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Review of PhD thesis by Monika Teresa Hoffmann,
Entitled "Roadless areas as tools for the conservation of functional ecosystems"

Overall assessment

I enjoyed reading this PhD thesis very much. While working in recent years especially on trophic cascading effects of large carnivores in temperate forest (Białowieża forest, Poland), I also realize more and more how pronounced human impacts can be. The work by Monika Hoffmann used an approach on a much larger scale, at country scale to global scale to show how pronounced human impacts are on ecosystem functioning by focusing on the areal extent of roadless areas. I am impressed by the work that is behind this PhD thesis and the overall quality of the performed studies. While working with freely available large (global) data sets may sometimes seem like an easy thing to do, I know that there is a lot of effort and sweating in cleaning this data and making them suitable for the performed analyses. Whereas my own scientific work is often limited by being able to collect enough data points, the work that Monika did is more limited by how to handle all the available data and find ways to do something sensible with it. To have two very decent scientific papers coming out of her work and one book chapter, I find an achievement to be proud of. Furthermore, I am impressed by the smooth text and high standard of scientific English writing throughout this thesis. Big compliments and congratulations with this achievement!

The compilation of two already published chapters, in combination with a very clear and to-the-point summary, illustrates that the candidate has a thorough knowledge of the current state of the art within this discipline. Furthermore, it shows evidence of the candidate's ability to place her work in a more general framework which makes these studies interesting for a general scientific audience and hence publishable in high standard scientific journals. Since the candidate is the leading author in one publication and one book chapter and the second author (with a crucial role in the global data collection, analyses and interpretation) in a paper published in Science, she demonstrates that she is able to handle large and complex data sets, carry out complicated analyses and work with top scientists to produce high quality output. So it illustrates the candidate's ability to carry out independent scientific research, as well as coordinate the work of different co-authors to come to a nice end result. In my opinion, especially this last ability to be able to work in a team of scientists, is one of the most important skills that modern scientist should have to be able to compete in the increasingly competitive scientific community.

Assessment of thesis

The chapters of this PhD thesis are clearly linked and present a coherent framework of how to map roadless areas globally, what affects precision of roadless areas mapping on a country scale, and the ecological significance and conservation challenges of roadless areas.

Chapter 1, based on freely available road data set to identified roadless areas on a global scale. This study also presented a well-argued definition of roadless areas based on an extensive literature review to reveal the documented ecological impacts of roads. Based on documented impacts, roadless areas were defined as being at least one kilometre away from any kind of road. The global analyses showed that 80% of the terrestrial earth surface remains

roadless but is highly fragmented. Moreover, only 9 % of roadless areas are protected, showing that recognition and protection of these ecologically valuable areas is urgently needed. Chapter 2 discusses what is the value of roadless areas in the light of the large variety of impacts roads can have, both direct and indirect, on ecosystem functioning. It also discusses the ways how conservation efforts should protect these valuable roadless areas. Finally, chapter 3 evaluates the efficiency of existing methods to map roadless areas and showed that especially in areas with lower road density and lower human foot print values, the completeness of available road data is lower. It illustrated that many roadless areas are not properly mapped and are in fact more dissected than we think. In my opinion these chapters illustrate crucial aspects behind the mapping, and difficulties connected to mapping of roadless areas and the ecological significance of these areas.

All thesis chapters have already been published in high-standard scientific journals: Science (5-year Journal Impact Factor: 50.3), Scientific Reports (5-year IF: 4.3), book chapter in Elsevier book 'Encyclopedia of the World's Biomes'. The encyclopedia of the World's Biomes is a unique, five volume book series that provides a global synthesis of biomes and presents the state-of-the art science connected to the topics covered. These books provide a valuable source for information for students and scientists especially because it combines currently available information on the main threats and conservation strategies for maintaining biomes in an increasingly human-dominated world. The quality of the books is represented by top scientists being the editors of the different volumes and being authors of the book chapters as well as by the well-established publisher (Elsevier).

Hence, all three chapters of the PhD thesis all went through a decent peer-review process and referees have already critically examined and commented on each chapter. Since they already passed the ultimate test that each scientific study has to go through, it feels for me unnecessary to comment in detail on each publication or review them again. Their acceptance in these high standard scientific journals sufficiently illustrates the quality of the work performed in my opinion. Additionally, worth to mention is that chapter 1 (Science) has a special indication in Web of Science to show it is a highly cited paper that received enough citations to place it in the top 1% of its academic field based on a highly cited threshold for the field and publication year, with 376 citations (Web of Science, all databases). This illustrates the important contribution this paper made to this field of science. Chapter 3, published in Scientific Reports has no citation yet which is related to the recent publication dte of 27.02.2024.

A remark still on the relatively large interval of 4 years between the publication dates of the three thesis chapters. Based on personal communication with her main supervisor (Nuria Selva) I learned that Monika did not follow a typical PhD path but her thesis is based on the work she did while working as a freelance and assistant in different projects. I therefore see it as a wonderful achievement to prepare a PhD thesis on the basis of good quality work that Monika did during different positions she had. Besides, publishing high quality scientific papers, require exponentially more work and time in comparison to publications in lower-impact scientific journals. To conclude, I do not see this as a negative part of her PhD thesis, but rather showing her dedication and valuable contribution to these papers/book chapter.

Discussion points per chapter

As all presented papers and book chapter have already been thoroughly evaluated during the peer-review process, I discuss below some points that came to me while reading the thesis, and do not discuss each chapter in detail. I would like to hear how the candidate thinks about these points, so they provide the basis for a discussion during the PhD defence.

Chapter 1, Chapter 3:

1) Biases in OpenStreetMap (OSM) data and potential effect on results

In Chapter 1 (published in Science) and Chapter 3 (published in Scientific Reports 2024) results are presented of Open Street Map data for either a Global analyses or a comparison of Boreal Canada and temperate Central Europe (Poland, Slovakia, Czech, Hungary). In Chpater 3, the accuracy of this data, i.e. the completeness of road mapping, was tested on the basis of visually examination of randomly selected circular plots (n= 1000 per region). The results (page 106) show that the majority of plots in Boreal Canada had no roads which accounted for 70% of all plots. Additionally, 3% of the plots had all roads properly mapped. This results in 73% of the plots being properly mapped. Considering the plots that had roads (n= 271) only 11% were properly mapped. These results show that there is actually a huge bias; the majority of plots has no roads and there the OSM does a pretty good job in correctly mapping roads. But the OSM does a very poor job (11 % correct road mapping) in plots with roads. That means there is 89 % of plots that had apparently more roads than predicted. How did these large biases in accuracy affect your results and potentially conclusions? Is the actual road density in Boreal Canada not very much higher, how much higher? Does it show that there is actually a much higher contrast in Boreal Canada between areas without/low road density versus areas with high road density, and is this the major difference between Boreal Canada & Central Europe?

This bias in data does not seem to be a problem for Central Europe as there were no plots without roads. But the accuracy of mapping in areas with roads was much higher than in Canada (40% of roads accurately mapped in Europe vs. 11% correct in Canada). What explains these differences in the level of accuracy in regions <u>with roads</u> between Canada & Europe?

Chapter 3:

2) Mapping completeness in relation to human pressure indices

Chapter 3 also presents results how the completeness of road mapping in different regions is related to indices of human pressure. A higher human foot print index & higher road density were correlated with higher proportion of correctly mapped plots (page 108). That makes sense as OSM is based on citizens-derived data and more intensively used areas have more correctly mapped all existing roads. But what surprised me is that these effects were more pronounced in Boreal Canada compared to Central European countries. What explains this contrast?

I am struggling with Figure 2 (page 109) as the patterns that these figure show are often opposite to the conclusions drawn from the study. For example, the conclusion that 'lower human footprint index and road density values were related to greater incompleteness in road mapping' (in abstract and discussion). What I see in figure 2 is that the probability of road completeness level (y-axis) declines with increasing human foot print index and increasing road density, in other words areas with lower human footprint (or road density) tend to have the highest probability of road completeness level. Also the coulours shown in the figures suggest the opposite patterns than written in the conclusions; there is more light green (=completely unmapped) at higher levels of human foot print index and road density. How do you explain this, or do I misread the figure?

Chapter 1 & general conclusions:

3a) Should (only) roadless areas with high biodiversity be conservation priority?

Based on chapter 1 (Science 2016) you conclude that; ''The largest roadless areas with high ecological values were found in the boreal and tropical forest. These regions provide essential

ecosystem services and avoiding their fragmentation should therefore be a conservation priority'. Indeed figure 1 at page 27 shows that these regions show large roadless areas and combine this with high Ecological Value Indices of Roadless Areas (EVIRA). These EVIRA index was calculated on the basis of different indices amongst others those related to biodiversity, ecological functionality. That results in general for the more biodiverse regions of the world to get high EVIRA indices. Also in the paper is mentioned that 'Some large tracts of roadless areas, such as arid lands in Northern Africa or Central Asia, occur in areas of sparse vegetation and low biodiversity and, thus, have low EVIRA (page 29).

So is the conclusion fully justified that roadless areas in the boreal zone and tropical forest should be conservation priority, when we know that ecologically highly valuable and highly threatened areas exists in roadless areas in the (sub)artic region which have low biodiversity but highly specialized species? These areas also typically have long recovery times following human disturbances. The same is true for desert regions in central Australia, north Africa or other extreme climates as in the Andes mountain range. So how careful should we be in using these predictive maps to guide conservation priorities? Should we focus conservation efforts in areas with high biodiversity or also, or even more, focus on areas with a unique value?

In connection to this, in your last conclusion (page 147) you mention that; 'Further research and road data collection efforts are necessary to better understand the ecological value of roadless areas ….as well as to identify where ***relevant*** roadless areas still exist'. I fully agree with your conclusion that it is highly necessary to identify where roadless areas exist, but how to correctly quantify which areas are ***relevant***? How could we improve the classification of valuable, roadless areas that conservation efforts should focus on?

3b) What should be our conservation priority: better protect roadless areas or save what is left in areas with high road density?

One important messages that comes out of Chapter 1 (Science 2016) is that the global protection of ecologically valuable roadless areas is inadequate and that better protection is urgently needed to halt their continued loss. Also in your conclusions (page 146) you emphasis that conservation efforts should prioritize on the largest roadless areas with high ecological value (in boreal and tropical forests). But the paper in Science also mentions; 'The relative conservation value of roadless areas is context-dependent. Comparatively small or moderately disturbed road less areas have higher conservation importance in heavily roaded environments, such as most of Europe, US, southern Canada (page 29)'. So on what conservation efforts should really focus on:

- better protect and prevent development in large roadless areas with high ecological value or
- preserve the roadless (or low road) patches in areas with high road density and already strongly decreased ecological value to maintain gene pools and allow potential recovery in the region.

Of course we better do both, but which will be most cost-effective given that large parts of the wealthy parts of world have high road densities?

4) Can we combine roads & areas of high conservation status? (Chapter 2)

In your chapter 2 you give a detailed overview of all direct and indirect impacts of roads on ecosystems. Whereas there are many direct effects documented resulting from pollution, noise etc. on a variety of species groups, the indirect effects resulting from the presence of roads (f.e. invasive species, increased logging, resource extraction, fires) seem even more

dramatic. Would you agree with me that the indirect effects are generally more pronounced than the direct effects? If so, the roads themselves pose many threats, but there are even more threats resulting from the human activities that result from road presence. Potentially this could provide alternative solutions for conservation. The direct effects of roads we can mitigate to a certain extent by creating sound barriers ('ekrany przeciwhałasowe') or green under- or over-passages for wildlife. When we are also able to reduce/mitigate the indirect effects that results from roads, we could potentially enormously reduce the negative impacts of roads on ecosystems. Are there examples of areas with a high road density but with 'well-behaved humans' that do not create additional, indirect impacts on ecosystem functionality? So can this also be a way forward for conservation efforts, to combine roads & nature to a certain extent by aiming at minimizing direct and indirect impacts of roads?

Summarizing and conclusion

The discussion points I raised above shows that I was inspired by your work and by no means are meant to criticize your work. To conclude, I declare that the thesis submitted by Monika Teresa Hoffmann, entitled "Roadless areas as tools for the conservation of functional ecosystems" illustrates her ability to carry out independent and team-based scientific research of high quality according to the requirements stipulated in **Article 13, section 1** of the Act of 14 March 2003 on academic titles and degrees. Therefore, I recommend Monika Teresa Hoffmann to be awarded with the title of doctor in biological.

Dries Kuijper