HANDBOOK OF ROAD ECOLOGY

Rodney van der Ree • Daniel J. Smith • Clara Grilo

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“Bonville Bypass Land Bridge”, Pacific Highway, NSW, Australia, photo by Rodney van der Ree

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NOTES ON CONTRIBUTORS

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Dr Tamar Achiron-Frumkin (DPhil, Oxford) is an ecologist and environmental advisor. Since the early 2000s, she has worked on various biodiversity conservation projects, gradually focusing on habitat connectivity and traffic-related issues. She was involved in the design of a few ecoducts and in monitoring usage. She produced a local version of COST 341, and initiated a project investigating the use and prioritization of existing road structures as animal passages to minimise fragmentation for the Israel National Transportation Infrastructure Company.

Graham Alexander is a professor at the University of the Witwatersrand, South Africa, where he heads a research laboratory that focuses on ecology, physiology, biogeography, and conservation of reptiles. He has a particular interest in elucidating causality of range limitation in reptiles, and using this information for conservation purposes.

John Altringham is Professor of Animal Ecology and Conservation at the University of Leeds in the UK. He has published three books on bats and numerous scientific papers and popular articles, many of them on bats and bat conservation. He works with a wide variety of conservation organisations.

Dr Kimberly M. Andrews has a joint position between Jekyll Island State Park Authority and University of Georgia (UGA) Savannah River Ecology Laboratory and is graduate faculty at the UGA Odum School of Ecology. Her lab focuses on small vertebrates and conducts field research on wildlife spatial ecology, land-use effects on habitat quality, and wildlife-human interactions. These field data serve as the basis for habitat management, land-use planning and infrastructure development, conflict resolution, and public education practices.

Fernando Ascensão holds a PhD in conservation biology. He studies animal–road interactions, including its effects on animal movement, landscape connectivity, gene flow, and population persistence. He undertakes his research in Portugal and Brazil, where he is currently a postdoc fellow in Brazilian Road Ecology Research Group (Lavras University). His goal is contributing to the development of sustainable transportation networks worldwide.

Alex Bager is the Coordinator of the Brazilian Road Ecology Centre (CBEE), and Professor at the Universidade Federal de Lavras, Brazil. Since 1995, he has been working on animal–vehicle collisions and barrier effects of roads. He is also coordinator of Urubu (Vulture) System, a social networking application to reduce the environmental impacts of roads and railroads on biodiversity.

Niko Balkenhol is Professor of Wildlife Management at the Faculty of Forestry and Forest Ecology of the University of Göttingen, Germany. His teaching and research focus on spatial and molecular approaches for wildlife ecology, conservation and management.

Christophe Barbraud is a researcher at Centre d'Études Biologiques de Chizé (CEBC) – Centre National de la Recherche Scientifique (CNRS) since 2001. He is mainly interested in modelling population dynamics of vertebrates in relation to climate variability. He uses long-term individual monitoring data (demography, biometrics, ecology at sea) of birds and marine mammals.

Hans Bekker was an eco-engineer with Rijkswaterstaat of the Dutch Ministry of Transport, Public Works and Water Management. He was a program leader with environmental issues, mainly wildlife, roads/rails and traffic, and acted as a bridge between civil engineers and ecologists, policy and projects, scientists and practitioners. Hans co-initiated the Infra Eco Network Europe (IENE), in 1995, was a member of steering committee of ICOET (USA), chaired COST 341 and ran the Dutch Long-Term De-fragmentation Program. Hans retired in 2015.

Dr Roberta Bencini is an associate professor in the Wildlife Research Group, School of Animal Biology, at the University of Western Australia. Since 2005, she has been investigating methods to mitigate the negative effects of roads and other developments on wildlife, including underpasses and rope bridges.

Dr Anna Berthinussen completed her PhD in 2013 on the effects of roads on bats and the effectiveness of current mitigation practice, at the University of Leeds, UK. She is currently working on a Defra-funded study of the interactions between bats and roads, and has plans to continue her career in research and wildlife conservation.

Bradley F. Blackwell, PhD, serves as a research wildlife biologist for the NWRC. His research focuses on exploiting animal sensory ecology and antipredator behavior in the development of technology, for example vehicle lighting systems, and habitat-management guidelines, to reduce animal–vehicle collisions, particularly wildlife–aircraft collisions.

Matt Blank, PhD, is an assistant research professor at the Western Transportation Institute and the Department of Civil Engineering at Montana State University. As part of the Road Ecology program at WTI, Dr Blank performs research focused on fish passage, fish swimming abilities, dam removal and river hydraulics. He has over 20 years of experience in the academic and practical engineering world. He also teaches applied fluid mechanics at MSU, and does water resource consulting with Environmental Resources Management (ERM).

Martijn Boonman is a consultant at Bureau Waardenburg, the Netherlands. He is involved in projects considering monitoring, environmental impact assessments (EIA), ecological infrastructure and the effectiveness of fauna crossings under motorways. An important part of the EIA's consists of studies on bats in windfarms.

Dr Carlos E. Borghi is the Director of the Centro de Investigaciones de la Geósfera y la Biósfera (CIGEOBIO) – Universidad Nacional de San Juan and Consejo Nacional de Investigaciones Científicas y Técnicas (Argentina). His research focuses on animal ecology and animal–plant interaction in deserts and the effect of human perturbations on wildlife.

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Dr Yung En Chee is a quantitative ecologist at The University of Melbourne with research experience in statistical, spatial and ecological modelling. Often working in multi- and interdisciplinary teams, her research focuses on applying ecological and decision analysis theory, models and methods to provide data-driven, practical decision support for conservation and ecosystem management problems. She has authored a reference resource of tools designed to guide and enhance the rigour of Strategic Environmental Assessments (Chee et al. 2011, http://www.academia.edu/3412596/Methodologies_and_Tools_for_Strategic_Assessments_under_the_EPBC_Act_1999).

Professor Jiding Chen received his MSc degree in ecology from Peking University in 1992 and since then works for China Academy of Transportation Sciences (CATS). Now he is the vice president of CATS. His research area includes road ecology, green transportation, scenic byway planning and management, and environmental impact assessment.

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Wendy Collinson is the project executant of the Endangered Wildlife Trust's Wildlife and Roads Project. She has an MSc (Rhodes University, South Africa), which examined the impacts of roads on South African wildlife. She is currently driving initiatives that address the now-recognised threat of roads in South Africa. In addition, she is creating a national network to raise awareness and further quantify road ecology issues through proactive mitigation measures such as a Roadkill Sensitivity Map and best practice guidelines for road development.

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Patricia Cramer is a research assistant professor at Utah State University in the United States, and an independent wildlife researcher. An expert on wildlife, roads and crossing structures, she works with Departments of Transportation and Wildlife Agencies to research wildlife near roads in Utah, Montana, Idaho, Oregon, Washington and other states. She received the Denver Zoo's 2010 Conservationist of the Year award, and the 2013 US Federal Highways Environmental Excellence Award in Research for her work in Utah.

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Dr W. Richard J. Dean is an ornithologist and research associate of the Percy FitzPatrick Institute for African Ornithology, University of Cape Town. After retiring from academia, he started an indigenous nursery and ecological consulting and restoration business in the arid Karoo region of South Africa with Sue Milton. See http://www.renu-karoo.co.za.

Travis L. DeVault, PhD, serves as a Research Wildlife Biologist and Project Leader for the NWRC. His research centres on wildlife ecology and behaviour, with an emphasis on resolution of human–wildlife conflicts. He is particularly interested in how land-use practices on and near airports can be modified to reduce wildlife–aircraft collisions, while increasing revenue potential and renewable energy production for airports.

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Benjamin Dorsey is a research assistant at Montana State University, where he also obtained his MSc on wildlife mortality along the Canadian Pacific Railway. He has also worked for several years on the Trans-Canada Highway Wildlife Crossings project. When not working he enjoys travelling the world by rail, and rock climbing.

Clinton W. Epps studies connectivity, gene flow, animal movement and wildlife conservation in Tanzania, southern Africa and the United States. He is an associate professor in the Department of Fisheries and Wildlife at Oregon State University. He is interested in documenting, modelling and conserving connectivity of animal populations in fragmented landscapes.

Lenore Fahrig is professor of biology at Carleton University, Ottawa, Canada. The overall goal of her research is to understand how landscape structure – for example spatial patterning of roads, forestry and agricultural regions – affects the abundance, distribution and persistence of organisms. A particular focus is on the effects of roads and traffic on wildlife populations, using a combination of spatial simulation modelling and field studies. She is currently a board member of the Ontario Road Ecology Group.

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Jeffrey W. Gagnon has worked for AZGFD since 1997, currently as a statewide, research biologist, focusing for the past decade on wildlife–highway interactions throughout Arizona, including State Route 260 and US Highway 93 wildlife crossing projects. Jeff works closely with Arizona Department of Transportation on numerous projects to ensure wildlife concerns are properly addressed. Jeff received his MS from Northern Arizona University where he studied the effects of traffic volumes on elk movements associated with highways and wildlife underpasses.

Dr T. Ganesh is a senior fellow at ATREE. For over three decades, he has worked and advised students on various ecological aspects primarily focussing on plant–animal interaction; bird and primate ecology; ecological restoration and long-term monitoring of forests. He was pivotal in establishing nature clubs and conducting outreach activities in various schools in Western Ghats and also authored a bilingual multi-taxa field guide. He is an avid bird watcher and enjoys travelling to natural landscapes.

Miriam Goosem is Principal Research Fellow in the Centre for Tropical Environmental Sustainability Science at James Cook University, Cairns, Australia. Her research in the field of rainforest road ecology spans 25 years including a variety of vegetation and wildlife fragmentation impacts. She was involved, together with colleagues, in the implementation in rainforest of the first purpose-built underpasses and rope canopy bridges between 1995 and 2005 and continues to monitor their effectiveness.

Clara Grilo is a postdoctoral researcher of the Department of Biology and CESAM, at the University of Aveiro, Portugal. Her primary interest is applied ecological research in support of active conservation projects. Currently, much of her research is focused on the impact of anthropogenic changes to the landscape and effects on wildlife.

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Éric Guinard is a civil engineer, doctor in Ecology in the Centre d'Études et d'expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement – Direction Territoriale du Sud-Ouest (CEREMA – DTerSO) near Bordeaux since 2005. He is in charge of expertise and management assistance of ecological studies on road and motorway projects. He also participates in the development of methods and conducts applied research projects, mainly concerning interactions between transportation infrastructure or urban extension and natural habitats.

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PD Dr-Ing. Heinrich Reck studied agricultural biology and landscape conservation at Hohenheim and Stuttgart Universities and obtained his post-doctoral lecturing qualification (Habilitation) in landscape ecology at Kiel University. He works as a senior researcher and lecturer on the interface between spatial environmental planning and animal ecology and is a member of the state planning council of Schleswig-Holstein, Germany. He has worked on road ecology and application-oriented research on impact mitigation and compensation work since 1990.

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Pierre L. Ibisch, Professor for Nature Conservation with Eberswalde University for Sustainable Development, Germany. He holds a research professorship on ‘Biodiversity and natural resource management under global change’ and is Co-director of the Centre for Econics and Ecosystem Management. He has special interests in adaptation to global change and integration of risk management in adaptive biodiversity conservation management, functionality of ecosystems and conservation priority setting, spatial planning, and protected area management.

Sandra Jacobson is a wildlife biologist for USDA Forest Service, Pacific Southwest Research Station specializing in transportation ecology. She designs mitigation for highway impacts to species ranging from elephants to butterflies internationally. Her projects and graduates have received numerous awards, including from the USA FHWA. She is a Steering Committee member of ICOET, a charter member of the Transportation Research Board’s Committee on Ecology and Transportation and a Steering Committee member of the ARC Design Forum for wildlife crossing structures.

Jochen A. G. Jaeger is an associate professor in the Department of Geography, Planning and Environment at Concordia University in Montreal, Canada. He received his PhD in Environmental Sciences from the Swiss Federal Institute of Technology (ETH) in Zurich in 2000. His research is in the fields of landscape ecology with a focus on landscape fragmentation and urban sprawl, road ecology, ecological modelling, environmental indicators, environmental impact assessment and novel concepts of problem-oriented trans-disciplinary research.

Darryl Jones is an Professor at Griffith University, in Brisbane, Australia, and Deputy Director of the Environmental Futures Research Institute at that university. He has been actively engaged in urban ecology since the early 1980s and in road ecology research for over 10 years.

Dr Nina Klar is working at the federal administration of Hamburg, Germany, being responsible for native species conservation. She is especially interested in wildlife species living in human-dominated landscapes. After her research on wildcats and road ecology, she is now conducting conservation projects for urban wildlife.

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Yaping Kong is a Professor who received her MS degree in ecology from Beijing Normal University in 2002, and since then has worked for the China Academy of Transportation Sciences (CATS). Now she is the vice-director of the Research Centre for Environmental Protection and Transportation Safety. Her research area includes vegetation restoration, water resource protection, road geological disaster control, ecological highway planning and management, transportation policy making, EIA and road ecology.

Stefan Kreft is a researcher with the Centre for Econics and Ecosystem Management, Eberswalde University for Sustainable Development, Germany. Under the impression of rapid land-use changes in South America, his research priorities have gradually shifted away from species conservation to ecosystem-based conservation approaches, addressing adaptation to climate change in particular. Besides a current focus on Europe, developing and transitional countries remain of great interest to him. He is member of the Roadless Areas Initiative of the Society for Conservation Biology.

Dr Tom A. Langen is Professor of biology, Clarkson University. He conducts road-related environmental research including winter road management, predictive modelling of road mortality hotspots, design of wildlife barriers and passageways for turtles, and the impact of highways on habitat connectivity in Costa Rican National Parks. He leads workshops in Latin America and North America on the environmental impact of roads and other infrastructure.

Thomas E. S. Langton is an International Consultant Ecologist based in Suffolk, UK, specialising in the conservation of herpetofauna and their communities and habitats. He has a wide range of experience working for government, industry and the non-profit sectors including linear transport developments and mitigation and applied road ecology solutions. His main activities include practical aspects of habitat and species surveys, habitat restoration and construction, and species and habitat management. He also works on wildlife law implementation.

Dr Scott LaPoint is a wildlife ecologist at the Max Planck Institute for Ornithology in Radolfzell, Germany. He has investigated mammalian responses to roads as an undergraduate and throughout his graduate studies, including his dissertation where he investigated urban landscape connectivity via movement data collected on free-ranging carnivores.

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William F. Laurance is a distinguished research professor and Australian Laureate at James Cook University in Cairns, Australia, and also holds the Prince Bernhard Chair in International Nature Conservation at Utrecht University, the Netherlands. He studies the ecology and conservation of tropical forests throughout the world, and to date has authored seven books and over 400 scientific and popular articles. He is a fellow of the American Association for the Advancement of Science and former president of the Association for Tropical Biology and Conservation. He is also director of the Centre for Tropical Environmental and Sustainability Science at James Cook University as well as founder and director of the leading international scientific organisation ALERT—the Alliance of Leading Environmental Researchers and Thinkers.

Dr Enhua Lee is a senior ecologist at the environmental consulting company, Eco Logical Australia. She has prepared numerous biodiversity strategies, biodiversity and natural resource management plans, and environmental impact assessments. Enhua conducted her PhD at UNSW on the ecological impacts of roads in arid ecosystems, investigating impacts on soil, vegetation, kangaroo, small mammal and lizard distributions and abundance, and kangaroo behaviour and mortality.

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Dr Juan E. Malo is an associate professor and researcher at the Terrestrial Ecology Group of Universidad Autónoma de Madrid. His research interests include ecological interactions and the effects of human activities on wildlife populations, with a special focus to environmental impact assessment of infrastructures and fragmentation.

Carlos Manterola is the General Director of Grupo Anima Efferus A.C. and the Director of Conservation of Jaguar Conservancy, A.C., in Mexico. He was General Director of the conservation NGO Unidos para la Conservación. He has led numerous conservation projects including the establishment of Protected Areas in Mexico, the protection and recovery of the pronghorn antelope in Mexico, management of desert bighorn sheep on Tiburon Island and the conservation of jaguars and their habitat in Mexico and Central America.

Dr Cristina Mata is a postdoctoral researcher at the Terrestrial Ecology Group of Universidad Autónoma de Madrid (Spain). Her main research is focused on monitoring and assessment of mitigation measures aimed at the reduction of habitat fragmentation by roads and railways.

Dr Vinod B. Mathur is the Director, Wildlife Institute of India. He obtained his doctoral degree in wildlife ecology from the University of Oxford in 1991. He is Regional Vice-Chair of the IUCN-World Commission on Protected Areas (WCPA-South Asia). He is a member of UN-IPBES Multidisciplinary Expert Panel (MEP). His areas of interest are Impact Assessment and Road Ecology.

Dr Markus Melber studies the impact of roads on bats as well as the effectiveness of mitigation projects for bats along a heavy-traffic motorway but also the ecology of forest-living bats. Besides working as a research associate at the University of Greifswald, Germany, he has also worked for several German federal agencies. He often acts as an advisor for public agencies on mitigation projects and on conservational topics. His work has resulted in several scientific publications, book chapters and reports.

Dr Suzanne J. Milton is a plant ecologist and research associate of the Percy FitzPatrick Institute, University of Cape Town. After retiring from academia, she started an indigenous nursery and ecological consulting and restoration business in the arid Karoo region of South Africa with Richard Dean. See http://renu-karoo.co.za/. Sue Milton and Richard Dean also founded the Wolwekraal Conservation and Research Organisation.

Mike Misso has been the Manager of Christmas Island and Pulu Keeling National Parks since late 2010. Prior to moving to Christmas Island, Mike worked as a Natural Resource Management facilitator, and prior to this in a range of national park management roles at Kakadu and Uluru Kata Tjuta National Parks in Australia, including as a Planning Officer, Chief Ranger and Natural Resource Manager.

Christa Mosler-Berger is a wildlife biologist and co-manager of the non-profit association WILDTIER SCHWEIZ and responsible for the Swiss Wildlife Information Service. She has been involved in the evaluation of animal detection systems (ADS) since they were first installed in 1993 in Switzerland.

Rob Muller has worked as the Chief Ranger of Christmas Island National Park since mid 2010. One of Rob's key responsibilities is, with other Ranger staff, to coordinate the road management activities for conserving red crabs during their annual breeding migration. Prior to moving to Christmas Island, Rob worked as a Ranger (including as a Chief Ranger), at Kakadu National Park in Australia for over 20 years.

Benezeth Mutayoba is an awardee of 2014 National Geographic/Buffett Award in 'Leadership in African Conservation' and works on wildlife movements, road kill dynamics, connectivity and gene flow in isolated wildlife populations as well as on wildlife health and forensics. He is a professor in the Department of Veterinary Physiology, Biochemistry, Pharmacology and Toxicology, Faculty of Veterinary Medicine, Sokoine University of Agriculture, Tanzania.

Katarzyna Nowak has studied primates and elephants in flooded and montane forests in Tanzania and South Africa. She is currently a junior research fellow at Durham University, UK, and a research associate at the University of the Free State, Qwaqwa, South Africa. She is interested in how flexibility in behavior affects species' capacity for persistence in human-dominated landscapes. She is currently researching samango monkeys' landscape of fear.

Kirk A. Olson has been promoting conservation of migratory ungulates and grazing ecosystems in Mongolia and Central Asian region since 1998. Kirk completed his PhD at the University of Massachusetts, Amherst, and his dissertation focused on the ecology and conservation of Mongolian gazelles. Kirk is a Research Associate at the Smithsonian Conservation Biology Institute and most recently worked with Fauna and Flora International's saiga conservation program.

Mattias Olsson has a PhD in biology and is working at EnviroPlanning AB and part time at SLU (Swedish University of Agricultural Sciences) in the Triekol research program. His research and enquiries are about wildlife and infrastructure, and he regularly works with civil engineers and landscape architects in order to mitigate the negative effects of highways and railroads. When he is not working, he spends time with the family and as a coach for a girl's handball team and a boy's soccer team.

Fabrice Ottburg, BSc, is a research scientist involved in applied and multi-disciplinary research, consultancy and acquisition for various projects in ecology (fundamental ecological research) and habitat fragmentation. He has extensive experience in ecological impact assessments in landscape areas and mitigation/compensation/monitoring studies for large-scale projects. He is also qualified in studies on nature development, ecological nature and juridical development and animal ecology (fishes, amphibians and reptiles).

Eugenia Pallares is General Director of the Mexican conservation NGO Jaguar Conservancy. She has collaborated and coordinated various projects on the conservation of jaguars and their habitat in Mexico, mitigation of the impact of roads on biodiversity in the Mayan Forest, and projects involving environmental policies. She has worked on editorial boards where a number of books, calendars, brochures and other materials have been produced. She is also a member of the Board of the Council for Sustainable Development in Mexico.

Dr Dan Parker is a wildlife biologist, based at Rhodes University in Grahamstown, South Africa. He supervises a large and vibrant post-graduate research school and is particularly interested in the biology and conservation of Africa's large carnivores.

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Sarah E. Perkins is a Lecturer in Ecology at Cardiff University. Sarah established and runs 'Project Splatter' a UK-wide citizen science initiative to collate wildlife roadkill using social media. Sarah is a strong supporter of the value of crowd-sourced data to both scientists and citizens. Away from roads her research focuses on the ecology of wildlife diseases.

H.C. Poornesha works on conservation of wildlife habitats in the Western Ghats of India through GIS analysis and conservation planning. He has also contributed largely to applied conservation issues in the landscape (see http://ncf-india.org/people/h-c-poornesha for further details).

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Dr Asha Rajvanshi heads the EIA Cell of the Wildlife Institute of India (WII). She works in the area of road ecology and has developed a range of best practice guidance manuals for mainstreaming biodiversity in impact assessment in different economic sectors including roads. She has been part of several global EIA initiatives and is a member of IAIA.

Dr Lisa J. Rew is an associate professor at Montana State University. Her research concentrates on the dispersal, distribution and dynamics of weedy plant species, and how best to manage them at a local scale. She is involved with this project due to her interest in how seeds are dispersed by vehicles, and how that could impact wildlife. When she isn't working she can often be found playing in the mountains.

Kevin Roberts is currently the Section Leader – Environment with consulting firm Cardno. From 2007 until 2014, he was the Senior Environmental Specialist (Biodiversity) for the NSW Roads and Maritime Services, Australia. Kevin's responsibilities were developing policy and procedures for managing biodiversity across the organisation. Prior to working for RMS, Kevin has held a range of senior roles in the NSW agencies responsible for regulating and planning for biodiversity conservation.

Dr Carme Rosell is a senior consultant at Minuartia and is part of a research group at the University of Barcelona. She has led numerous projects to design and monitor wildlife passages in roads and high speed railways. Her recent projects are focused on reducing animal-vehicle collisions and improving road maintenance practices. She has co-authored guidelines including the COST341 handbook *Wildlife and Traffic*. Carme is a member of the Infra Eco Network Europe Steering Committee.

Trina Rytwinski is currently working as a post-doc in the Geomatics and Landscape Ecology Research Lab, at Carleton University, Ottawa, Canada. Her research focuses on understanding the circumstances in which roads affect population persistence, specifically looking at species traits and behavioural effects of roads, and ways to mitigate road effects.

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Stephen Tonjes has worked 28 years in environmental compliance for the Florida Department of Transportation, and now consults part-time. Before FDOT, he served in the US Coast Guard, taught marine science in the Florida Keys, and monitored compliance for the Coast Guard bridge permit program in Juneau, Alaska, and for the US Fish and Wildlife Service in Washington, DC. He has a special interest in communicating wildlife ecology to transportation professionals and transportation development to wildlife ecologists.

Marguerite Trocmé has been responsible for setting the environmental standards for the Swiss highways since 2008 at the Federal road office. She began working on roads and environmental issues in 1989 as an environmental project reviewer at the Swiss federal office for the environment. She was vice-chairman of the European COST 341 project on habitat fragmentation due to transport infrastructure and is currently president of the VSS commission on traffic and wildlife and has initiated a number of research projects in the field.

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Susie Weeks has been the Executive Officer of the Mount Kenya Trust since 2001. She and her team have managed a number of successful private–public conservation partnerships to protect the integrity of Mount Kenya's forests and wildlife. The Mount Kenya Trust spearheaded the pioneering Mount Kenya Elephant Corridor project alongside the project's partner organisations. Susie is a gazetted Kenya Wildlife Service Honorary Warden.

Cameron Weller is an environmental manager with Jacobs and has over 7 years experience, primarily in the delivery of large infrastructure projects in Australia. He also has experience in working on large multi-disciplinary design teams as the environmental design lead. His work involves designing and managing the installation of fauna mitigation measures, writing environmental management plans and ensuring environmental compliance.

Patricia White began the US Habitat and Highways Campaign in 2000 to address impacts of highways on wildlife and encourage transportation planning that incorporates conservation. Her first report, *Second Nature: Improving Transportation without Putting Nature Second* was awarded the 2004 NRCA Award of Achievement for best publication. Patricia was a founding member of the International Conference on Ecology and Transportation (ICOET) Steering Committee, a founding member of the TRB Committee on Ecology and Transportation and proud founder of the TransWild Alliance.

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FOREWORD

Roads smoothly and efficiently move us from place to place, and, by concentrating movement in somewhat straight strips, limit the big footprint of impacts on nature. But most roads were built before the rise and spread of ecology through society. As a consequence in part, roads with traffic cause significant and widely permeating effects on natural systems. Mitigation of today's surface transportation system therefore stands as a primary challenge of society and transportation. Furthermore in rapidly developing areas worldwide new roads proliferate, which now can be built with solid ecological foundations.

Nature within the strip of road and roadside is, of course, degraded. Mitigation reduces that effect, but especially minimizes the outward-rippling degradation across the land. What nature is affected, or natural systems disrupted? Three dimensions are central: (1) habitat and plants, (2) water quantity and quality and (3) wildlife. Roads and wildlife are the highlight of this book, though valuable insights on the other two dimensions appear.

The pages in your hand are a *tour-de-force*, a gem, indeed a treasure chest. I find it readable, interesting, practical, useful and ambitious. The remarkable cast of authors has uncovered a goldmine for us. The editors catalysed extra rigor and consistency, thus encouraging comparisons and usability. Virtually, every chapter begins with several succinct topic statements, which pinpoint the essence and also provide an overview. These statements are then analysed as the sections of text. Mitigation is the focus, though new road construction in developing nations is included. Wildlife, including different faunal groups and different regions, is emphasised. An international perspective thoroughly permeates the presentation. Policy, planning and practice are highlighted alongside research and state-of-the-science results. I gained insight into every chapter perused.

Building on this accomplishment, analogous books highlighting roads and vehicles relative to vegetation and water would be valuable. Habitat, vegetation and plants are emasculated by roadside cutting and mowing. Fortunately, converting most (though not all) roadside area from grassy to woody vegetation is consistent with traffic safety and cost efficiency. Consider the numerous ecological and societal benefits. New habitat created, and existing adjacent woody habitat enhanced. Wildlife populations increased, probably well exceeding any increase in roadkills. Road crossing facilitated, thus reducing the habitat fragmentation and barrier-to-movement effect against wildlife and pollinators. There was reduced spread of airborne chemical pollutants from roadway and vehicles. Rare plants, animals and habitats enhanced on roadsides, especially important where scarce in agricultural and urban landscapes.

Water in varied forms poses endless problems, both familiar and as surprises, for transportation. Think of road-closure flooding, washouts/roadbed failures, wet driving surfaces, drainage-ditch filling, eroded roadsides, mudslides/landslips, frost cracks and potholes, snow-and-ice surfaces, blowing snow and too much snow. Water quantity-and-quality problems for nature are also severe. The soil water table is widely altered (raised or lowered) by roads. Where the water table is close to ground surface, wetlands are altered (drained or expanded). Fortunately, 'eco-piping' or permeating the roadbed with pipes crossing beneath a road maintains more natural water tables and wetlands. With permeated roadbeds, floodwaters seldom reach road surfaces and rarely wash out roads. The hydrologic connectivity through roadbeds supports more natural fish movements, and happy anglers. The same pipes connect the land for many small terrestrial animals. Drilling and inserting horizontal pipes is a routine, and in view of this array of benefits, cost-effective technology.

Water-quality pollution benefits follow suit. Most vehicle- and road/roadside-generated chemicals are readily 'treated' near roads in elongated mitigation structures (depressions, wetlands, ponds). Soil and microbes mainly clean the water. Polluted heated ditch-water entering nearby water bodies is largely eliminated using familiar stream features (convoluting, step-damming) plus tall vegetation (wind-and-sun evapotranspiration pumping). Again these manifold water quantity and quality benefits are consistent with safety and efficiency, cost effectiveness, and engineering design creativity.

A decade ago, four transportation leaders, a leading hydrologist, and nine ecology-research scholars co-wrote the book, *Road Ecology: Science and Solutions*. This synthesized a scattered literature and articulated principles linking roads/vehicles, soil/water/air and plants/animals. One of our dreams was the highly useful compendium now in your hand.

The scientist in me inexorably jumps from this treasure chest of insight to pregnant and important research frontiers awaiting us. How do our current ecological science results apply to the diverse types of roads and traffic levels criss-crossing the land? The ecology of road segments and especially road networks in a landscape cries out for study. Where is the ecology of different truck, car, tire, even road surface types? What is the (ecology and cost) optimum distance between road-crossing structures for different wildlife types? How can the ubiquitous utility poles along roads be used in mitigation solutions? To understand roads and wildlife populations, the non-roadkill dimensions now need much greater emphasis. As suggested earlier, habitat/plant and water quantity/quality dimensions of road ecology are lurking giants, awaiting a few prescient researchers and leaders.

My government-and-citizen-side hones in on the need and opportunity to accelerate solutions now for transportation, the land and us. Every roadbed, bridge and culvert repair/replacement is the cost-effective moment to concurrently address other goals of society, such as walking/biking paths, reduced flooding, enhanced fish movement, reconnected split communities and so forth. Roadsides represent a massive little-used resource (for nature and us) at our doorstep. Roadside food production, trail networks, stormwater and pollution mitigation, history-and-nature education effectively create variegated roadsides, bulging with useful solutions for society. Light, noise, vibration and wind can be dispersed or concentrated, as well as decreased or increased. Eco-piping or pipe-perforated roadbeds provide lots of benefits quickly. The 'road-effect zone' provides a ready framework for ecologically planning, engineering and mitigating roads. In parks, towns and sprawl areas, curvy, slightly bumpy and seemingly narrow roads slow traffic and reduce effects on wildlife. In every jurisdiction, remove a road segment or two to create continuous ecologically valuable, large natural-habitat patches. By lowering (e.g. 2–3 m) short stretches of roads in good-drainage areas, inexpensive green-bridges (with some 10 cm of sandy soil) will help re-establish semi-natural wildlife movement patterns across the land. And just on the horizon, a transportation system slightly above or below ground level, using lightweight renewable-energy automated pods, effectively recovers an extensive area of road/roadside-covered terrain. Furthermore this 'netway system' reconnects today's fragmented land for nature and us. Indeed, on an exhilarating netway ride at London's airport I experienced the future.

Road ecology and this book's impressive synthesis highlight a great opportunity for planners, engineers and ecologists to collaborate for new successes, and receive important accolades together. History will record that transportation, land-and-water, and society are the big beneficiaries.

Richard T. T. Forman
Harvard University

PREFACE

This book brings together some of the leading researchers, academics, practitioners and transportation agency personnel from around the world to focus on the challenge of improving the ecological sustainability of the linear infrastructure – primarily road, rail and utility easements – that dissects and fragments most landscapes around the world. Where possible, we aimed to have co-authors from different continents on every chapter – and indeed, many authors are collaborating together for the first time on this book.

When authors were invited to contribute, we gave them this initial challenge: 'Imagine you are in charge of your professional world for a day, and could change anything to improve the ecological sustainability of roads (or other linear infrastructure) and traffic: what six to eight things would you change or want people to learn and do differently?' Conversely, a second challenge posed to the authors was slightly more pessimistic: 'Identify the six to eight mistakes that you regularly see or experience in your area of practise and write about those and how to avoid them'. This approach appeared to stimulate our authors and provided a tangible grounding for their writing – but the *real* challenge came when we tried to impose an average word limit for each chapter of 3,000 words! In hindsight, the word limit was probably too restrictive for some topics, but it forced authors to be concise and succinct – which we hope you, the reader, appreciate!

Chapters are written as a series of lessons, insights or principles (hereafter referred to only as lessons) that forced authors to be very specific about their key points. Many struggled with this style – but our hope is that it allows you to quickly identify the pertinent information to help you in your day to day tasks. We realised that time is precious – and for most of you – time is money (yours or your bosses!) and we have designed the book so you can quickly and efficiently find the answers to your questions and get back to the planning, designing, building, maintaining or granting approvals to build roads or other transportation infrastructure. And in the likely event that this book does not answer all your questions, the further readings and up-to-date reference lists for each chapter should point you to the extra information you need.

The chapters span the project continuum – starting with planning and design, through construction and into maintenance and management. Research and monitoring is such an important aspect that it sits like an umbrella, encompassing all phases of a transportation project. Rigorous monitoring and evaluation of the impacts of a road or effectiveness of mitigation often requires the collection of data before the road or mitigation is built – hence the chapters on monitoring, evaluation and maintenance come before the impacts and mitigation are described. A significant proportion of the book focuses on impacts and solutions for species groups and specific regions. The rate of major road construction in the United States, Australia and Western Europe has slowed, while developing countries are expanding their road and rail networks at an incredibly rapid rate. This book highlights some of the unique regional challenges with case studies from Asia, South America and Africa.

Chapters are designed to be stand-alone – you do not need to read the book from cover to cover, or even from front to back, to be able to use its contents. We envisage that readers will come to our book when facing a challenge – or rather an opportunity – and they can dive into the relevant chapter to improve their understanding of the major problems and the array of current possible solutions. Nevertheless, we have endeavoured to ensure that chapters build upon and complement each other – so reading (or even skimming) it from cover to cover won't be a waste of time. Extensive cross-referencing among chapters directs the reader to relevant material elsewhere in the book.

We should point out what this book is not: it is not a series of standards for the design of roads or mitigation measures. These standards and guidelines already exist in many countries, states or regions and we did not want to repeat them here. If they don't exist in your region, there are enough around to borrow from in order to develop your own. And because the optimal design and placement of, for example, crossing structures, fences or wildlife detection systems should evolve as our understanding and technology improves, such specific information would be quickly out of date. All the authors in this book have strived to identify the greatest challenges and opportunities and write about them in a way that is timeless.

Our sincere hope is that this book improves the way roads and other linear infrastructure are planned, designed, approved, built, maintained and studied.

Rodney van der Ree
Daniel J. Smith
Clara Grilo
September, 2014

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Edited books such as the *Handbook of Road Ecology* are a combined effort of many people – not the least of which are the 115 people from 25 countries that contributed to the 62 chapters. It was a privilege for us to combine your individual expertise into a product that truly exceeded the sum of its parts! Zoe Metherell and Scott Watson generously illustrated numerous figures, and many others assisted in developing the concept, providing figures and editing the final product – including Alan Crowden, Ward Cooper and Kelvin Mathews at Wiley, Radjan LourdeSelvanadin at SPi Global, Lee Harrison, Cindy van der Ree and Marcel Huijser.

Road ecology is most definitely a collaboration between industry and academia, researchers and engineers, government agencies and road construction companies. This handbook is no different. Numerous companies, government agencies, not-for-profit conservation groups and university/research centres have contributed financially to the production and distribution of this book. Funds provided by these generous supporters have allowed us to provide over 200 copies of this handbook to practitioners in developing countries. Further details are available at www.handbookofroadecology.net. We sincerely thank these organisations for their support: ACO Polycrete Pty Ltd, Animex – Animal Exclusion Solutions, the Australian Research Centre for Urban Ecology at the Royal Botanic Gardens Melbourne, Chinese Academy of Transportation Sciences, Eco-Kare International, Florida Wildlife Federation, Melbourne Sustainable Society Institute, School of Ecosystem and Forest Sciences at the University of Melbourne and the Federal Road Office of Switzerland of the Department of Environment, Transport, Energy and Communications.

Rodney: I thank the many ecologists, road practitioners and government regulators who have shared time and experiences discussing, planning, designing and building better roads and other linear infrastructure. I am grateful to Andrew Bennett for guiding me through the perilous days of designing and completing a PhD in what was the nascent days of 'road ecology'. Mark McDonnell encouraged me to write and edit this volume, and he and the Baker Foundation supported this undertaking. To my co-editors – thanks for bringing complementary skills to the editing table and for sharing the vision of this book! I am particularly appreciative of Cindy's continuing love and support, who once again allowed me to disappear from family life to complete this project. To Ethan and Ezra – thanks for tolerating my absences and may you forever contemplate the solutions to roadkill and barrier effects as you travel life's roads.

Dan: I extend a special thank you to four individuals that encouraged, mentored and guided me toward a career in the disciplines of landscape ecology, road ecology and conservation planning – Larry Harris, Gary Evink, Leroy Irwin and Richard Forman. I'd also like to thank Reed Noss for his support and collaboration, which has helped me sharpen my research design and analytical skills and furthered my success as a scientist. My sincere appreciation goes to my co-editors, even though each of us ended up spending many long nights and days on this collaboration, the spirited camaraderie made it an enjoyable learning experience.

Last but not least, thank you to family, friends and colleagues that have inspired me and kept me steadfast towards making a positive difference in the world.

Clara: I thank my parents for their support and enthusiasm for my research and John A. Bissonette for inspiring me to work on road and landscape ecology. Thanks to Rodney for inviting me to participate in this book project. A very special thanks to IENE, ICOET and ICCB conference organisers that allowed me to meet researchers from all parts of the world. Social events at these conferences were priceless to meet most of the authors who contributed to this book, who also share a passion for road ecology as well as the love of good beer and hilarious moments.

ABOUT THE COMPANION WEBSITE

This book is accompanied by a companion website:

www.wiley.com\go\vanderree\roadecology

The website includes:
- Powerpoints of all figures from the book for downloading
- Pdfs of all tables from the book for downloading

Chapter 1

THE ECOLOGICAL EFFECTS OF LINEAR INFRASTRUCTURE AND TRAFFIC: CHALLENGES AND OPPORTUNITIES OF RAPID GLOBAL GROWTH

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SUMMARY

Roads, railways and utility easements are integral components of human society, allowing for the safe and efficient transport of people and goods. There are few places on earth that are not currently traversed or impacted by the vast networks of linear infrastructure. The ecological impacts of linear infrastructure and vehicles are numerous, diverse and, in most cases, deleterious. Recognition and amelioration of these impacts is becoming widespread around the world, and new roads and other linear infrastructure are increasingly planned to avoid high-quality areas and designed to minimise or mitigate the deleterious effects. Importantly, the negative effects of the existing infrastructure are also being reduced during routine maintenance and upgrade projects, as well as targeted retrofits to fix specific problem areas.

Handbook of Road Ecology, First Edition. Edited by Rodney van der Ree, Daniel J. Smith and Clara Grilo.

Companion website: www.wiley.com\go\vanderree\roadecology

1.1 Global road length, number of vehicles and rate of per capita travel are high and predicted to increase significantly over the next few decades.
1.2 The 'road-effect zone' is a useful conceptual framework to quantify the negative ecological and environmental impacts of roads and traffic.
1.3 The effects of roads and traffic on wildlife are numerous, varied and typically deleterious.
1.4 The density and configuration of road networks are important considerations in road planning.
1.5 The costs to society of wildlife-vehicle collisions can be high.
1.6 The strategies of avoidance, minimisation, mitigation and offsetting are increasingly being adopted around the world – but it must be recognised that some impacts are unavoidable and unmitigable.
1.7 Road ecology is an applied science which underpins the quantification and mitigation of road impacts.

The global rates of road construction and private vehicle ownership as well as travel demand will continue to rise for the foreseeable future, including at a rapid rate in many developing countries. The challenge currently facing society is to build a more efficient transportation system that facilitates economic growth and development, reduces environmental impacts and protects biodiversity and ecosystem functions. The legacy of the decisions we make today and the roads and railways we construct tomorrow will be with us for many years to come.

INTRODUCTION

Since ancient times, trails and roads have connected settlements and facilitated the movement of goods and people around the world. The Appian Way (over 500 km long), built in the second and third centuries BC in Italy for military and trade purposes, was one of the first improved (hard-surfaced) highways. Portions of this road still remain today, a testament to the high-quality engineering and construction practices of the Roman Empire and the importance of roads to human society. Up until the early 1900s, the majority of the roads linking cities and towns were mostly unimproved, and paving with brick, concrete or asphalt only became common when mass production of vehicles began and the demand for better quality roads and more efficient routes increased. Depression-era public work programs designed to provide employment opportunities and stimulate economies also facilitated a significant increase in paved roads. Today, road construction is still an important driver of economic growth, both during construction and for its long-term effects. Roads are now conspicuous components of almost all landscapes globally, and set to expand even further into the future (Lesson 1.1).

Transportation infrastructure and roads, in particular, are pivotal to economic and social development by providing access to markets, places of employment, businesses, health and family care, leisure activities and education. Governments and international development banks see the construction of new roads and improvement of existing roads as priorities to improve livelihoods. However, the benefits of improved access vary regionally and by road type (e.g. Fan & Chan-Kang 2005), and not all rural road projects result equally in increased agricultural productivity and/or poverty reduction (Laurance et al. 2014; Chapter 2), and in some cases the costs outweigh the benefits. Once built, roads are nearly permanent elements in the landscape, and the wrong road (e.g. motorway/expressway vs. unpaved road) in the wrong place (e.g. roadless wilderness vs. agricultural landscape) can have long-term consequences for both society and the environment. Planning and impact assessment processes must properly account for all the costs, benefits and environmental impacts to ensure that the future road network is as sustainable as possible, particularly in regions where the rate of road construction is currently high or set to increase (see Chapter 5).

The broad aim of this chapter is to provide the necessary background and context for the many topics covered in this book. While primarily focused on roads and vehicles, the lessons in this chapter and book can be applied to all types of linear infrastructure.

LESSONS

1.1 Global road length, number of vehicles and rate of per capita travel are high and predicted to increase significantly over the next few decades

The total length of paved and unpaved roads on earth currently exceeds 64 million km; enough for 83 round-trips to the moon (CIA 2013). Roads dominate most landscapes worldwide – for example, 83% of the continental United States is now within 1 km of the nearest road of any type (Riitters & Wickham 2003). There is approximately 5 million km of road across the 27 countries of the European Union (EFR 2011). The emerging economies of China, India and Brazil are already among the top five countries in road length (4.1, 4.7 and 1.6 millions km, respectively) (CIA 2013) and they have ambitious plans to further increase the capacity of their transportation networks (Chapters 50, 52 and 57). Globally, an additional 25 million lane-kilometre of paved road are to be built by 2050, 90% of which will be in non-Organisation for Economic Co-operation and Development (OECD) countries (Dulac 2013). The 870 million vehicles around the world in 2009 are expected to more than double by 2050 to between 1.7 and 2.8 billion (WEC 2011; Meyer et al. 2012). The majority of these cars will still be in developed countries (with a 33% increase from 2000 to 2050), even though non-OECD countries will have a five-fold increase in vehicles by 2050 (Fulton & Eads 2004). In 2000, the total vehicular travel worldwide was estimated at 32 trillion passenger kilometre per year (up from 2.8 trillion in 1950), and by 2050 is predicted to be 105 trillion passenger kilometre per year, of which about 42% will be by car, the remainder by bus, rail and air (Schafer & Victor 2000).

The predictions of growth in road length, per capita travel and car ownership are based on models with a range of assumptions and will ultimately be influenced by fuel availability and pricing, climate change limits, a desire for increased mobility and other technological, economic, environmental and social priorities and constraints. While the magnitude of the predictions may be debated, all models predict a massive increase in the number of vehicles, road length and travel distances. The challenge for society is to acknowledge this potential rate of growth and decide (i) if it is necessary or desired; (ii) where it should occur; (iii) the preferred mode of transport (e.g. cars, high-speed trains or air travel); and (iv) the design and management of the transport network (e.g. road design and type of mitigation). Importantly, the impacts and solutions proposed in this book and the wider road ecology literature are based on the scale and extent of the current road network. The predictions of growth, even if only partially correct, require urgent and effective actions now.

1.2 The 'road-effect zone' is a useful conceptual framework to quantify the negative ecological and environmental impacts of roads and traffic

The 'road-effect zone' is defined as the area over which the ecological effects of roads and traffic extend into the adjacent landscape (Forman & Deblinger 2000), including noise, light and chemical pollution; disturbance effects; and habitat modification (Fig. 1.1). The size of the road-effect zone is determined by the characteristics of the (i) road (width, surface type, elevation relative to adjacent landscape); (ii) traffic (volume, speed); (iii) adjacent landscape (topography, hydrography, vegetation type, habitat quality); (iv) prevailing wind speed and direction; and (v) species traits and their sensitivity to the impact. Road effects have been observed many hundreds to thousands of metres from the road itself (Reijnen et al. 1995; Forman & Deblinger 2000; Boarman & Sazaki 2006; Eigenbrod et al. 2009; Benítez-López et al. 2010; Shanley & Pyare 2011). The impacts are usually greatest closer to the road and either diminish gradually with increasing distance from the road or exhibit thresholds with steep changes in responses (Eigenbrod et al. 2009). The road-effect zone is a useful approach to quantify and mitigate the negative effects of roads and traffic because it helps regional planners calculate the extent of the area impacted by existing roads (e.g. 15–22% of continental United States) (Forman 2000) or likely to be impacted by proposed roads (e.g. Williams et al. 2001).

1.3 The effects of roads and traffic on wildlife are numerous, varied and typically deleterious

Roads and traffic can significantly affect individual wildlife, populations and communities, and landscapes (Figs 1.1 and 1.2). These impacts can begin during construction and may continue as long as the road

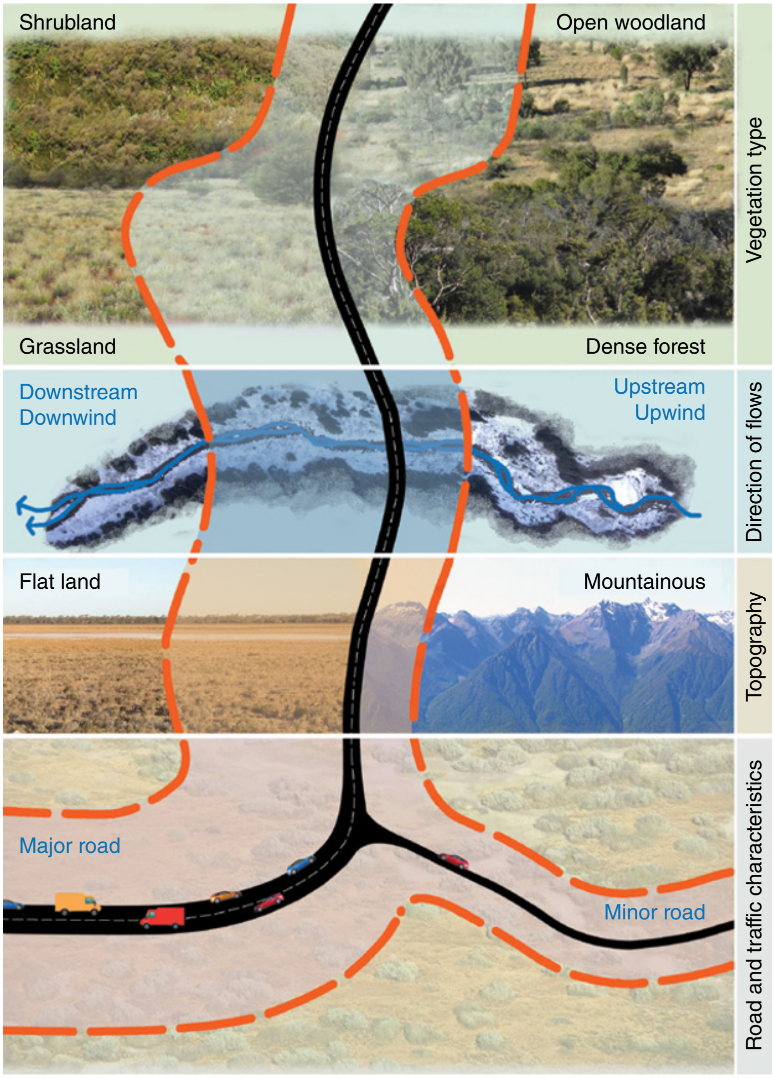

Figure 1.1 The road-effect zone, showing the area over which the ecological impacts of roads and traffic extend. The size of the road-effect zone is affected by a range of parameters – here we show four: (1) vegetation type; (2) direction of flows such as wind and water; (3) topography; and (4) road and traffic characteristics. The relative size of the road-effect zone for each parameter is illustrative only and not indicative; for example, the road-effect zone is not necessarily three times larger in flat than mountainous terrain. Source: Photograph by Zoe Metherell. Reproduced with permission of Zoe Metherell.

remains operational or until the impacts are mitigated. The majority of impacts are typically deleterious, and if severe enough, can reduce the size of populations of wildlife, with a concomitant increase in the risk of local extinction. These impacts are summarised here, and expanded on in subsequent chapters:

- **Habitat loss**: The construction and expansion of transportation corridors results in the clearing of vegetation and a loss of habitat at and adjacent to the road (Figs 1.2 and 2.1). Roads attract people and encourage further development, often resulting in further clearing of vegetation after road construction. Indirect loss of habitat also occurs through degradation, and this can exceed the amount of habitat directly cleared for the road.
- **Habitat degradation**: Due to a range of interacting biotic and abiotic effects, habitat quality often declines

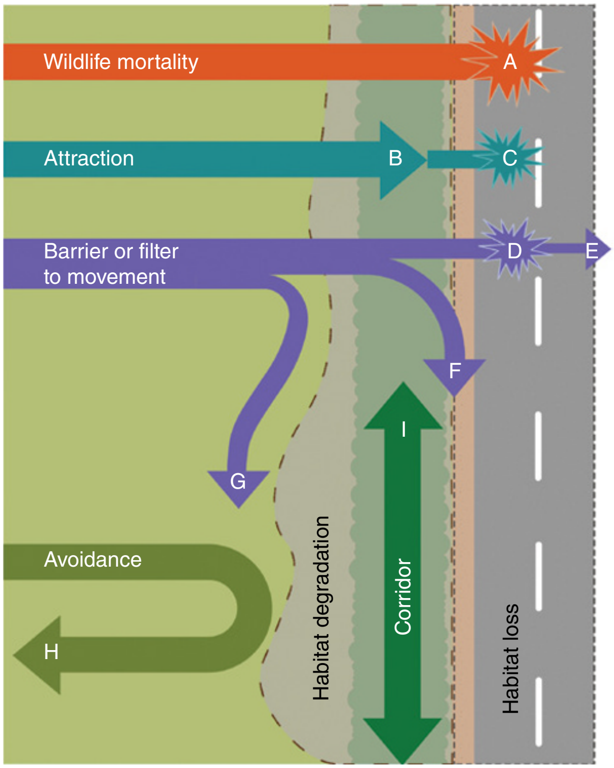

Figure 1.2 Impacts of roads on individual wildlife, populations and ecosystems. Habitat is lost to build the road and habitat adjacent to the road is degraded. The most obvious impact of roads and traffic on wildlife is mortality due to Wildlife-vehicle collisions WVC (A). Some species are attracted to resources (e.g. carrion, spilled grain or heat for basking) on the road or roadside (B) which, depending on the animals ability to avoid traffic, may result in death due to WVC (C). The barrier or filter effect reduces the movement of animals across the road and a proportion of individuals that attempt to cross are killed due to WVC (D) and some make it across (E), while others are deterred from crossing by the road (F) or degraded roadside habitat (G). Other species actively avoid the road or degraded habitat (H). By contrast, some species use the roadside vegetation as habitat and/or as a corridor for movement (I). Source: Illustration by Zoe Metherell. Reproduced with permission of Zoe Metherell.

adjacent to linear infrastructure. For example, the abrupt edges along linear clearings modify microclimatic conditions and encourage weed invasion, and specialist 'habitat interior' species of plants and animals are often outcompeted by 'edge-adapted' generalist species. Edge effects are particularly pronounced in tropical ecosystems (Chapter 49).

• **Barrier or filter to movement**: The creation of gaps in habitat can prevent or restrict the movement of wildlife that avoid clearings, and the noise, light, and chemical pollution and disturbance from vehicles will exacerbate these effects. Road width, whether it is paved or unpaved, and traffic volume affect the severity of the barrier effect (Riley et al. 2006) and species-specific thresholds exist. The type of movement affected varies, including (i) individuals' daily access to important resources; (ii) seasonal migrations of entire populations; and (iii) once-in-a-lifetime dispersal events, all of which can have significant consequences for individual survival, gene flow and population persistence.

• **Wildlife mortality** due to wildlife-vehicle collisions or WVC: Animals that attempt to cross roads or are attracted to the road surface have an increased risk of being involved in WVC and being killed or injured (e.g. Figs 26.2A, 32.2, 32.3, 33.1, 35.1, 38.2).

• **Avoidance**: Some species of wildlife avoid the road-effect zone due to traffic disturbance and/or habitat degradation, resulting in a reduction of habitat or a barrier to movement.

• **Attraction**: Roads and roadsides can attract some species by providing resources or enhanced opportunities. For example, reptiles may bask on the warm surface of the road, herbivores may forage on the enhanced plant growth on roadsides and scavengers can be attracted to feed on roadkill (e.g. Figs 26.2B, 26.3A, 26.4, 46.6).

• **Habitat and/or corridor for movement**: In some highly modified landscapes, roadside strips can provide the majority of habitat for wildlife (e.g. Fig. 46.3). Many adaptable species of wildlife, including invasive species (Seabrook & Dettmann 1996), use the cleared roadways and railways to efficiently move around the landscape (Fig. 26.3B).

The nature and severity of these effects vary among species because of their different morphological, ecological and behavioural traits. Importantly, most effects rarely operate in isolation (e.g. Farji-Brener & Ghermadi 2008), and many act synergistically. For example, animals that avoid roads have low rates of mortality due to WVC because they rarely attempt to cross, but barrier to movement effects may be high, potentially subdividing the population into smaller sub-populations. This arrangement is often called a metapopulation – a set of discrete populations of the same species occurring within the same area that exchange individuals through dispersal, migration or human-assisted movement (after Hanski & Simberloff 1997). The persistence of the metapopulation depends on the number and size of the sub-populations and the level of connectivity among them, and the risk of extinction increases as sub-populations become fewer, smaller and/or less connected. Species that are attracted to roads may suffer high rates of mortality due to WVC if they are unable to avoid oncoming vehicles, or conversely, low rates of mortality if they avoid oncoming vehicles (e.g. low-mobility species such as amphibians versus high-mobility species such as scavenging carnivores).

A recent review demonstrated that roads and traffic have had detectable population-level effects by reducing the size or density of populations near roads for many species (Fahrig & Rytwinski 2009; Chapter 28). These included frogs and toads (Fahrig et al. 1995; Hels & Buchwald 2001), salamanders (Gibbs & Shriver 2005), turtles (Steen & Gibbs 2004), birds (Erritzoe et al. 2003), European hares (Roedenbeck & Voser 2008), badgers (Clarke et al. 1998), bobcats and coyotes (Riley et al. 2006), Iberian lynx (Ferreras et al. 1992) and bighorn sheep (Epps et al. 2005). Roads and traffic can also alter population structure by affecting specific groups of animals, resulting in populations with skewed age or sex ratios (e.g. Aresco 2005; Nafus et al. 2013). These impacts are of particular concern when roads pass through protected areas or ranges of rare and threatened species or sever access to important breeding areas.

1.4 The density and configuration of road networks are important considerations in road planning

The density and configuration of the road network across the landscape are important drivers of the scale and intensity of road impacts on wildlife. Road density is a measure of the abundance of roads within a region, and is measured as the length of road per unit area. Thresholds in road density have been identified for populations of a number of species, including gray wolves in the Great Lakes region, USA which generally avoided landscapes when road density exceeded approximately 0.6 km per km^2 (Thiel 1985). The configuration of the network describes how roads and other linear infrastructure are arranged – such as bundled together or spread out across the landscape. Road networks are typically (i) rectangular/block/grid patterns that decrease in density from urban to rural areas; (ii) radial spokes and concentric rings that form around a city or other central feature; or (iii) linear configuration typically following natural features in the landscape. Road configuration has an enormous bearing on the scale of road impacts across the landscape, and bundling them together and having fewer roads with higher traffic volume is almost always preferred to having them spread out (Jaeger et al. 2006; Rhodes et al. 2014; Chapter 3).

1.5 The costs to society of wildlife-vehicle collisions can be high

The cost to society of WVC with large animals is high, primarily from human injury and loss of life, as well as costs associated with damage and repair of vehicles. There are approximately two million WVC with large mammals in the United States every year, injuring 29,000 people and killing 200 more (Conover et al. 1995), and there were an estimated 500,000 WVC with ungulates in Europe during 1995 (Groot Bruinderink & Hazebroek 1996). The likely rates of collisions are undoubtedly much higher because (i) collisions resulting in minor or negligible damage remain unreported, and (ii) the cause of single-vehicle collisions with roadside objects (e.g. trees) that result in human death may be due to swerving to avoid collisions with wildlife, which remain unreported. The death of wildlife due to WVC will also reduce the size of animal populations, which in some regions are an important source of food for people or income via tourism or hunting. Reduced populations of other species due to WVC may also impact people if such species are important pollinators or perform other critical ecosystem services (e.g. insectivorous bats and birds that help control populations of mosquitoes and other flying insect pests).

1.6 The strategies of avoidance, minimisation, mitigation and offsetting are increasingly being adopted around the world – but it must be recognised that some impacts are unavoidable and unmitigable

The impacts of roads and traffic have been recognised globally as significant threats to the persistence of species and functioning of healthy ecosystems. The principles of the hierarchy of avoiding, minimising, mitigating and offsetting these impacts have also been widely adopted and increasingly practised (Chapter 7). Many governments and communities around the world have accepted the challenge and additional cost of building an efficient transportation network that is safe for wildlife and people. In some regions, priority has shifted to retrofitting the existing network to reduce its impacts on biodiversity. The global proliferation of numerous professional networks (Chapter 61) and non-government organisations with the intent to improve best-practice road mitigation and the membership that includes planners, designers, regulators, ecologists and engineering/construction firms is a testament to this.

However, not all impacts can be fully mitigated, and not all mitigation measures are equally effective. For example, it is difficult and likely impossible in some locations to control the effects of human activities after roads are built, such as increased land clearing and development, the migration and movement of people, and increased hunting or poaching (Chapters 2 and 51). Similarly, the inclusion of mitigation measures in a proposed road project does not automatically mean that all effects have been mitigated and the project should proceed. For example, the likelihood of crossing structures effectively permitting the annual migration of hundreds of thousands of mammals in the Serengeti is extremely low (Chapter 56). Therefore, it is essential to include a 'no-road' option when ranking different route options during the planning of new roads or expansion of existing roads in remote and/or intact ecosystems (Selva et al. 2011; Chapter 3).

1.7 Road ecology is an applied science which underpins the quantification and mitigation of road impacts

The accurate quantification and effective mitigation of road impacts relies on scientifically rigorous research and monitoring (Chapter 10). The first published road ecology studies reported rates of WVC, the most visible ecological effect of roads and traffic (e.g. Stoner 1925; DeVos 1949; Fitch 1949). As road networks expanded and traffic volumes increased in the latter half of the 20th century, research began to focus on quantifying and reducing rates of WVC with large herbivores to save human lives and reduce societal costs. More recently, attention has expanded to include smaller species and encompass a range of biological and ecological parameters such as species distribution, abundance, reproductive rate, behaviour and dispersal (e.g. Legagneux & Ducatez 2013). There have also been recent calls to understand effects at larger spatial and temporal scales and to focus on populations, communities of species and ecosystems (van der Ree et al. 2011). However, quantifying the full breadth of impacts and the effectiveness of mitigation measures as well as reporting practical issues associated with road planning and management are still scarce in research findings (Roedenbeck et al. 2007). Consequently, a large proportion of published road ecology studies appear to have little influence on road planning and design. In moving forward, road agencies should recognise and support good-quality research, scientists and practitioners should collaborate more effectively and researchers should ask applied questions that provide relevant information which road agencies need (Chapter 10).

CONCLUSIONS

The global network of roads, railways, artificial waterways, trails and utility easements is extensive in its length and spread. The total number of vehicles in use is escalating and already difficult to comprehend, and the total distances travelled annually even more so. However, these statistics are to be dwarfed over the next 20–40 years, even if the predictions in growth of road length, number of vehicles and travel distances are only partially met. The impacts of linear infrastructure and vehicles on many species and ecosystems are sufficiently well known to allow the development of effective strategies to avoid, minimise, mitigate and offset most negative effects. The challenge facing society is to identify and retrofit the worst parts of the existing network and build and manage a network for tomorrow that is as good for biodiversity as it is for people.

FURTHER READING

Beckman et al. (2010): An edited volume focussing on North America that aims to collate and integrate information and approaches from various disciplines, as well as a series of case studies that demonstrate effective innovations in planning and mitigation.

Benítez-López et al. (2010): A meta-analysis of almost 50 studies, demonstrating that populations of many species of wildlife declined in close proximity to infrastructure, including up to about 1 km for birds and 5 km for mammals.

Forman et al. (2003): A seminal and comprehensive review and introduction to the field of road ecology, encompassing ecological concepts, planning, wildlife and vegetation, and pollution.

van der Ree et al. (2011): The introduction to a special issue of the open access journal, *Ecology and Society*, which contains 17 articles focussed on the 'Effects of roads and traffic on wildlife populations and landscape function' (http://www.ecologyandsociety.org/issues/view.php/feature/41).

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Chapter 2

BAD ROADS, GOOD ROADS

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SUMMARY

Roads greatly influence the footprint of human activity, but they are often constructed with little consideration of their environmental impacts, especially in developing nations. Here, differences between environmentally 'good' and 'bad' roads are highlighted, and it is argued that a proactive road-zoning system is direly needed at international and national scales. Such a zoning system could identify areas where the environmental costs of roads are likely to be high and their socioeconomic benefits low, as well as areas where road improvements could have modest environmental costs and large societal benefits.

2.1 Land-use pressures will rise sharply this century and will be strongly influenced by roads.
2.2 Agricultural yield increases alone will not spare nature – land-use zoning is crucial too.
2.3 Roads in pristine areas are environmentally dangerous – the first cut is critical.
2.4 Paved highways have especially large-scale impacts.
2.5 Roads can be environmentally beneficial in certain contexts.
2.6 Roads are amenable to policy modification.
2.7 A recently proposed global road-mapping scheme could serve as a potential model for these efforts.

This road-planning scheme could be an important tool for prioritising road investments and for underscoring the transformative role of roads in determining environmental change. An overriding priority is to proactively zone roads at a range of spatial scales while highlighting their critical role in provoking environmental change. Keeping roads out of surviving irreplaceable natural areas is among the most tractable and cost-effective ways to protect crucial ecosystems and the vital services they provide, whereas roads in the right places can facilitate increases in agricultural productivity and efficiency.

Handbook of Road Ecology, First Edition. Edited by Rodney van der Ree, Daniel J. Smith and Clara Grilo.

Companion website: www.wiley.com\go\vanderree\roadecology

INTRODUCTION

Many would be surprised to learn that the Amazon, the world's greatest rainforest, now has over 260,000 km of legal and illegal roads (Barber et al. 2014) – enough to encircle the Earth more than six times. This is not an isolated example. Even in formerly remote corners of the world – from the Congo to Borneo and Siberia to Namibia – roads and transportation networks are expanding apace.

The global road rush is being driven by escalating demands for minerals, fossil fuels, timber and arable land, and by the needs of developing nations to improve their transportation and energy infrastructures (Laurance et al. 2009). Road expansion is favoured by many economists and international donors and lenders (e.g. Jacoby 2000), who see it as a cost-effective way to promote regional integration and spur economic growth.

Scientists, however, often see roads in a negative light because they can open a Pandora's box of environmental problems. In the Amazon, for instance, new roads in forested areas often promote illegal colonisation, mining, hunting and land speculation (Laurance et al. 2001, 2002; Fearnside & Graça 2006). As a result, nearly 95% of the deforestation (Fig. 2.1), fires and atmospheric carbon emissions in Amazonia occur within 5 km of roads (Barber et al. 2014). In Equatorial Africa, road expansion and associated hunting are driving major declines of forest elephants (Laurance et al. 2006; Blake et al. 2007) and other vulnerable wildlife (Fig. 2.2).

Here, I argue that roads can either benefit or harm nature, depending on their location and design. Understanding how roads affect land-use dynamics will be vital for balancing future development needs and the environment.

LESSONS

2.1 Land-use pressures will rise sharply this century and will be strongly influenced by roads

The 21st century will witness profound changes in land use, many of which are necessary and unavoidable. Meeting the needs of a projected 11 billion people for food, fibre and biofuels will require a major increase in the footprint of agriculture. According to projections of strong, consistent relationships between economic growth and food consumption, food production alone will need to increase 100–110% by the middle of this century (Tilman et al. 2011). Based on current trends in farming practices this would require about 1 billion ha of additional farming and grazing land (Tilman et al. 2011), an area larger than Canada.

The tsunami-like changes in land use this century will be strongly influenced by patterns of road development. This follows from massive road building in the past; by the year 2000, roads totalled over 28 million km in length globally (CIA 2008). Roads are sometimes

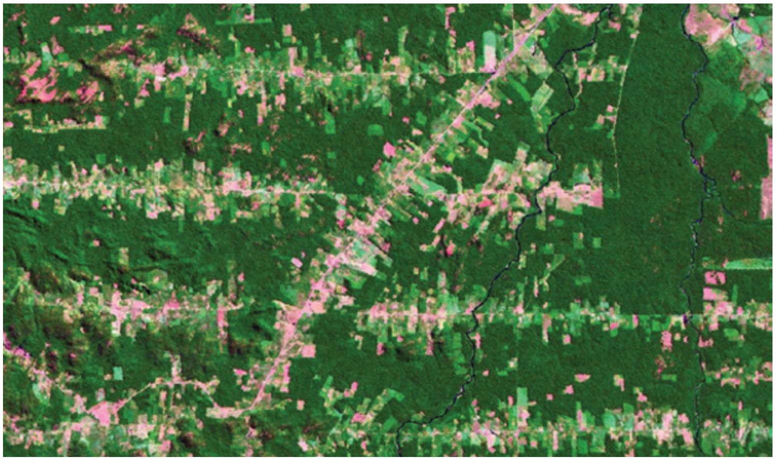

Figure 2.1 Forest clearing along roads in Rondônia, Brazil, 1989. Source: Google Earth (Imagery date 7 August 1989, 10°02′43.59″S, 63°10′03.82W).

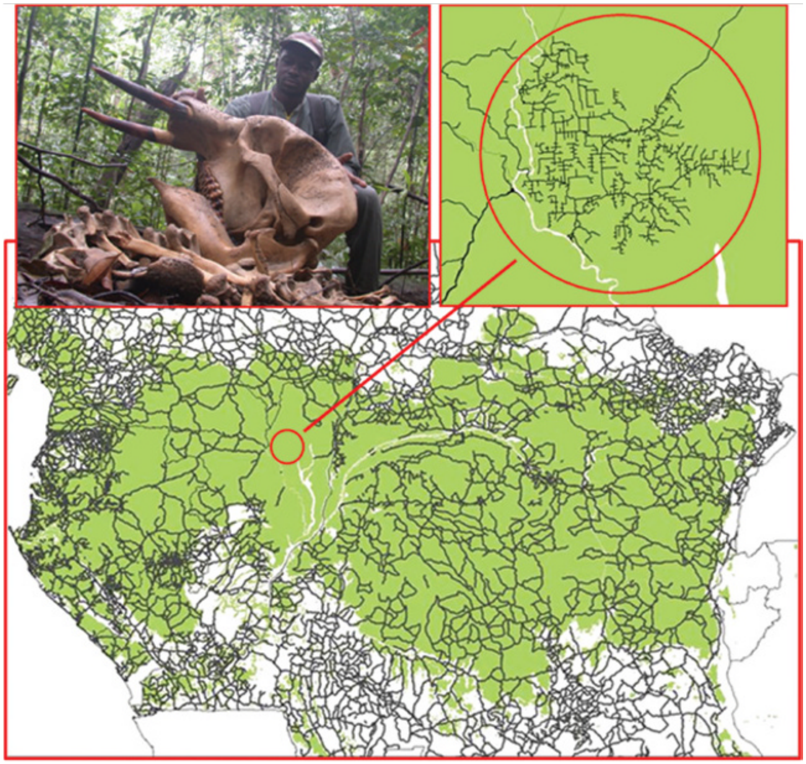

Figure 2.2 A rapid proliferation of roads is allowing hunters to penetrate into the heart of the Congo Basin, imperilling wildlife such as the forest elephant. Insets: gunshot elephant in Gabon, and smaller logging roads not shown in the larger image. Source: Photograph by Ralph Buij. Reproduced with permission of Ralph Buij; Small and large road images by Stephen Blake. Reproduced with permission of Stephen Blake and the World Resources Institute.

built specifically to promote agricultural expansion but, often, agriculture follows roads created for other purposes, such as mining or logging (Laurance et al. 2009). This can result in farms and ranches expanding into places with marginal soils or climates, or that are too far from markets to be cost-effective (Chapter 51; Fearnside 1986).

2.2 Agricultural yield increases alone will not spare nature – land-use zoning is crucial too

Given the escalating demands for food and biofuel, many environmental scientists and agronomists have highlighted a need to improve agriculture – using modern crop varieties, fertilisers, pest control and improved transportation to raise yields while limiting the footprint of agriculture and thereby 'sparing' lands for nature conservation (Green et al. 2005; Edwards et al. 2010; Phalan et al. 2011). Unfortunately, improving yields alone is unlikely to conserve nature. If it increases farming profitability, yield increases can actually do the opposite – encourage conversion of vast areas of land for production (Angelsen & Kaimowitz 2001). This is occurring today with the rapid expansion of lucrative oil palm plantations across the tropics, often at the expense of biodiversity-rich rainforests (Koh & Wilcove 2008; Butler & Laurance 2009).

Increasing agricultural yields will only benefit nature if it is coupled with effective land-use planning (Balmford et al. 2012). A key element of such planning is roads, which profoundly influence the footprint of human activities.

2.3 Roads in pristine areas are environmentally dangerous – the first cut is critical

While many factors influence road planning, a few key principles can help guide their siting and design. The environmentally most dangerous roads are those that penetrate into relatively pristine regions, such as a large forest tract (Laurance et al. 2001, 2002, 2009; Chapter 3). Deforestation is highly contagious spatially, such that the probability that a land parcel will be cleared rises dramatically if it is adjacent to an area that has already been cleared (Boakes et al. 2010). For this reason the first cut into a forest is the critical one; if it occurs, then other cuts are likely to follow.

2.4 Paved highways have especially large-scale impacts

Paved highways typically have much larger-scale environmental impacts than do unpaved roads (Laurance et al. 2002; Kirby et al. 2006; Barber et al. 2014). In wetter environments, paved roads provide year-round access to natural resources such as timber, minerals or agricultural land, whereas unpaved roads can become seasonally impassable (Fig. 51.4). Paved roads are also typically wider and have more traffic that is faster-moving than is the case for unpaved roads, and thereby are a greater danger and movement-barrier to wildlife (Laurance et al. 2009).

Disentangling the specific contributions of paved and unpaved roads to environmental damage is challenging because paved roads tend to spawn networks of secondary, unpaved roads (Laurance et al. 2009). Nevertheless, paved roads are much stronger predictors of deforestation than are unpaved roads, and their effects extend for considerably larger distances away from roads (Laurance et al. 2002; Kirby et al. 2006). For instance, the paved Belém-Brasília Highway, completed in the early 1970s, has today evolved into a 400-km-wide slash of forest destruction and secondary roads across the eastern Brazilian Amazon (Laurance et al. 2009). In the wrong place, a paved road can provoke an environmental disaster.

2.5 Roads can be environmentally beneficial in certain contexts

Although many roads promote environmental damage, paving and other road improvements can be socially and environmentally beneficial in certain contexts. In areas well-suited for agricultural development, road improvements can act as 'magnets', attracting migrants away from vulnerable frontier areas (Andersen et al. 2002; Weinhold & Reis 2008; Rudel et al. 2009). Concentrating people in carefully defined areas is beneficial because the relationship between deforestation and human population density is nonlinear, such that later migrants into an area clear much less forest on average than do those who arrive initially (Laurance et al. 2002). Better transportation infrastructure also increases access to markets, cutting waste and improving farmers' profits.

As a result, building high-quality roads in places where farming is already widespread, where there is little intact habitat, and where sizeable gaps between current and potential farm yields exist can help increase agricultural production (Weinhold & Reis 2008). This can enhance rural livelihoods and limit the negative environmental impacts of farming, by raising production efficiency and helping to keep farming more contained and localised. The global road-mapping scheme described in Lesson 2.7 and in Laurance et al. (2014) highlights a strategy for advancing these aims.

2.6 Roads are amenable to policy modification

It is notable that roads are much more amenable to policy modification than are socially complex problems such as human population growth and overconsumption. Roads can be re-routed, projects cancelled or construction delayed. Many large road projects are funded by taxpayers, investors or international donors that are responsive to environmental concerns. If publicly named and shamed, corporations that build environmentally bad roads can lose customers and shareholders. For instance, a Malaysian logging corporation, Concord Pacific, was publicly vilified for bulldozing a 180-km-long road into the highlands of Papua New Guinea – ostensibly to aid local communities. After the company took more than US$60 million in illegal timber, it was fined $97 million by the national court of Papua New Guinea (Greenpeace 2002).

2.7 A recently proposed global road-mapping scheme could serve as a potential model for these efforts

Given the environmentally transformative roles of roads, it has recently been argued that a global zoning exercise is needed to identify areas that should ideally remain road-free as well as those where transportation

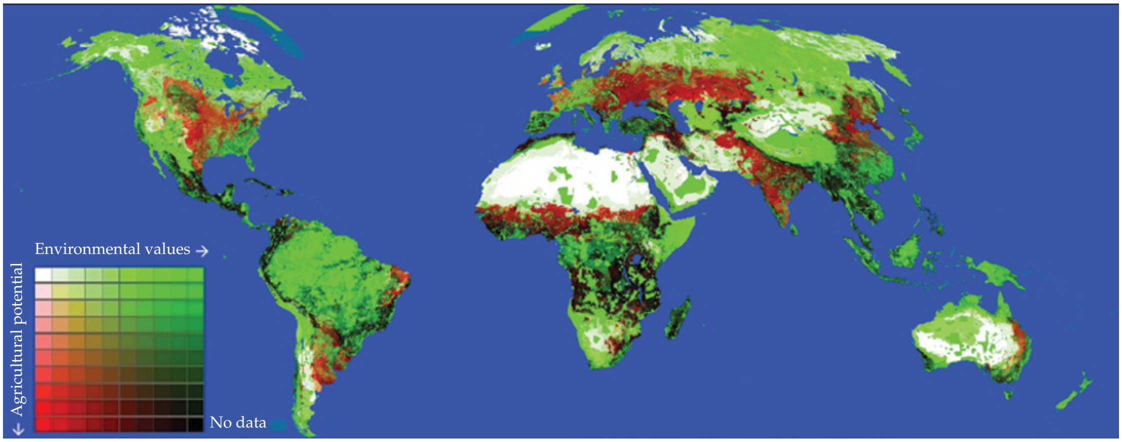

Figure 2.3 A global roadmap that attempts to estimate the relative risks and rewards of road building. Green-shaded areas are where road building would have high environmental costs, whereas red-shaded areas are where new or improved roads could help to promote increased agricultural production. Dark-shaded areas are 'conflict zones' where environmental costs and potential road-building benefits are both high. Light-shaded areas are lower priorities for environmental values and road building. Source: From Laurance et al. (2014).

improvements are a priority (Laurance & Balmford 2013; Laurance et al. 2014). This strategy integrated spatial data on remaining intact habitats and wilderness areas, existing transport infrastructure, agricultural yields and losses, biodiversity indicators, carbon storage and other relevant attributes (Fig. 2.3).

The key goal of this road-zoning effort is to promote roads and road improvements in areas that contain existing rural development and increase agricultural yields while at the same time limiting roads where the prospects for environmental damage are great. Some examples of the latter include the proposed Serengeti Highway that could disrupt one of the world's great remaining wildlife migrations (Chapter 56; Pimm 2010); Brazil's Manaus-Porto Velho Highway, which when completed will link major population centres to the heart of the Amazon (Chapter 51; Fearnside & Graça 2006); and the proposed Ladia Galaska road network, which threatens the largest surviving block of forest in northern Sumatra, Indonesia (Gaveau et al. 2009).

Beyond reducing overall habitat destruction, road zoning would also focus on safeguarding rare environments and areas with many endemic species, such as remaining intact habitats within biodiversity hotspots (Myers et al. 2000). In regions where transportation projects are unavoidable but environmental costs are high, alternatives such as railroads or river transport might be effective compromises (Laurance et al. 2009). Such projects can move people and products while stopping only at specific places, limiting their human footprint.

CONCLUSIONS

An overriding priority is to zone roads proactively on varying spatial scales while highlighting their critical role in provoking environmental change. Keeping roads out of surviving irreplaceable natural areas is among the most tractable and cost-effective ways to protect crucial ecosystems and the vital services they provide, whereas roads in the right places can facilitate increases in agricultural productivity and efficiency. In a world struggling to conserve nature and support human well being as land-use pressures intensify, managing transportation networks is where the rubber meets the road.

FURTHER READING

Laurance (2009): A hard-hitting essay on the high environmental costs of many roads.

Laurance and Balmford (2013): Highlights a global road-mapping scheme designed to maximize the social and economic benefits of roads while minimizing their environmental costs.

Laurance et al. (2009): A balanced overview of the diverse impacts of roads on tropical forests and their biodiversity.

Laurance et al. (2014): Presents a global scheme for prioritising road building based on their relative environmental costs and their potential societal benefits, particularly for promoting increased food production.

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Chapter 3

WHY KEEP AREAS ROAD-FREE? THE IMPORTANCE OF ROADLESS AREAS

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SUMMARY

Roadless and low-traffic areas are typically large, natural or semi-natural areas that have no roads or few roads with low-traffic volume. They are relatively unaffected by roads and subsequent developments, and therefore, represent relatively undisturbed ecosystems, which provide important benefits for biodiversity and human societies. Roadless areas are rapidly becoming rare across the globe due to construction of road networks that serve widely expanding human activity. With a few exceptions, roadless and low-traffic areas are not considered in national or international legislation; and consequently, they have been widely neglected in transport planning.

3.1 Roadless areas contribute significantly to the preservation of biodiversity and ecosystem services.
3.2 Planning of new transport routes should identify existing roadless areas and avoid them.
3.3 Subsequent ('contagious') development effects of road construction should be avoided in roadless and low-traffic areas.
3.4 Unnecessary and ecologically damaging roads should be reclaimed to enlarge roadless areas and restore landscape-level processes.
3.5 It is crucial to systematically evaluate the need for and location of proposed roads and implement the principle of 'no net loss' of unfragmented lands when there is no alternative.

An important question during planning is whether the proposed road is really needed, and if so, where should it be placed. When the dissection of a roadless area is absolutely unavoidable, measures to prevent contagious development should be implemented, as well as compensation measures to restore the same amount of unfragmented habitat.

Handbook of Road Ecology, First Edition. Edited by Rodney van der Ree, Daniel J. Smith and Clara Grilo.

Companion website: www.wiley.com\go\vanderree\roadecology

INTRODUCTION

With more than 64 million km of roads worldwide (CIA 2013), road networks play a primary role in shaping the environment. Approximately 90% of the world's land surface can be reached within 48 hours of travel by road or rail from the nearest city (Williams 2009). The ecological effects of roads extend far beyond the edge of the road itself; and despite the efforts to minimise road impacts in the past decades, a large portion of the planet is affected by roads (e.g. about one-fifth of the continental United States, Forman 2000). Among the numerous impacts of roads, probably the most important is what we have termed 'contagious' development: roads provide access to previously remote areas, thus opening them up for more roads and developments, and triggering land-use changes, resource extraction and human disturbance (Fig. 2.1, Chapter 51). In this context, the importance of keeping the remaining large unfragmented lands road-free becomes an urgent task.

Roadless and low-traffic areas either have no roads or few roads with low-traffic volumes (see Lesson 3.2 for definitions). They have become a rare element of the landscape; only 3% of the conterminous United States is more than 5 km away from a road (Riitters & Wickham 2003). Consideration of unfragmented lands is typically neglected in road planning and biodiversity conservation. The aims of this chapter are to highlight the value of roadless and low-traffic areas, the need to consider them in sustainable transport planning and the importance of road removal to restore them.

LESSONS

3.1 Roadless areas contribute significantly to the preservation of biodiversity and ecosystem services

Lands without roads have not been altered by road effects such as traffic, noise pollution or wildlife mortality due to collision with vehicles. Roadless areas contain natural and semi-natural habitats with a low level of human disturbance, where wide arrays of ecological processes are preserved. Habitats that are more intact provide greater benefits for biodiversity and human societies than degraded habitats (see reviews in DellaSala and Strittholt (2003) and Selva et al. (2011)).

Roadless areas are biodiversity reservoirs. They are important for wildlife and have the potential to conserve sensitive and endangered species (Loucks et al. 2003). They are crucial for species that move across large tracts of habitat, such as brown bears, wolves or elephants (e.g. Blake et al. 2008). Even large unfragmented areas which have been moderately modified (e.g. for agriculture) can still provide landscape connectivity. Roadless areas are known strongholds for salmonids and other fish species (Quigley & Arbelbide 1997), and a significant refuge for native wildlife and plants (Gelbard & Harrison 2003). They also serve as a barrier against invasive and exotic species, and diseases of wildlife, livestock and humans. For instance, the risk of humans contracting Lyme disease is reduced in larger patches of unfragmented forest, where the diversity of vertebrate hosts is higher (Allan et al. 2003).

Roadless and low-traffic areas perform numerous ecosystem services that are vital for humans. These include the maintenance of healthy soil, clean air and clean and reliable supply of water (DellaSala & Strittholt 2003). While some managers suggest that roads are needed to manage fire and pests, roadless areas are generally characterized by lower fire risk and lower frequency of insect outbreaks than roaded areas (DellaSala & Frost 2001). The social and economic benefits of roadless areas, such as non-motorised outdoor recreation, education and scientific values, are large and well documented (e.g. Loomis & Richardson 2000). As human population increases, the demand for undisturbed land and for wilderness experiences will likewise increase.

Roadless and low-traffic areas are important in the context of climate change (Selva et al. 2011). Undisturbed and mature ecosystems provide buffering capacity, moderate weather extremes (e.g. by retaining water) and help to stabilize local climates (e.g. Norris et al. 2012), thereby protecting against the impacts of storm events, like flooding or landslides. Roadless and low-traffic areas of mature forest and peatland are significant in the sequestration of carbon. Roadless areas accommodate adaptations and range shift responses by plants and animals to climate change by providing important landscape connections and moderating the rate of change of local environmental conditions.

With the current rate of road encroachment, biodiversity crisis and global change processes such as climate change, roadless and low-traffic areas may far exceed roaded areas for their benefits provided to human societies (Selva et al. 2011). Therefore, it seems sensible that sustainable transport policies retain and re-establish unroaded lands in order to conserve biodiversity and maintain the health of ecosystems on which we depend (Textbox 3.1).

3.2 Planning of new transport routes should identify existing roadless areas and avoid them

While roadless and low-traffic areas can be broadly defined as natural and semi-natural areas without roads or with few roads of low-traffic intensity, respectively, there are different legal descriptions and criteria used around the globe to identify them. Although road-free areas and areas with low road density or low traffic volumes are not automatically considered in conservation and transport planning, there are two basic approaches to incorporate roads in spatial planning. The first approach identifies road-free areas of a minimum size (e.g. Wilderness and Inventoried Roadless Areas in the United States) or areas with traffic volume below a specified threshold (e.g. Unfragmented Areas by Traffic in Germany, see Textbox 3.1), and the second approach identifies areas with high conservation status. Under this approach (e.g. Last of the Wild global program or areas of good conservation status in the Chiquitano dry forest, Bolivia), roads and their impacts are combined with other indicators, such as human population density, deforestation or cattle grazing, in order to prioritize areas for biodiversity conservation (Table 3.1).

Roadlessness typically correlates with relatively good conservation status. Therefore, indices that assess the environmental impact of roads by identifying roadless and low-traffic areas should be applied during spatial planning (e.g. SPROADI, Freudenberger et al. 2013). The definition of thresholds to identify such areas, such as the minimum size of roadless areas or the maximum tolerable traffic volume, depends on the landscape context. For example, the dissection of relatively small roadless areas (e.g. Fig. 3.2) is a conservation issue in highly populated regions like central Europe, while large road-free areas are a priority in relatively pristine and unfragmented regions, like the Amazon or Siberia.

Textbox 3.1 Recognition and protection of roadless and low-traffic areas in the world.

Wilderness and roadless area protection in the United States

In the United States, many roadless areas were first protected when the Wilderness Act (1964) was passed. Wilderness was defined as 'an area where the earth and its community of life are untrammeled by man, where man himself is a visitor and does not remain'. Wilderness areas in the United States do not allow permanent improvements or human habitation and were originally required to be larger than 2024 ha (Table 3.1). The National Wilderness Preservation System in the United States has grown to more than 40 million ha today. In 2001, the US Forest Service protected an additional 24 million ha of road-free areas larger than 405 ha under the 'Roadless Conservation Rule'. These inventoried areas are protected from building new roads, although they still allow for motorized use, such as all-terrain vehicles, helicopter logging and other uses that are prohibited in wilderness. Walking trails are common in both Wilderness and Inventoried Roadless Areas.

Low-traffic and unfragmented areas in Europe

Large roadless areas are rare in Europe, and, instead, definitions referring to low-traffic areas have been developed. The concept of unfragmented areas by traffic (UAT) was developed by the German Federal Agency for Nature Conservation as a landscape assessment tool (Table 3.1). The UATs are greater than 10,000 ha and not dissected by roads with more than 1000 vehicles/day, by railway lines (twin-track and single-track electrified lines) or by human settlements, airports or channels. The 2008 inventory identified about 9 million ha of UATs in Germany, of which a quarter are protected under European Directives. The eastern part of Germany contains more UATs than western Germany (Fig. 3.1), which may be illustrative of the different degree of fragmentation between eastern and western Europe.

Global roadless areas

A prototype map of roadless areas in the world was developed in 2012 by Google Earth, the Society for Conservation Biology – Europe Section and Members of the European Parliament (http://earthengine.google.org/). Here, roadless areas were defined by using buffers of different distances (from 1 to 10 km) from the nearest road (including dirt roads), rail or navigable waterway (Table 3.1). This map was presented in 2012 at the Rio + 20 Conference in Brazil and at the eleventh meeting of the Conference of the Parties to the Convention on Biological Diversity in India to demonstrate that roadlessness is the most cost-efficient and effective way to protect biodiversity.

Table 3.1 Examples of initiatives across the world which have identified roadless or low-traffic areas for biodiversity conservation.

Initiative	Framework	Region	Criteria	Indicators	Legal enforcement
Wilderness areas	Wilderness Act, 1964	USA	Size	≥2024 ha	Yes
			Relative naturalness	—	
			Roads	Presence/absence	
Last frontier forests	World Resources Institute, 1997	Global	'Wilderness areas'[a]	Sierra Club's global 'wilderness areas' map	No
			Forest cover[b]	Dominance	
			Size[b]	Ability to support viable populations of large, wide-ranging animals for a century	
			Naturalness of structure and composition: various indicators[b]	Dominance	
Inventoried Roadless Areas	Roadless Conservation Rule, 2001	USA	Size	≥405 ha	Yes
Areas of good conservation status	Chiquitano dry forest conservation and sustainable development plan, 2002	Bolivia	Population/km^2	Five classes ranging from 0–4.4 to ≥95.3	No
			Roads, railways, pipelines	Eight classes ranging from 'principal road' to 'pipeline crossing wet savannah'	
			Navigable rivers and lakes	Presence/absence	
			Deforestation	Two classes: values > and ≤30%	
			Cattle grazing	Four classes ranging from 'semi-intensive cattle-grazing in open and semi-open areas' to 'no cattle grazing'	
			Forest concessions, forests accessible by roads	Presence/absence	
Last of the wild	Wildlife Conservation Society and Center for International Earth Science Information Network, 2002–2005	Global	Size	>500 ha	No
			Population/km^2	10 classes ranging from 0–0.5 to >9.5	
			Railroads	Beyond 2 km buffer	
			Major roads	Beyond 2 and 15 km buffer, respectively	
			Navigable rivers	Beyond 15 km buffer	
			Coastlines	Beyond 15 km buffer	
			Night-time stable lights values[a]	Four classes ranging from 0 to ≥89	
			Urban polygons	Presence/absence	
			Land cover categories	Four classes ranging from 'urban' to 'forests, tundra and deserts'	
Unfragmented areas by traffic (UAT)	German Federal Agency for Nature Conservation, 2008	Germany	Size	10,000 ha	No
			Heavily used roads, railway lines, channels, urban centres	Presence/absence	
			Traffic intensity	<1000 vehicles/day	
Roadless areas	Google Earth and Society for Conservation Biology, 2012	Global	Roads, rails or navigable waterways	Beyond 1 and 10 km buffers, respectively	No

[a]McCloskey and Spalding (1989).
[b]Assessed by qualified expert opinion.

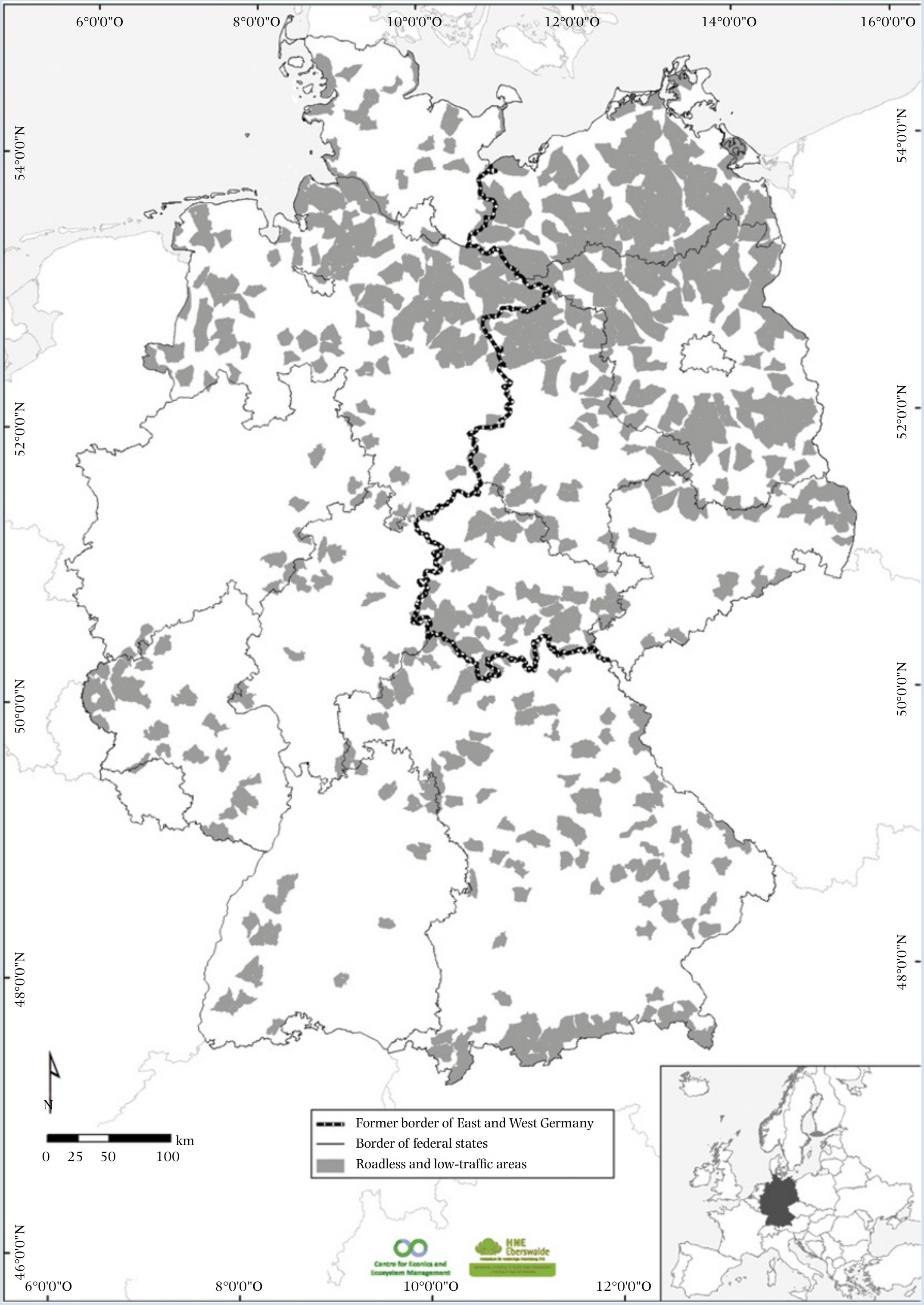

Figure 3.1 Low-traffic areas in Germany (Unfragmented Areas by Traffic, UAT). UATs cover 45% of the new federal states (eastern Germany) versus 18% of the old federal states (western Germany). Source: Adapted from Selva et al. (2011).

Figure 3.2 The Rospuda valley in northeastern Poland (6.3 km^2) is the last pristine percolating fen (or active peatland) of the European temperate zone. Its untouched hydrological system guarantees the stability of the ecosystem (no succession) and the presence of endangered and relict species. In 2007, a road project dissecting this peatland was stopped due to legal infringements of the EU nature directives, after more than 10 years of campaign. The road was finally re-routed through agricultural fields, something that could have been done with proper transport planning years before, thus avoiding high social conflicts and economic costs. Source: Photograph by Piotr Małczewski. Reproduced with permission of Piotr Małczewski.

The roads that cause the greatest environmental damage are those dissecting pristine and unfragmented ecosystems. Even in human-dominated landscapes, the construction of new roads may add additional disturbances to those related to land uses. In this sense, an agricultural landscape without roads still might provide better habitat quality (e.g. connectivity for wildlife) than the same farmland with numerous roads. Given the intensification of land-use pressures across the globe, influencing the patterns of road development to keep roads out of natural areas is the most tractable way to conserve nature (Laurance & Balmford 2013; Laurance et al. 2014; Chapter 2).

3.3 Subsequent ('contagious') development effects of road construction should be avoided in roadless and low-traffic areas

Roads are one of the main drivers of ecosystem change. By facilitating access to previously remote areas, new roads trigger a cascade of land-use changes and habitat degradation (Chapter 51). Roads are almost inevitably followed by urban and agricultural development, and they promote mining, hunting, fishing and logging (Wilkie et al. 2000; Southworth et al. 2011). In Central Africa, logging roads, which represent 38% of all road length, boost unsustainable hunting and the massive loss of wildlife; for example, wildlife densities decreased by 25% 3 weeks after logging roads were opened in Congo (Laporte et al. 2007; Wilkie et al. 2011). The role of roads in deforestation is undisputable and the most rapid rate of forest clearing occurs within 10 km of the road, especially if paved. As demonstrated in the Amazon, greater than 95% of deforestation, fires and atmospheric carbon emissions occur within 50 km of roads (Laurance et al. 2001; Southworth et al. 2011).

Roads also accelerate human migration to the area and subsequent illegal colonization and land speculation (Chapter 51). Road paving, demand for agriculture and cattle ranching areas and ambiguous land tenure systems promote new settlements in undisturbed areas (Southworth et al. 2011). New roads, as well as road improvements in low-traffic areas, have important economic and social impacts, mainly derived from facilitated market access. These collateral or contagious development effects of roads are often more destructive than the direct impacts of the road itself. Sensible transport and land-use planning should carefully regulate contagious development and be supported by appropriate law enforcement (Textbox 3.2).

Textbox 3.2 Roads in developing countries. The case of conservation planning and 'contagious' development in Bolivia.

Road development is often used as an indicator of socioeconomic development. Roads improve mobility of people, but also catalyse the extraction of natural resources and subsequent degradation of ecosystems, and cause profound changes in local socioeconomic systems (Chapter 2).

Bolivia is a socioeconomically poor and biologically rich country that still has a significant portion of its territory covered by natural ecosystems; the latter partly due to a poorly developed road infrastructure (Fig. 3.3, Ibisch & Mérida 2004). However, as in most developing countries, the pressure on ecosystems is increasing rapidly, making the contagious development effect of roads particularly troubling. Whenever new roads provide access to formerly remote areas, people will migrate from other parts of the country and establish (often illegally) new settlements (Chapter 2).

Recent landscape-scale planning in Bolivia used roads as indicators of biodiversity degradation (e.g. Araujo et al. 2010). Roadlessness was taken as a proxy for functional and intact ecosystems and used as a criterion for identifying important areas for conservation. However, the implementation of conservation measures (e.g. land-use planning, including the creation of protected areas) has not been enough to safeguard the high-priority regions. In 2002, an internationally financed road was constructed through the Chiquitano dry forest ecoregion in southeastern Bolivia. A decade later, the indirect impacts of the road (namely forest clearing and expansion of agriculture) have exceeded those outlined in even the most pessimistic environmental impact assessment (S. Reichle, personal communication). The fear that the impacts of new roads cannot be effectively mitigated by accompanying conservation measures has been confirmed. The development and improvement of the road network across Bolivia has continuously accelerated deforestation and other forms of biodiversity degradation. This highlights the importance of keeping unfragmented and natural habitats free of roads as the most effective way to conserve them.

Figure 3.3 Especially in forests, even small and unpaved roads give access for land use such as agriculture or settlement, which may ultimately replace the original ecosystem. Porongo, Santa Cruz, Bolivia. Source: Photograph by Pierre L. Ibisch.

3.4 Unnecessary and ecologically damaging roads should be reclaimed to enlarge roadless areas and restore landscape-level processes

Land managers are restoring roaded areas by closing and reclaiming unneeded or ecologically damaging roads (Fig. 3.4). Many of these roads are historical legacies, but new roads built to support resource extraction should be restored once the activity ceases. There are various treatments possible, ranging from simply blocking the road entrance to full removal and recontouring of the roadbed which allows hydrological and ecological processes and properties to return (Switalski et al. 2004). Increased infiltration and revegetation reduces fine sediment erosion from roads into streams, improving habitat quality for fish and other aquatic species (McCaffery et al. 2007).

Reclaimed roads improve wildlife habitat quality primarily through limitation of motorised access and the restoration of vegetation providing food and shelter for wildlife. Black bears were found to use recontoured roads at much higher rates than roads open to traffic, but also at greater rates than roads closed to traffic with a gate or other barrier (Switalski & Nelson 2011). Similarly, grizzly bears expanded their distribution in Montana, USA, following extensive road reclamation (Summerfield et al. 2004), and moose populations increased following road removal in Nova Scotia, Canada (Crichton et al. 2004). Removing roads at a large scale such as is occurring in the United States has increased the size of core wildlife habitat and has the potential to restore landscape-level connectivity.

Road reclamation efforts and the expansion of roadless areas increase the resilience of ecosystems and help mitigate climate change. For example, as larger storms become more common in the face of climate change, more culverts catastrophically fail during high flows, releasing large amounts of sediment into streams. Removing culverts and restoring stream crossings eliminates this risk and associated negative impacts on aquatic habitats (Chapters 44 and 45). Additionally, when roads are decompacted during reclamation, vegetation and soils can develop more rapidly and sequester large amounts of carbon. Total soil carbon storage increased 6-fold to 65 metric tons C/km (to 25 cm depth) in the northwestern United States compared with untreated abandoned roads (Lloyd et al. 2013). With more than 100,000 km of roads slated for reclamation in the United States alone in the coming decades, road reclamation has the potential to sequester large amounts of carbon.

Figure 3.4 After treatment, vegetation recolonises reclaimed roads reducing erosion and providing food and cover for animals. This photo was taken 10 years after road reclamation on the Clearwater National Forest in the northwestern USA. Source: Photograph by Adam Switalski.

3.5 It is crucial to systematically evaluate the need for and location of proposed roads and implement the principle of 'no-net-loss' of unfragmented lands when there is no alternative

It is important to systematically evaluate whether a road is *really* needed; and if so, explore alternative route options before dissecting and eliminating roadless areas or increasing traffic volumes in low-traffic areas (Fig. 3.5). Infrastructure development and, particularly, road construction should avoid dissecting roadless areas. Road-free areas of natural and semi-natural habitats should be maintained by concentrating traffic on existing highly travelled roads and bundling infrastructure close together (Chapter 5). When this is not possible, it is crucial to protect the remaining area by avoiding contagious development and to apply compensation policies of no net loss to unfragmented lands (Chapter 7). Measures such as road reclamation, promotion of railroads or speed and traffic limitation should also be considered. The implementation of sustainable development schemes at large spatial scales should help prevent the degradation of roadless and low-traffic areas (Fig. 3.5)

CONCLUSIONS

Roadless and low-traffic areas have become scarce, indicating a reduction in well-preserved and functioning ecosystems worldwide. The maintenance of roadless areas is more cost-effective than measures to mitigate or minimise road impacts, or even road reclamation. In this context, a vital task is to identify, map and describe the remaining roadless and low-traffic areas, and to promote their maintenance and protection. Developed countries are removing unnecessary roads and restoring landscape processes to enlarge roadless areas. This exemplifies the need for rewilding in a human-dominated planet. Roadless and low-traffic areas are a timely tool to preserve intact functioning ecosystems at local and global scales in the face of climate change. Their rarity and the services they provide to society call for systematically considering them in modern land-use and road planning.

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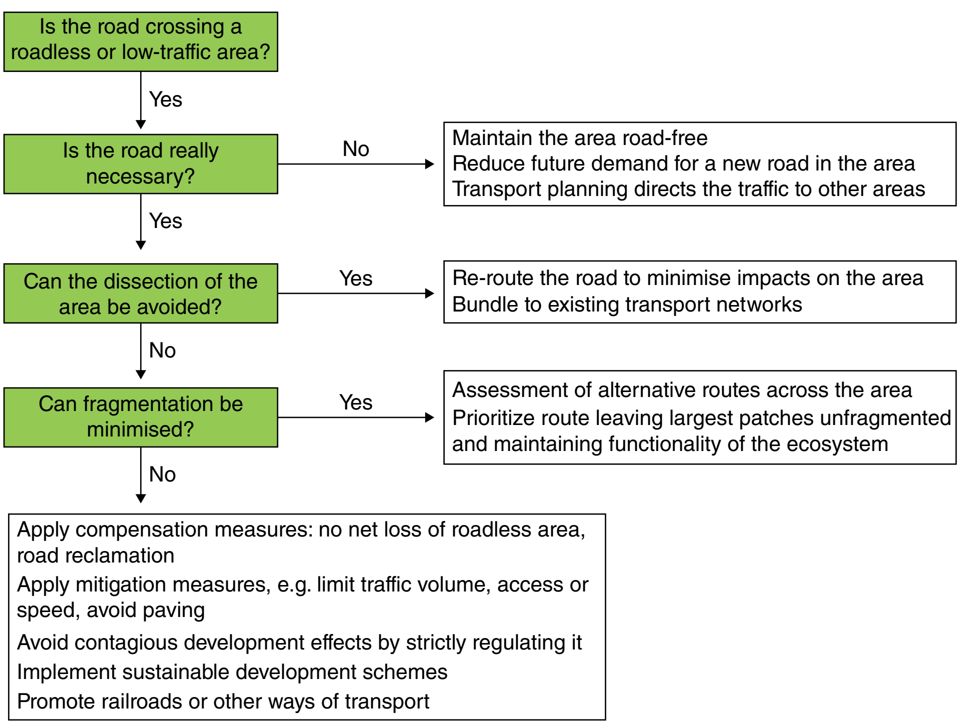

Figure 3.5 Four main questions to ask when planning a road project in roadless or low-traffic areas.

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FURTHER READING

DellaSala and Strittholt (2003): Review of the ecological, social and economic benefits of roadless areas conservation in the USA, with special focus on the conservation assessments of two case studies of roadless areas.

Selva et al. (2011): Identifies the importance of roadless and low-traffic areas for biodiversity conservation and ecosystem services to society, and urges for their inventory and inclusion in urban and transport planning. It includes a legal analysis of roadless areas in Europe and their overlap with the Natura 2000 network, using Germany as a case study.

Switalski et al. (2004): Summary of the current understanding in the science and practice of road reclamation. Taking a multi-disciplinary approach, the article reviews how road reclamation benefits and impacts different natural resources and identifies knowledge gaps.

http://earthengine.google.org/: This is the Google platform for environmental data at a planet scale. It includes a prototype map of global roadless areas.

http://roadlessland.org/: This is an interactive website that shows the inventoried roadless areas in the US and has a number of maps and scientific resources for roadless areas.

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Chapter 4

INCORPORATING BIODIVERSITY ISSUES INTO ROAD DESIGN: THE ROAD AGENCY PERSPECTIVE

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SUMMARY

Road agencies have a responsibility to design, build and operate roads in an environmentally sensitive manner, which includes addressing ecological issues. Agencies that manage other linear infrastructure, such as railways and utility easements, have similar responsibilities. All major infrastructure projects follow similar stages and processes from inception through planning, design, construction, operation and maintenance. Within this process, there are limited and specific opportunities to most effectively implement ecologically sensitive planning and design.

4.1 Road planning, design, construction and operation are complex challenges that attempt to balance environmental, economic and social demands.

4.2 Road projects have a typical series of stages that begins with strategic planning and ends with operation.

4.3 Appropriate ecological input into a road project should occur in every stage.

4.4 Standards and guidelines are critical to ensure a consistent and high-quality approach to roads and road mitigation.

Road agencies around the world are responding to the changes that society is demanding by including greater consideration of ecological issues when planning, building and managing the road network. This is an important challenge for road agencies because their traditional role as managers of the transportation network is expanding and becoming more complicated. It is imperative that road agencies successfully adapt to these changes to ensure the future road network is as environmentally friendly as possible.

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