

SUMMARY

Roads are a ubiquitous feature of human civilization, but their expansion comes at a cost to biodiversity and ecosystem integrity. The negative impact of roads on ecosystem functionality is manifold, ranging from direct impacts such as habitat fragmentation, wildlife mortality, and pollution to indirect effects including deforestation, changes in wildlife behavior, and disruption of ecological processes. As a result, the preservation of roadless areas has just emerged as a fundamental conservation tool. The main goal of this dissertation is to comprehensively evaluate if roadless areas can represent cost-effective conservation targets and proxies for functional ecosystems. Through a comprehensive synthesis of existing literature and original research contributions, this thesis aims to explore the ecological and policy implications of roadless areas conservation. By assessing their extent on a global scale and evaluating their quality I aim to provide a better understanding of their role in preserving biodiversity and ecosystem functionality. Roadless areas, characterized by the absence of roads or human infrastructure, are (partly) free from road impacts and can play a crucial role in maintaining ecological integrity and ecosystem functioning. These roadless landscapes can serve as vital refugia for biodiversity and provide essential ecosystem services globally.

In the first paper, roadless areas were defined as areas at least 1 km away from any type of road following a thorough review of the spatial extent of road impacts. Utilizing a freely available road dataset (OpenStreetMap 2013), I conducted a global assessment to determine their extent and evaluated their status, quality, and coverage by protected areas. Although approximately 80% of the Earth's terrestrial surface remained roadless, it was fragmented into approximately 600,000 patches; more than half of these patches were less than 1 km² and only 7% exceeded 100 km². Furthermore, I investigated the proportion of roadless areas classified under different protection status and developed an index (the Ecological Value Index of Roadless areas, EVIRA) incorporating three indicators (Ecosystem Functionality Index, roadless area patch size, and patch connectivity using Thiessen polygons) to assess the quality of these areas. Although the world's protected areas cover 14% of the terrestrial surface, only 9% of roadless areas were within protected areas. Large tracts of unprotected roadless areas with high EVIRA values exist in both tropical and boreal forests. Africa and Asia have the lowest level of protection of high-value roadless areas. The only continent with strictly protected roadless areas exhibiting high EVIRA values is Australia. Roadless areas characterized by low EVIRA values constitute 35% of the total area, primarily due to their small size, fragmentation,

isolation, or high levels of human disturbance. Almost two-thirds of all roadless areas had medium to high EVIRA values. The conservation of roadless areas is in line with several United Nations' Sustainable Development Goals, particularly with goals 15 and 9.

The second paper explores the ecological significance and conservation challenges of roadless areas, particularly focusing on forest ecosystems in large, unfragmented regions such as the Amazon, Congo basin, and East and Southeast Asia. These areas play a crucial role in regulating ecosystem services, including habitat availability, maintenance of genetic diversity, water retention, and soil protection. They contribute to carbon sequestration and storage and serve as local climate buffers. However, they are also objects of resource exploitation, posing a significant conflict between short-term economic interests and long-term conservation goals. In this study, I highlight roadless areas as vital indicators of pristine ecosystems and emphasize their importance in ecosystem integrity. The number of roadless areas decreased by more than 30% between 2013 and 2018, particularly in Africa and Southeast Asia, presumably as a result of increased mapping efforts, but also due to the expansion of road infrastructure. There is substantial evidence of the ecological importance of roadless areas due to the absence of complex interacting anthropogenic factors that directly or indirectly impact ecosystems. We recommend to include prioritizing the conservation of roadless areas, integrating roadlessness as a criterion for sustainable development planning, re-routing planned roads, and exploring alternative transportation technologies to reduce the impact of roads on ecosystems.

The third paper presents a comprehensive assessment of roadless areas using the OpenStreetMap road dataset 2020 in two regions with contrasting levels of human impact: the boreal region of Canada and temperate Central Europe. I used high-resolution satellite images to visually interpret and manually add unmapped roads in randomly selected roadless areas. I analyzed road mapping completeness and its relationship with anthropogenic influences, including road density, travel time to major cities, Human Footprint Index, and Human Modification Index in 1000 random plots in both regions. Results reveal large differences in road mapping completeness between the two regions, with Central Europe exhibiting significantly higher levels of mapped roads. Roads were completely mapped in 3% of the plots in boreal Canada, compared to 40% in Central Europe. Lower Human Footprint Index and road density values were associated with greater incompleteness in road mapping, highlighting the influence of human activities on mapping quality. After manually incorporating previously unmapped roads in 30 randomly selected roadless areas in each region, I found a similar

decrease in roadless areas in both boreal Canada and Central Europe (27% and 28%, respectively). While in 70% of the random plots no roads were present in boreal Canada, there were no plots without roads in Central Europe. This study underscores the urgent need for improved road mapping techniques to promote research on roadless areas and to understand their role as conservation targets.

This PhD thesis deals with the emerging topic of roadless areas and represents an important contribution to conservation science. It underscores the importance of roadless areas as conservation targets and helps lay the foundations for the emergence and development of “Roadless Ecology” to further study their positive contribution to the preservation of biodiversity and ecosystem functionality.