 WHO report ranks Faridabad as the second most polluted city in the world. To assess the sources of industrial air pollution, CSE surveyed seven districts in Delhi-NCR. The study revealed that diesel generators contributed significantly to air pollution in the studied regions. Faridabad had the highest number of DG sets among the districts surveyed.

This report assess the feasibility of converting existing diesel generators to natural gas generators, with technical, economic and environmental aspects taken into account. The analysis shows that a shift to natural gas generators will result not only in significant reduction in air pollution but will also prove to be cost-effective for users.

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International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 12, December-2018

EMISSION INVENTORY OF AIR POLLUTANTS FROM DIESEL GENERATOR USED AT SELECTED LOCATIONS IN JAIPUR CITY, INDIA

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Abstract— The use of diesel generator (DG) sets for power backup at various places like malls, shopping centres, wedding gardens, offices buildings etc. increases the air pollution levels in the cities and causes severe health and environmental problems. A study of emission inventory for the air pollutants released from the diesel generators used at malls, shopping centres and wedding gardens in Jaipur city, India has been carried out to estimate concentration of air pollutants viz: oxides of nitrogen (NO_x), oxides of sulphur (SO_x), particulate matter (PM_{10}), hydrocarbon (HC) and carbon monoxide (CO) by using questionnaire survey of the users comprising of managers and DG operators. 16 wedding gardens, 6 malls and 2 shopping centres located within the city were identified for calculation of data for the period between May 2018 to July 2018. It has been observed that in the wedding gardens 62, 125 and 250 KVAs of DG sets are used, whereas, malls and shopping centres used 8 types DG sets ranges from 62 to 1650 KVA. In wedding gardens, the estimated emission rate of air pollutants from 250 KVA DG set (running with the average of 3 hours per day) emit 0.183 kg/day of PM_{10}, 3.08 kg/day of NO_X and 1.50 kg/day of CO. 62 KVA DG sets produces 0.072 kg/day of PM_{10}, 1.296 kg/day of NO_X and 0.77 kg/day of CO.

Keywords: Emission Inventory, Pollutants, Particulate Matter, Environment, Concentration

I. INTRODUCTION

In the last two decades the global warming has increased which has created the various environmental problems. The diesel generators are contributing to the environmental problems which are the sources for the distributed generation of electricity [1]. These can also be used at peak demand of electricity and for backup for the electricity distribution systems [2]. A study by Environmental Protection Agency (EPA) reported that the global warming is caused due to the change in concentration of air constituents which are measure by accumulating a database for discharge of air pollutants into the atmosphere called as emission inventory [3]. An emission inventory generally comprises of the total greenhouse gases in a specific geographical area within a definite time span [4]. The International Energy Agency (IEA) estimates that the discharges of CO_2 will increase by 92 percent from the year 1990 to 2020 and it has been projected that 8.6 billion metric tons of CO_2 will be emitted into the atmosphere from the year 2020 to 2035 [5,6]. During the last two decades in India, diesel and petrol consumption has risen by 300 percent and 400 percent, respectively due the rise of transportation as well as by using DG sets, waste incinerators and industries [7]. Emissions of pollutants from the DG sets give rise to deterioration of air quality and have negative effects on human health in the surrounding environment [8]. A specific DG exhaust contains more than 40 air pollutants which include SO_X, NO_X, CO_2, CO, HC etc. besides various containing carcinogenic compounds such as arsenic, benzene and Formaldehyde. Emissions from DG in the form of NO_X, SO_X, CO_2, PM_{10}, CO and HC are the primarily pollutants influencing the poor air quality in a particular region [9]. However, the operation of DG sets increases the unsafe and damaging factors (exhaust gases, vibration, noise) which break the ecological balance of an area. The gases from diesel engines constitute of solid particles and their presence in the air cause serious illness as well as oncological violations [10]. The gases that emit from DG sets are very harmful for living beings which are also responsible for the ozone layer degradation and formation of carcinogenic substances leading to premature deaths [11]. The aim of this study is to estimate the concentration of air pollutants from the DG sets use at wedding gardens, malls and shopping centres in Jaipur City, India.

II. METHODOLOGY

A. Selection of City

Jaipur city located at latitude 26° 55' 19.4520'' N and longitude 75° 46' 43.9860" E has a population of 3.1 million [12]. The location of Jaipur city is shown in Fig. 1. With the increase in urbanization the demand of electricity has increased but still not meeting the energy demand. So, people are using diesel generator sets for their electricity power backups. DG sets generates various types of air pollutants which are further contribute to the poor air quality of an ambient environment which has been measure as Air Quality Index (AQI). As per Central Pollution Control Board (CPCB) (2017), the AQI increased to 247 in 2017 [13]. The AQI at Police Commissionerate air pollution station in Jaipur city reported 220 on 13 November 2018 [14].

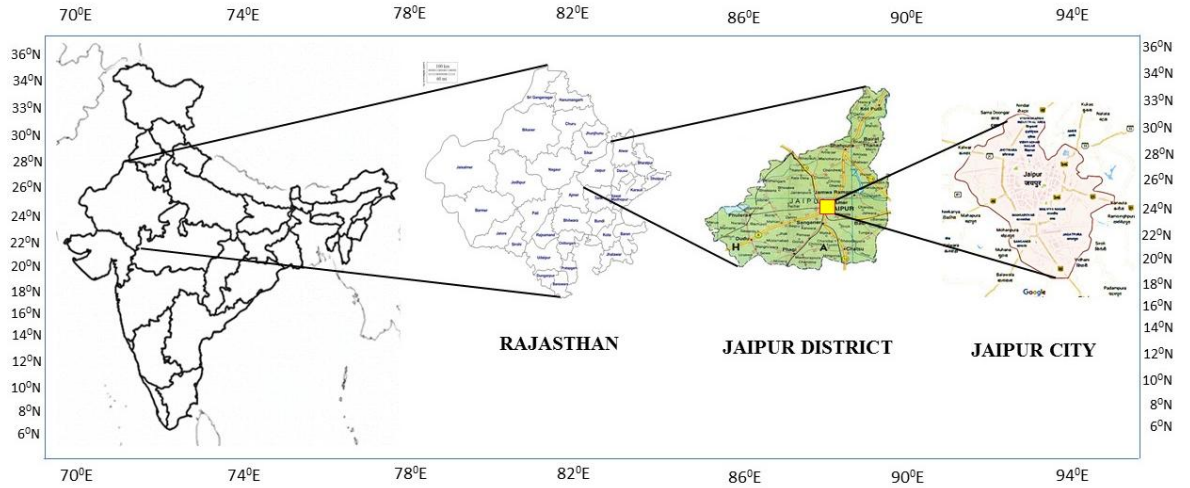


Fig. 1 Location of Jaipur city

B. Site Selection

1) DG Sets at Wedding Gardens: The selection of sites has been made on the basis on the areas, capacity and DG sets usage. The data has been collected by conducting a questionnaire survey at malls, shopping centres and wedding gardens in the city to identify the factors such as amount of fuel consumed by a DG sets, operational time, maintenance duration, age, vendors etc. Managers and DG operators has been identified as respondents. 16 wedding gardens, 6 malls and 2 shopping centres were selected for the study which used 8 types of DG sets ranges from 62 to 1650 KVA. The locations of the malls and shopping centres are shown in Fig. 2.

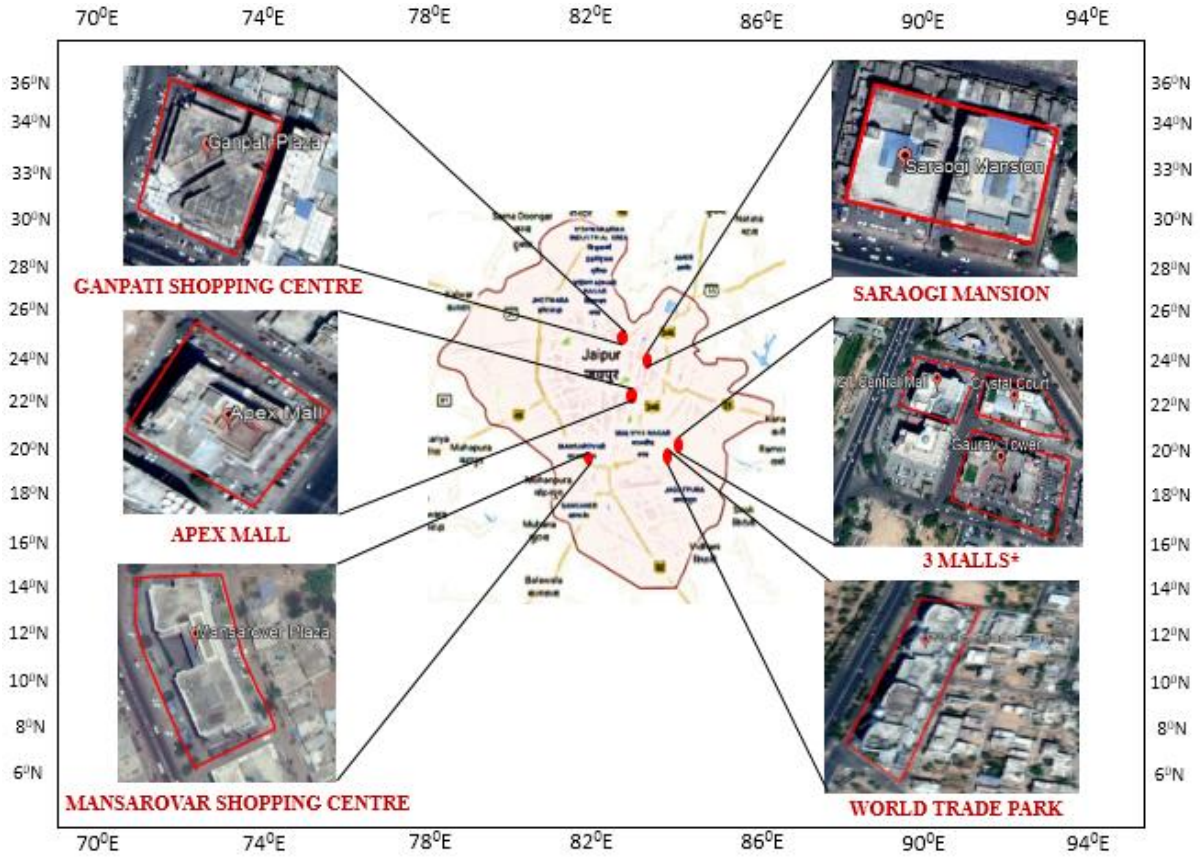


Fig. 2 Location of malls and shopping centres in Jaipur city

C. Estimation of Concentration of Air Pollutants in Jaipur City

For estimating the rates for air pollutants i.e. NO_X and PM_{10} by the method as described by Masood et al. has been used [15]. Whereas, the air pollutants which were CO, SO_X and HC have been estimated by the method described by Rukmini et al. [16]. The conversions of KVA to Kilowatt (KW) and KW to Horsepower (HP) have been made as reported by Diesel Service and Supply Industry (DSSI) [17]. The power factor is considered as 0.8 for DG sets [18]. The formulas based on the above references [15-18] are described as:

i. Emission rate of NOx

$$NOx\ (gm/s) = [3.85 \times DG\ set\ capacity\ in\ HP] / 3600 \quad (1)$$

ii.Emission rate of PM_{10}

$$PM10\ (gm/s) = [0.24 \times DG\ set\ capacity\ in\ HP] / 3600 \quad (2)$$

iii.Emission rate of carbon monoxide (CO)

$$CO = 15 \times 10^{-3} \times P^{0.68} \times N \quad (3)$$

Where, P = Engine power in (KW) x engine load (85 %); N = number of DG sets

iv. Emission rate of hydrocarbons (HC)

$$HC = 4.86 \times 10^{-3} \times P^{0.69} \times N \quad (4)$$

v. Emission rate of Sox

$$SOx = 2.31 \times 10^{-3} \times P \times N \quad (5)$$

III. **Results and Discussion**

A. Emission Rate of Air Pollutants

The capacity of DG sets (range from 60 to 1650 KVA) which are installed at different locations i.e. wedding gardens, malls and shopping centres are given in Table 1.

TABLE I
CAPACITY OF GENERATOR IN KVA, KW, HP

Generator's Capacity (KVA)	Generator's Capacity (KW)	Generator's Capacity (HP)
1650	1320	1796.436
500	400	536.193
250	200	268.096
160	128	171.581
150	120	160.857
125	100	134.048
100	80	107.238
62	50.4	67.560

The emission rate of the air pollutants from the DG sets depends upon the amount of fuel it consumes, its age, operational time, maintenance etc. Table 2 shows the estimated emission rate of NO_X, SO_X, CO, HC and PM_{10}. DG sets with capacity of 1650 KVA generator shows the huge amount of air pollutants released because it consumes 300 litres per hour (lt/hr) of diesel which releases 0.119 gm/s (gram/second) of PM_{10} and very high amount of NO_X which was about 1.949 gm/s. The DG sets with capacity 125 KVA (used for on an average 3 hours in day) is used at majority of the wedding gardens. By consuming diesel about 20 lt/hr it released 0.008 gm/s of PM_{10}, 0.143 gm/s of NO_X, 0.064 gm/s of SO_X, 0.087 gm/s of CO and 0.029 gm/s of HC. The generator with 62 KVA capacity which is used at few malls and shopping centres but mainly used at wedding gardens. 62 KVA generator consumed on an average 10 lt/hr and emits concentration of $PM_{10,}$ NO_X, $SO_{X,}$ and CO which are estimated as 0.004, 0.072, 0.032, and 0.054 gm/s, respectively.

TABLE II
EMISSION RATE OF AIR POLLUTANTS

Capacity of DG (KVA)	**Average fuel Consumption (lt/hrs)***	**PM_{10} (gm/s)**	**NOx (gm/s)**	**SOx (gm/s)**	**CO (gm/s)**	**HC (gm/s)**
1650	300	0.119	1.949	0.847	0.504	0.171
500	70	0.035	0.572	0.256	0.224	0.075
250	35	0.017	0.286	0.128	0.139	0.046
160	30	0.011	0.183	0.082	0.103	0.034
150	25	0.010	0.171	0.077	0.098	0.032
125	20	0.008	0.143	0.064	0.087	0.029
100	15	0.007	0.114	0.051	0.075	0.024
62	10	0.004	0.072	0.032	0.054	0.018

***Average fuel consumption of DG used at 16 wedding gardens, 6 malls and 2 shopping centres**

1) Emission Rate of Air Pollutants from DG Sets at Wedding Gardens: Three types of generators are used at wedding gardens which are 60, 125 and 250 KVAs which produce different emission rates of pollutants. Their emission rates are estimated by the operational time and diesel quantity they consume. 250 KVA generator is often used in the wedding gardens but a few wedding gardens in Jaipur city use this capacity of generator which are operational for 3 hr/ day and emit PM10, NOX, SOX, CO and HC are 0.183, 3.08, 1.38, 1.50 and 0.49 kg/day, respectively. However, the emission rates of pollutants were less observed in 62 KVA generator sets which operated for 5 hr/day and released 0.77 kg/day of CO and 1.296 kg/day of NOX in the atmosphere, respectively.

TABLE III
EMISSION RATE OF AIR POLLUTANTS FROM DG SETS AT WEDDING GARDENS

DG set (KVA)	Average* Operational time (hr/day)	Concentration of air pollutants by a DG				
		PM_{10} (kg/day)	NO_X (kg/day)	SO_X (kg/day)	CO (kg/day)	HC (kg/day)
250	3	0.183	3.08	1.38	1.50	0.49
125	4	0.115	2.05	0.92	1.25	0.41
62	5	0.072	1.296	0.57	0.77	0.324

*** Average operational time DG used at 16 locations of wedding gardens**

2) Emission Rate of Air Pollutants from DG Sets at Malls and Shopping Centres: The Gaurav Tower mall used 6 types of generators of capacities 62, 100, 150, 160, 250 and 500 KVAs and emitting huge amounts of NOX SOX, CO. 500 KVA DG produce NOX which has been observed to be 6.177 kg/day, 2.764 kg/day SOX and 2.419 kg/day of CO. It can be observed from Table 4 that the World Trade Park having huge capacity of generator (1650 KVA) and generate emission rates of 7.016 kg/day of NOX, 3.049 kg/day of SOX, 0.428 kg/day of PM10 and 0.615 kg/day of HC. If the current trend of using DG continues then it will degrade the environmental quality. Crystal Court, Mansarover Shopping centre, Ganpati Shopping centre and Saraogi Mansion uses only one type of DG set (250 KVA) and all them are operational for 1 hour/day.

TABLE IV
EMISSION RATE OF AIR POLLUTANTS FROM DG SETS AT MALLS AND SHOPPING CENTRES

Malls or Shopping centre	**Average Operational Time (hr/day)**	**Capacity (KVA)**	**Concentration of air pollutants**				
			PM10 (kg/day)	**NO_X (kg/day)**	**SO_X (kg/day)**	**CO (kg/day)**	**HC (kg/day)**
Gaurav Tower	3	62	0.043	0.777	0.345	0.583	0.194
		100	0.075	1.231	0.550	0.810	0.259
		150	0.108	1.846	0.831	1.085	0.313
		160	0.118	1.976	0.885	1.112	0.345
		250	0.183	3.088	1.382	1.501	0.367
		500	0.378	6.177	2.764	2.419	0.496
GT Central Mall	2	500	0.252	4.118	1.843	1.612	0.331
World Trade Park	1	1650	0.428	7.016	3.049	1.814	0.615
Crystal Court	1	250	0.061	1.029	1.382	0.500	0.165
Saraogi Mansion	1	250	0.061	1.029	1.382	0.500	0.165
Ganpati Shopping centre	1	250	0.061	1.029	1.382	0.500	0.165
Mansarover Shopping centre	1	250	0.061	1.029	1.382	0..500	0.165
Apex Mall	3	62	0.043	0.777	0.345	0.583	0.194
		100	0.075	1.231	0.550	0.810	0.259
		250	0.183	2.700	1.382	1.501	0.367

IV. **CONCLUSIONS**

The study is carried out for the emission inventory of diesel generators used between the months of May 2018 and July 2018 at the various locations like wedding gardens, malls and shopping centres in Jaipur City, India. The emission rates of PM_{10}, NO_X, SO_X, CO and HC are estimated for 8 types of DG sets ranges from 62 to 1650 KVAs. The estimated emission rates of NO_X, SO_X and CO from all generators are very high. The generators with capacity of 62 KVA use at wedding gardens emitted 0.072 kg/day of PM_{10} and 125 KVA generator emits 0.115 kg/day of PM_{10}, respectively. 250 KVA capacity of DG sets use at shopping centres emitted PM_{10} which was observed to be 0.061 kg/day, 1.029 kg/day of NO_X, 1.382 of SO_X, 0.583 kg/day of CO and 0.165 kg/day of HC. Among all DG sets, the highest amount of air pollutants emission is estimated from the use of 1650 KVA capacity of generator which consumes diesel quantity of

about 300 lt/hr and shows the emission rate was observed for NO_X which is 7.016 kg/day, 0.428 kg/day of PM_{10}, 3.049 kg/day of SO_X, 1.814 kg/day of CO and 0.615 kg/day of HC in the atmosphere.

ACKNOWLEDGEMENT

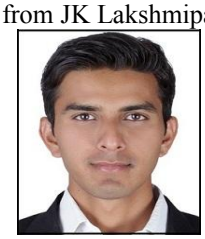
We would to show our gratitude to all the managers, staffs and worker at wedding garden, malls and shopping plaza who helped us by providing us the details for diesel generators.

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BIOGRAPHY

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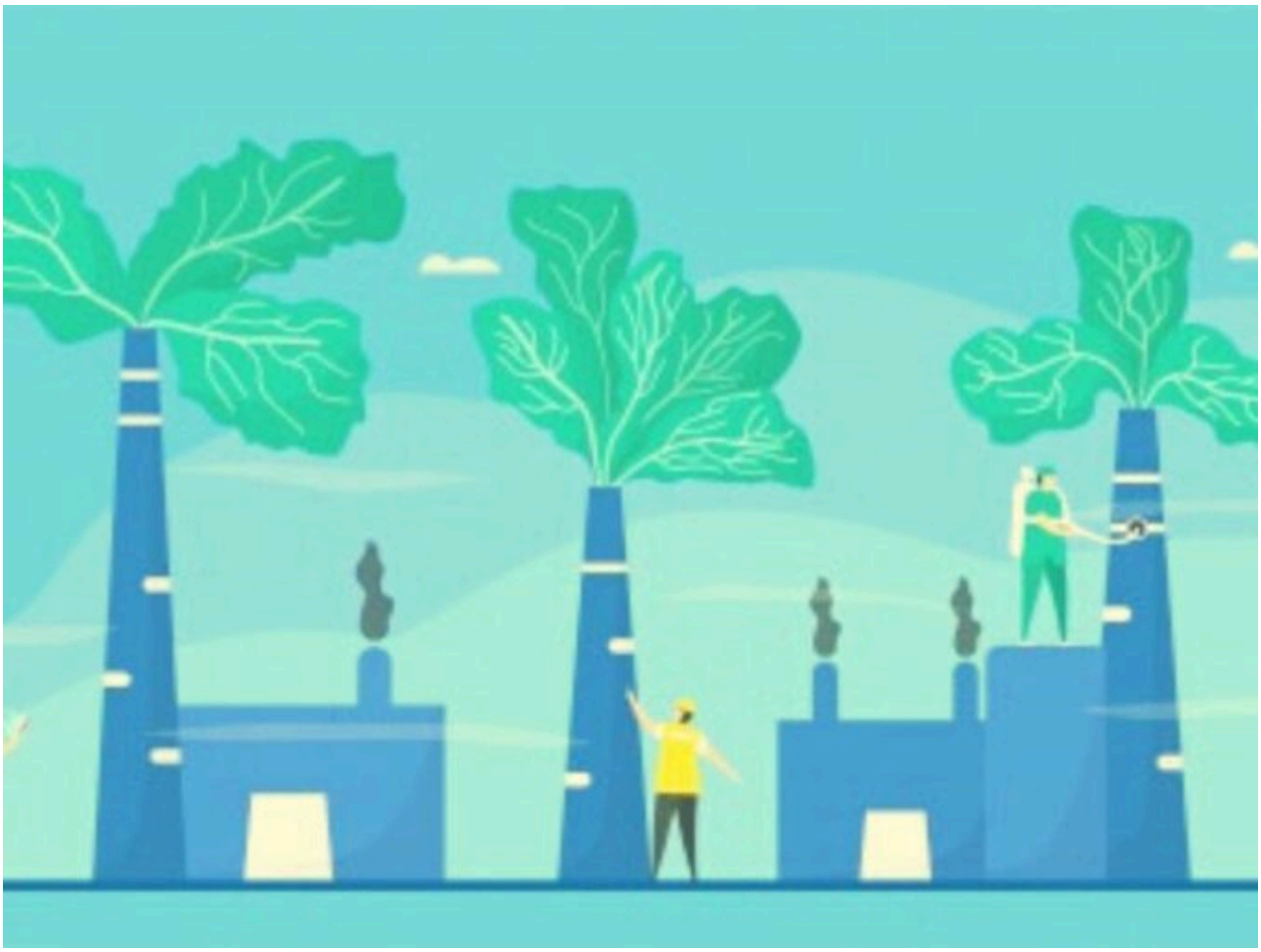


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Are Smog Towers An Effective Solution For Air Pollution?

inc42.com/resources/are-smog-towers-an-effective-solution-for-air-pollution/

Madhusudan Anand July 12, 2020



Every year, over 7 Mn deaths across the world are due to air pollution. Every day, across the world about 1700 children under the age of five die because of unhealthy air. On the home front, Air pollution kills 1.2 Mn Indians in a year and it's the third biggest cause of death in the country. Air pollution has been the cause of millions of premature deaths, including children, many of those who are suffering from irreversible health hazards and reduced life-span (by upto 17 years) in India.

If Covid-19 has killed 2,000 people (at the time of writing this article) in spite of the lockdown, Air pollution has killed a lot more. To add to this, 8 out of 10 diseases can be linked to air pollution. This means that, when we fall sick, we wouldn't even know that it is because of Air pollution. Heart attacks, failed kidneys, lung infection, cancer and a lot more diseases are linked to or triggered by rising levels of air pollution.

Air Pollution is a familiar story in India. Every few months, Delhi makes it to the headlines for its hazardous air quality. In an effort to find a solution to this problem, smog towers were installed in Delhi a couple of months ago. We saw many lauding this and we bet our

hopes on it to improve the situation. Are smog towers helpful in reducing air pollution? Are they good enough to solve this problem? Let's evaluate.

Smog Towers are nothing but a 20 Feet tall air purifier that costs 7 Lakh rupees each and requires about INR 30K- INR 40K every month on maintenance. It sources power from the grid whose cost is perhaps a lot higher than the cost of maintenance. As per the claims made, a smog tower can clean up the air in about 100 mts to 500 mts radius and has a clean air delivery rate of 20-30 Mn cubic metres of air per day.

Before we talk about the effectiveness of a Smog tower, let's first understand what exactly Smog is. Smog, as we know, is a major issue, more so in the Indo-Gangetic plain and specifically in the capital region of our country. To put it very simply, smog is a type of intense visible air pollution that comprises a mixture of smoke and fog. It's composed of air pollutants like nitrogen oxides, sulphur oxides, ozone, smoke and other particulates that can cause a number of health effects. That brings us to the question, do Smog towers remove smog? The simple and short answer to this question is No. Smog towers only remove particulate matter (small particles that are smaller than a human hair).

A Smog tower is made of multiple Air purifiers on the inside. An air purifier, to put it very simply, is nothing but a fan and a HEPA filter (High-efficiency particulate air that can trap harmful particles present in the air). A smog tower comprises 8-10 air purifiers but they only act upon particulate matter and do not purify the gaseous pollutants.

HEPA filter purifies only Particulate matter by up to 90%, that means all the SOx, NOx, CO, O3 and other dangerous gaseous pollutants in the air you breathe. The case in point is the Smog tower installed in China. Smog towers in China failed as they could only remove a spoonful of particulate matter in an entire day. They received a lot of flak from experts in spite of all the gadgetry that went into the making of it. Instead of learning from this, India set out to build its own and seemed to have reached the same obvious, inevitable result.

If smog towers were to really work, the air quality in Delhi's Lajpat Nagar where the tower was installed should have seen an improvement. However, looking at the numbers, there has been no change or impact of the smog tower. Therefore, just like how a giant air conditioner won't solve the global warming problem or a bandage can't save a patient from cancer, a smog tower is not the most effective way to deal with air pollution.



L to R: A seven-metre high anti-smog tower, designed by Dutch designer Daan Roosegaarde, was the first to be put up in an art district in Beijing in 2016. On the right, Smog tower in Delhi

In addition to the efficacy of a smog tower, let's also look at the practicality of the solution in terms of the costs associated with it. Delhi NCR region has an of Area of 54,984 km². This means that we will need at least 275 smog tower units to cover the entire city which can be equated to about 5% of 20Ft and above buildings in Delhi. The cost of installation will be INR 19.25Cr (7,00,000 per unit) and INR 13.2 Cr a year to maintain them. A sum total of INR 32.45 Cr for the first year. According to WHO, a safe limit for PM2.5 is under 40 micrograms per meter cube.

The average PM2.5 in Delhi is around 220 micrograms per meter cube. This means that we need to have 5.5 times the number of units, i.e., we need 1600 smog towers in Delhi NCR alone. And the cost will be close to INR 1,78.475 Cr. What about the 25 other cities with similar requirements and can it really bring down pollution? This solution looks far from practical.

Plus to put things into perspective, we need a better measure of spread and source of air pollution. If you cannot measure it, how can we even estimate solving it? The measure of air pollution is so sparse in the country that we only have about 180 air monitoring stations working as of today. Air quality in hundreds of other cities are classified as non-attainable cities, it means that we can never measure air quality in those cities.

In addition to this, there are no sensors to measure air quality for Indian conditions or sensors made in India. Thus, just like how a doctor needs to diagnose a patient to prescribe medicines, there is a pressing need to measure air quality first using a combination of on-ground and remote sensing with acceptable flexibility to accuracy to which we are ignorant.

What Can We Do To Make Things Better And Immediate?

According to Teri, amongst the sources for air pollution within Delhi, the share of the transport sector is significant (39%) in PM2. 5 emissions. This reduces to 19% in PM10 emissions in Delhi, due to the presence of other major sources, such as road dust and construction, which emit more particles in the coarser range of PM. Similarly, a study by Urban emissions on average, across the urban airshed of Greater Delhi reports that the annual average PM2.5 concentrations vehicle exhaust is responsible for up to 30%, a leading source for PM2.5 emissions.

This is followed by biomass burning (seasonal open fires, cooking, heating) that adds to 20% of the annual share, industries are responsible for up to 20%, soil and road dust is responsible for up to 15%, diesel generators and open waste burning is responsible for 15% each and power plants contribute to 5%.

Some of the immediate measures that can be taken include stopping usage of all Diesel Generators (a law exists but not implied enough), driving strict policies to curb construction dust and cap industries to adopt methods of not letting any pollutant in the air. All these measures can bring down at least 50% of air pollution in Delhi. In addition to this, there should be more emphasis on adoption of EV buses that can reduce transport dust by a significant margin.

Secondly, there's a lot of talk on stubble burning and how it's the cause of major pollution in Delhi. This is only partially true because stubble burning is a seasonal activity. The air quality of the entire Indo-Gangetic plain of India is bad and polluted more or less throughout the year.

Apart from this, we should also take into consideration all the biomass burning that occurs in many areas of Jharkhand, Uttarakhand etc, today due to lack of penetration of LPG, forest fires and an increasing number of hotels and resorts in these areas. Infusion of millions of travellers travelling up the mountains increases the distribution of pollution. All of this can be controlled through better policies and restrictions. Additionally, other factors like garbage burning, burning of waste on road, heating during cold months outdoors in Delhi etc., worsen the situation

On one side there is increasing emissions, and no matter how many smog towers we install, there will be a negligible reduction in Air pollution. Hence we can conclude that Smog Towers are not the most effective solution to air pollution. Dealing with air pollution requires better measurement of air quality, awareness about sources of pollution, tracking of changing patterns of air quality in cities, installation of air quality monitors and consistent efforts towards reducing emissions.

> Our efforts as responsible citizens and as a government should be focussed on innovative solutions that can actually be a long term solution rather than a temporary relief for pressing problems like air pollution.

In China, questions raised over efficacy of smog towers

hindustantimes.com/cities/in-china-questions-raised-over-efficacy-of-smog-towers/story-HUQ2D3UqzDvybHVXYMiMOJ.html

November 13, 2019



Within months, China's state-controlled media had trashed the tower, calling it an "eyewash" and ineffective in a megacity with more than 20 million people like Beijing.

Beijing: China's experiment with installing giant outdoor "smog-free towers" in its polluted cities haven't had the desired results despite generating interest when first talked about in 2016.

Instead, emission control remains the only effective way to control pollution, experts told HT.

A seven metre high anti-smog tower, designed by Dutch designer Daan Roosegaarde, was the first to be put up in an art district in Beijing in 2016.

It was the last.

Within months, China's state-controlled media had trashed the tower, calling it an "eyewash" and ineffective in a megacity with more than 20 million people like Beijing.

A larger, skyscraper-sized smog-tower was also built in Xi'an, the capital of northwest China's Shaanxi province, another heavily polluted city, the same year.

Two years later, in 2018, the evidence of its effectiveness was questioned by a research institute.

“A skyscraper-sized air purifier curbed pollution by about 15% in a 10-square kilometer area over two years in one of China’s most polluted cities,” the state-controlled tabloid, Global Times said in a report.

“It would take about 1,000 to do the same for the entire city of Xi’an,” the tabloid quoted Cao Junji, from the Institute of Earth Environment at the Chinese Academy of Sciences as saying.

The 60-meter-high air purifier cost 12 million yuan ($1.91 million) when it was installed in 2016.

About 1,000 such structures could handle 10,000 square kilometers, Cao said.

“It is costly and works for a limited area like 100 metres, and the pollutants can be easily transported to clean air (area) again. It is not practical to use these (smog-towers) to control air pollution,” Hongliang Zhang from the Department of Environmental Science and Engineering from Shanghai’s Fudan University told HT.

“People build it for reasons but no one academia thinks it is effective,” Hongliang added.

“The haze towers in Chinese cities have not been used much; their effectiveness is limited to 100 metres (in the immediate surrounding areas). It has a limited effect on the environment,” a Liping Zhang, a consultant on pollution based in eastern China’s Hangzhou said.

“The economic feasibility of such towers is relatively poor for improving the environment on a large scale. They could have an impact on the environment at a very local level,” Liping added.

“Emission is the only way to control pollution,” Hongliang, the first expert, said.

In March, Beijing announced that it will allocate 25 billion yuan or $3.73 billion to prevent and control air pollution, an increase by 25% year on year.

As for the towers, they could probably work as anti-pollution symbols but the cost involved in building such structures in the first place puts a question mark on the projects.

The one already put up in Beijing, for example, has since been renamed as “smog reminder” instead of the more ambitious “smog tower”, state media reported, adding that the structure was retained for educational purposes.

‘No scientific data on effectiveness of smog towers’

sundayguardianlive.com/news/no-scientific-data-effectiveness-smog-towers

November 20, 2021

Tanmaya Das

- Published
- :
- November 20, 2021,
- 8:12 pm
- |
- Updated
- :
- November 20, 2021,
- 8:12 PM



Huge gap between science-based air pollution research and policies on air pollution, say experts and environmentalists.

New Delhi: Various experts and environmentalists have claimed that no scientific data is available to understand the effectiveness of smog towers. The experts have also highlighted that there is a huge gap between science-based air pollution research and the policies on air pollution that we have in our country.

“There is no scientific data available in the public domain that addresses the efficacy of

smog towers. Given the scale of pollution, size and the population of the city, no smog towers would work. Also, each smog tower will cost Rs 20 crore. We need to look at the source of pollution, rather than allowing pollution to happen and then spending money and technology to clean it," Vimlendu Jha, an environmentalist, told The Sunday Guardian.

Similarly, the smog towers are expected to work only in the areas where they are located. Dr Pratima Singh, a research scientist at the Centre for the Study of Science, Technology and Policy (CSTEP), said, "Smog towers will not be effective in reducing the ambient air pollution level in any city, they can just help reduce pollution levels in the vicinity that they are placed."

However, the data shows that the smog towers' installation will not be a successful pilot project. Smog towers installed in Connaught Place have not worked well. Asked whether installing smog towers will be a successful idea, Vimlendu said, "The data we have from Connaught Place in Delhi shows that the smog towers have not worked, otherwise, the Air Quality Index (AQI) of Connaught Place would have been better. Similarly, a smog tower was installed in Anand Vihar last year, but we see that it has remained a pollution hotspot. From the data point of view also, smog towers are not showing the desired result."

Dr Pratima also shared the same view and said that such projects are a sheer waste of public money. "Had smog towers been effective, most of the polluted cities in the world would have installed them by now. Many governments across the world, such as the UK, the US, believe and have informed us that these kinds of solutions are not effective. Spending public money on such measures is a sheer waste of resources," she told the newspaper

She also added, "Smog towers cover only a small area, lack of understanding on air pollution, science, how pollutants interact with the atmosphere, and how it travels, are one of the key reasons why governments adopt such measures." There is a huge gap between science-based air pollution research and policies to control the pollution in our environment. Also, the AQI doesn't help in the scientific analysis since the lawmakers have cut off access to actual data from several monitoring stations. "AQI is just an index, it doesn't measure the actual quantity of pollutants in the air. We should do more research on air pollution. Nobody looks at the nature of pollution and the nature of smoke in stubble burning. The burning of partially dried up material is dangerous because the constituents of that smoke are hazardous. Similarly, the number of metallic compounds that are released after burning is also hazardous to our health. AQI only looks into the amount of suspended particulate matter. We should also look into the fact whether the stubble is partially green or completely dried up," Prof Dr Maharaj Pandit, department of environmental science, Delhi University, told this paper.

Also, many tier-2 and tier-3 cities ignore the sources that add emissions. Additionally, the lack of monitoring stations makes it difficult to grasp the actual pollution levels. "Most of the evidence of air pollution levels in the country is available only in the major cities like Delhi, Mumbai, Bengaluru and so on, but the tier-2 and tier-3 cities ignore the emission inventory and source apportionment study, they don't even have enough monitoring stations to capture the pollution levels. These are some of the main reasons for the lack of evidence-based policies in such areas," Dr Pratima said.

There is a strong need for law enforcement in our country. People must have obligations to follow the laws of the government. Prof Dr Pandit recommended, “As a citizen, we need to obey laws. However, the government does not enforce some traffic laws that have been formulated for the public. In Delhi, we see unnecessary engine idling when the signal turns red. Many roads in Delhi are congested due to roadside shops and stalls. Some people often take kutcha roads due to traffic jams adding pollutants in the air. Many trucks and buses take kutcha roads, but not many studies are conducted on the number of dust particles spread by these vehicles. This is a multi-faceted problem so the enforcement and discipline to follow the laws must be ensured by the government.” Advising on controlling the pollution and emission, Dr Pratima suggested: “Carrying out certain measures and focusing on controlling vehicular emission, industrial emission and seasonal episodic events will play a key role in reducing emissions, which will lead to improved air quality. Instead of going for measures such as smog towers, the government should focus on direct sources.”

Smog towers ‘quick fix’, no scientific evidence they tackle pollution long-term: experts

livemint.com/news/india/smog-towers-quick-fix-no-scientific-evidence-they-tackle-pollution-long-term-experts-11629727301777.html

August 23, 2021



NEW DELHI : Smog towers may provide immediate relief from air pollution in a small area but they are a costly, quick fix measure with no scientific evidence to back their efficacy in the long-term, several experts said on Monday as the first such structure was inaugurated in Delhi.

Governments should instead tackle root causes and promote renewable energy to tackle air pollution and reduce emissions, the experts said.

“It will be really unfortunate if other cities decide to follow suit and set up these expensive, ineffective towers. They are an enormous distraction from what should be the governments' focus: reducing emissions," Santosh Harish, a fellow at the Centre for Policy Research, told PTI.

While smog towers might come across as a visible solution to air pollution, there is no scientific evidence -- even globally -- to support that they can filter outdoor air effectively, added Tanushree Ganguly, programme lead at the Delhi-based Council on Energy, Environment, and Water (CEEW).

Their comments came soon after Delhi Chief Minister Arvind Kejriwal inaugurated India’s first smog tower in the city’s Connaught Place area. The government claimed it will purify 1,000 cubic meters of air per second within a radius of around one kilometre.

Kejriwal said the over 24-meter tall structure, the first of its kind in India, has been set up as a pilot project and initial trends will be available within a month. If the pilot project is successful, more smog towers will be installed in the national capital.

Another 25-metre tower, built by the Central government at Anand Vihar, is expected to become operational by August 31.

Each tower costs around Rs. 22 crore. The two towers will have 1,200 air filters. Air will be sucked in from the top of the tower, filtered, and released through the fans at the bottom.

Arguing that anti-smog towers are an ineffective means to control pollution, environment experts raised concerns over their feasibility and said there are no studies to assess the impact of this technology on ambient air quality.

Environmentalist Harjeet Singh noted that the installation of the smog tower in Delhi is just a quick-fix solution. It will provide immediate relief from air pollution, and that too in a small catchment area.

"We must tackle the root causes of air pollution and promote green public transport, adopt better waste management practices and switch to renewable energy," Singh told PTI.

CEEW’s Ganguly said the data on the effectiveness of the newly installed smog tower should be pursued rigorously by the government and be made available publicly.

“Only once the evidence is available should the state and other parts of the country consider investing in more such towers," Ganguly told PTI.

Severe air pollution in north India has become an annual affair and smog towers have often been viewed as a quick solution to counter the foul air.

In November 2019, an expert panel estimated that Delhi will need a total of 213 anti-smog towers to battle the pollution crisis.

In 2018, China built a 100-metre smog tower in Xian. The project led to noticeable improvement in air quality in the city, according to the researchers from the Chinese Academy of Sciences, who monitored the project.

However, experts in India were unimpressed.

According to Singh, questions have been raised about the efficacy of even smog towers in China.

“We need to focus on the sources and promote solutions that are systemic and promote behavioural changes," he added.

Agreeing that smog towers have no scientific basis as a policy measure to tackle air pollution, Harish said, “… there is no evidence from previous pilots to justify setting up this tower at such high costs."

Ganguly concurred. Rather than investing further in unproven technologies, Delhi must set an example by redirecting these funds on strengthening monitoring of construction sites and industrial units, improving waste management in the city, and prioritising health risk communications, she said.

There are different technologies used to clean the air. One uses a highly effective particulate arrestance (HEPA) filter, which filters smaller pollution particles and is used in indoor air purifiers.

Another method uses electrostatic precipitators that attract pollution particles and collect them at the base of the tower.

The smog tower in Connaught Place has 40 fans and 5,000 filters developed by experts at the University of Minnesota which also helped design the smog tower in Xian.

A Delhi government statement said the smog tower is based on a downdraft air-flow model. Its 40 huge fans will suck air from the top of a special type of canopy structure and release clean air filtered through novel geometry filters, it said. Since it's a new technology, it is being implemented on an experimental basis. Tata Projects Limited (TPL) built the smog tower with technical support from IIT-Bombay and IIT-Delhi, which will analyse its data.