Preserving biodiverse river corridors for sustainable city development

As the global population continues to soar and the number of inhabitants in cities climbs ever higher, sustainable development strategies are urgently needed to prevent catastrophic ecological decline in our urban environments. Understanding anthropogenic threats is the first step towards conservation: Jochen Hack, Professor of Ecological Engineering at the University of Darmstadt in Germany and leader of the interdisciplinary research group SEE-URBAN-WATER, utilises habitat quality assessment software to model the effects of urban infrastructure and pollution on the Pochote river's ecosystem ecology in Nicaragua, Central America.

The Pochote river flows through León, a rapidly expanding city in Nicaragua. The river corridor is composed of different levels of urbanisation.

Today's global population clocks in at around 7.9 billion people. Approximately 55% of these inhabitants live in urban areas – a proportion set to increase to 68% by 2050, according to the United Nations Department of Economic and Social Affairs. Over the last 70 years, the global urban population has grown by almost 3.5 billion people, but this growth has not been spread equally across all continents – in Africa, rural living is still the norm, with less than 50% of its population living in cities. Megacities – cities with 10 million or more inhabitants – are predicted to dominate the habitation landscape by 2030, with 43 of these mega-metropolises worldwide, many of them in developing regions.

While the benefits of urbanisation include better access to jobs, healthcare and education for citizens, the challenges associated with mass migration to cities is manifold. With exploding populations comes the need to house, feed and transport millions of inhabitants daily as well as to deal with the wastes that they produce. Without adequate planning and management, rapid urbanisation can result in not only poor life quality for people living in cities, but wider-reaching environmental impacts, including water and air pollution, and ecological destruction.

ECOLOGICAL EXPLOITATION

In 2019, a landmark report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) painted a stark picture of the current ecological landscape: approximately 75% of the Earth's land surface has been significantly altered, 85% of wetlands have been lost, and 1 million species face extinction, due to human activity. The IPBES report explored how land use changes have impacted terrestrial and freshwater ecosystems, finding agricultural and urban dwelling expansion to be two of the biggest drivers of habitat degradation over the last 50 years. For freshwater ecosystems such as rivers, IPBES identified water extraction and pollution, climate change, and man-made infrastructures (road networks, oil and gas pipelines, hydroelectric dams) as principal threats causing the highest levels of decline.

Rivers play an essential part in maintaining viable ecosystems, by functioning as ecological corridors – narrow portions of habitat that connect wildlife populations and preserve environmental cohesion over fragmented landscapes. In cities, rivers connect isolated wildlife populations with their rural counterparts, making them a crucial player in urban biodiversity conservation. However, many urban rivers are utilised as drainage reservoirs for stormwater, wastewater disposal systems for factories or sewage plants, or energy producers, through the construction of hydroelectric dams. While these functions provide essential services to the cities' inhabitants (storm prevention, power production), they can disturb the natural ecological functions of the river corridor. Understanding freshwater ecosystem threats and having the ability to assess the health of river corridors over time is essential to maintaining biodiversity in urban environments.

The researchers utilised high-resolution remote sensing images to develop maps of land use and threats for their study.

The health of a river corridor can be assessed through the use of habitat quality models – computer-based models that examine land use and biodiversity threats across specific areas. Although many habitat assessment tools have been developed over the past decade, few are freely available. As the regions expecting the largest population growth over the next thirty years are mainly confined to the developing world, where funding is short and ecological protection low on the agenda, free-of-charge, accessible ecology assessment tools are paramount if the United Nations Sustainable Development Goal (SDG) 11, to make cities inclusive, safe, resilient and sustainable, is to be realised.

MODELLING DEGRADATION

InVEST is a freely available open-source software suite. Its primary function is to assess habitat quality based upon land use and human-derived threats. It has thus far been applied to large-scale terrestrial ecosystems. Within the model, habitat quality is defined as the ability of an ecosystem to provide conditions appropriate for population persistence, and 'high-quality' habitats are those with intact ecological functions. The model assumes that habitat quality decreases as the intensity of anthropogenic land use increases, and utilises 'raster maps' on land use to calculate the quality of the zone under investigation. Each cell in the raster map is assigned a land use type (for example, forest, grassland, cropland, built-up) and the user defines the suitability of each land use type for conserving biodiversity. Suitability scores range between zero and one – the closer the score to zero, the lower the suitability and the lower the survival of species. Intact habitats, such as forests, will have a higher suitability score while modified habitats, such as cropland, will exhibit lower scores.

The IPBES report found agricultural and urban dwelling expansion to be two of the biggest drivers of habitat degradation over the last 50 years.

The suitability score is then combined with threat parameters that describe the impact of the threat, whether distance from the threat decreases its impact, the accessibility of the threatened area, and the sensitivity of the threatened area, to give the total threat level, or degradation score. A degradation score is calculated for each threat identified, for example built-up areas, road networks or pollution, and computed with the habitat suitability score to give overall habitat quality. Habitat quality can be measured over a period of time, or it can be modelled on predictions about future scenarios, such as those involving megacities. Prediction scenarios can be used by governmental bodies to make informed decisions about how urban expansion will impact habitat quality in the future.

Prof Jochen Hack, in collaboration with Manuel Beißler, Diana Molewijk and his team at the Technical University of Darmstadt, have employed InVEST to examine a small-scale urban river corridor in the city of León, Nicaragua, in Central America. Prof Hack and his team set out to assess the individual and combined impacts of anthropogenic threats, specifically, built-up areas, road networks, and river pollution, on the Pochote river corridor.

THE ANTHROPOGENIC TRIFECTA BUILDINGS, ROADS, AND POLLUTION

León is Nicaragua's second largest city, home to 180,000 inhabitants. The Pochote river flows in a southwest direction through the city, and confluents with the Chiquito River outside the city's boundaries before discharging into the Pacific Ocean. In their study, Prof Hack and his team selected a 200-meter-wide corridor of the Pochote river, composed of three river branches, each one kilometer in length and representing different levels of urbanisation: densely urbanised, urban-rural transitional, and mostly rural.

The researchers utilised high-resolution satellite images as input data for the development of raster maps for their model. When applying InVEST to measure habitat degradation (HD) due to built-up areas, the upper branches of the river in the northeast, which are closely surrounded by densely packed buildings, were the most affected, with a HD score of 0.3. As anticipated, the further away from the settlement, the lower the habitat degradation; the southwest portions of the river, furthest away from the city's historical center, exhibited a HD score of less than 0.1. Overall, built-up areas appeared to reduce river habitat quality (HQ) by up to 40%.

The team then examined river habitat degradation due to road networks. The impact of the roads correlated with the distribution and density of the settlements, with roads in built-up areas resulting in the biggest reduction in habitat quality, reducing the HQ score in these zones to almost zero. Habitat quality was reduced most dramatically where roads were present on both sides of the river, or where the road network invaded the river corridor via bridges.

Prof Hack then investigated the influence of water pollution on Pochote habitat degradation. Water pollution was most intense in built-up areas due to solid waste disposal and leakage of untreated wastewater from upstream water treatment plants. The threat due to river pollution in these zones was equivalent to that derived from built-up areas, with a HD score of 0.3. As with built-up areas, the impact of river pollution decreased as the distance from settlements increased, though degradation from water pollutants remained in low levels throughout the course of the studied river section due to natural freshwater hydrodynamics carrying pollutants downstream.

When looking at the effects of combined threats, the researchers found the highest levels of habitat degradation (HD score of up to 0.85) in the upper branches of the river, closest to densely settled areas. Habitats in this area of the river had already been damaged or destroyed by buildings and roads, and the degraded environment was further exacerbated by water pollution.

INVESTING IN OUR FUTURE

Prof Hack and his team successfully used InVEST to assess the environmental degradation caused by buildings, roads and water pollution in León, Nicaragua. Their conceptual approach to assessing ecological health is accurate and rapid, has low data requirements, and is free of charge. These characteristics make InVEST a viable method for governmental bodies to use when identifying high-risk areas and conservation hotspots during city planning in developing regions. Prof Hack's version of the model used in this study considered limited land use types and anthropogenic threats focusing on urban aspects – expansion of these variables to include land use types such as protected areas and agricultural land use, and threats such as agricultural run-off contaminated by fertilizer or pesticides as well as industrial wastewater discharge, would allow a more comprehensive understanding of the ecological status of the study area. The model could also potentially be used to investigate particular species rather than biodiversity as a whole, in areas where endemic animals and plants are identified as particularly vulnerable to urban threats. In previous studies by Prof Hack and his team, they developed several novel methodologies such as MAPURES (Methodology to Assess the Potential of Urban River Ecosystem Services), to investigate ecosystem services and nature-based solutions based upon field data and high-resolution true-color images obtained from Google Earth. Together, these methods shed light on the impacts of urbanisation on a previously unexplored river ecosystem and help to reveal the beneficial functions and services river provide to urban populations.

Overall, the trends in data derived from this conceptual study suggest a cause-effect relationship between anthropogenic threats and habitat degradation, proving the InVEST model capable of modelling impacts of urban expansion on ecology in a developing country. The city of León is currently expanding its built-up zone into the urban-rural transitional area, which will likely result in increased habitat degradation unless preventative action is taken. In this age of unprecedented environmental decline, every aspect of society's interactions with nature offers the opportunity to either cause further destruction, or pave the way toward a healthier future for all. This kind of detailed, high-resolution analysis is essential in understanding how we can limit the spatial distribution of anthropogenic impacts, and plan towards more sustainable cities by taking advantage of the blue-green infrastructure that river corridors provide. Nature-based solutions, such as Shenzhen's rain gardens and sponge city design, or Berlin's creation of a 'green belt' are fantastic initiatives, but progress cannot be made without first understanding the nature of the problem. Models like Prof Hack's provide the foundations for building solution-led sustainable cities.

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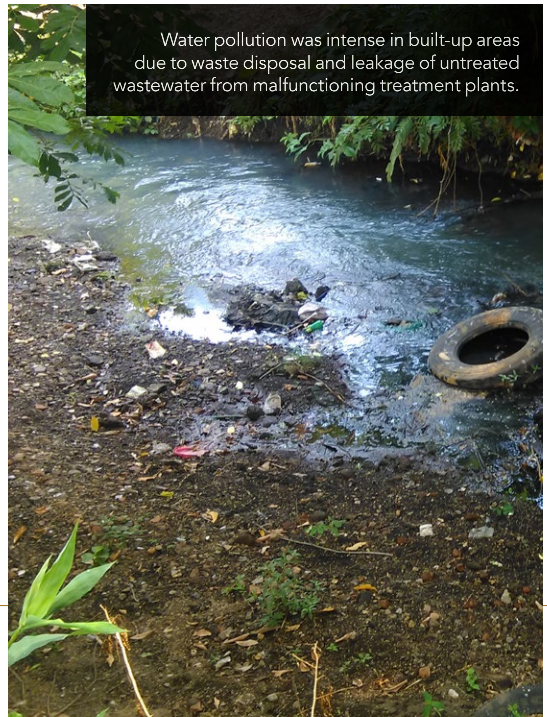

Water pollution was intense in built-up areas due to waste disposal and leakage of untreated wastewater from malfunctioning treatment plants.

Behind the Research

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Research Objectives

Prof Hack examines the ecological state and societal importance of the Pochote river in León, Nicaragua. His research aims to reduce the impact of urban threats, leading to more sustainable urban development.

Detail

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Jochen Hack is Professor for Ecological Engineering and Leader of the Inter- and Transdisciplinary Research Group SEE-URBAN-WATER at Technical University Darmstadt, Germany. He is an expert in Environmental Modelling of Nature-based Solutions, the study of Green Infrastructure and Ecosystem Services. Prof Hack holds a PhD in Environmental Engineering from Technical University Darmstadt, Germany.

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Personal Response

Would it be difficult to model specific species vulnerability rather than total habitat quality?

" Modelling habitat suitability for specific species and their vulnerability to habitat degradation is more complex and requires more detailed data on the species, their ecological networks, and their susceptibility to specific threats to be considered. While a total habitat approach focuses on characteristic ecological structures and processes (e.g., related to the provision of food, shelter, reproduction and breeding conditions in general) and their susceptibility to specific threats, a species vulnerability approach would depart from the demand and susceptibility of specific species. For the latter, information is often much scarcer. "

Do you think results would differ if you modelled a developed city, such as London, using InVEST and the parameters described in your most recent study?

" The result of modelling a developed city would certainly differ. Both habitat conditions and threats are usually different in more developed cities. River corridors and their hydromorphology commonly change with higher level of development as rivers are increasingly channelised and engineered to convey runoff from urban areas faster and safer as well as to gain more space for urban development. This often results in a loss of natural floodplains and river corridor vegetation leading to degraded or lost habitat suitability. On the other hand, threats stemming from untreated wastewater or solid waste disposals usually decrease with higher developments as treatment plants and waste collection systems are implemented and stronger enforcement of environmental regulations are in place. "