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Review of doctoral thesis Mr Chahura Dineth Perera titled "Goldenrods invasion in Central Europe- drivers of invasion and environmental effect"

The review has been prepared on the basis of the decision of Agriculture and Horticulture Discipline Advisory Board of Institute of Agroecology and Plant Production, WUELS in Wroclaw, POLAND made on the 16th of May 2023 No PD000000.4100.11.2023.
The PhD thesis has been conducted in Institute of Agroecology and Plant Production in Wroclaw University of Environmental and Life Sciences under dr Magdalena Szymura, associate professor leadership. That work has been prepared in two parts : 1) three articles listed in the Journal Citation Reports printed in Ecology and Evolution in 2021, Management of Biological Invasions (2021 and in Scientific Reports (2022), 2) first-person narrative summary where the author has presented the purpose of research, material and methods, results, discussion and conclusions. The PhD thesis has been written in English and I would like to underline that English is very good and the professional terminology has been used in a proper way. That is why the doctorate is clear, easy to understand with interesting research hypotheses, results and very good discussion and conclusions which are connected with notation and could be a good inspiration for further research.
The main part of the thesis consists not only of the text of three scientific papers but also of the short summary and the author contribution statements. It confirms that the contribution of Mr Perera in conceptualisation and realisation of all parts of PhD thesis and in all scientific papers is significant and clear There is no doubt about the formal part of the thesis which is correct and fulfils the rules.

Introduction.

In chapter 1 the author presents the problem of biological invasion of different species which could be treated as worldwide phenomenon. On the basis of the literature (Catford, Janson and Nilson 2009) he tries to explain the biological invasions by three interacting processes: propagule pressure (P), abiotic characteristic of the environment (A) and biotic characteristics

of both the addressee community and the invading species (B). It is important that all these factors are influenced by human activity so we can predict the invasion or maybe to limit the scale of invasion of some species if we use PAB theory and PAB framework.

As a main subject of the PhD thesis Mr Chathura Perera chooses goldenrods species (*Solidago sp*) which successfully invade many countries and can be a serious problem also in Central Europe. Invasive goldenrods are highly competitive for nutrients, water and space and can limit the growth of other species. They can also decrease the biodiversity of plant communities and causes a decrease in the production and feeding value of meadows and pastures. The EU Members are obligated to prevent the introduction control and eradicate the invasion alien species, but I agree with the author that prevention is possible only in the first stage of *Solidago* invasion. Later we have to use the combination of different methods to control that weed. However, there is still a lack of knowledge about the *Solidaco* biology and habitat resistance to invasion, also grassland communities' reaction to the goldenrods invasion is not fully known. We need more knowledge about the ecological effect of biological invasion and its environmental changes in soil properties and soil invertebrates communities. On the basis of previous studies and present estimation of *Solidago* invasion in Poland (particularly in south-western Poland) the author focuses in his thesis on the three much more important problems:1) identification of goldenrods invasion drivers, 2) analysing the grassland communities resistance and 3) environmental changes in soil invertebrates communities during restoration methods applied on *Solidago* –invaded land. As a consequence of that purpose of research three scientific hypotheses are conceptualized (page 6 of the first-person narrative summary), the first one looks maybe too general but the second and third ones are interesting for both practice and research point of view. I generally think that the subject of the thesis is very interesting, current and important both for research and practice.

Material and methods

In the first article titled "Drivers of *Solidago* species invasion in Central Europe – case study in the landscape of the Carpathian Mountains and their foreground" the author evaluates the effectiveness of proxies of PAB framework to explain the spatial pattern of *Solidago gigantea* Aiton and *Solidaco candiensis* L invasion in the regional scale. The study area is a Polish part of Carpathian Mountains and their foreground. Data showing the distribution of goldenrods on the base square grids 2 x 2 km2 is used. The proxies of PAB factors are used as explanatory variables in Boosted Regression Trees model. It is very interesting that the data on distribution of the Solidago sp. is obtained from the atlas published earlier by Zając and Zając (2015), but

maybe it is a pity that the author doesn't compare the present distribution of *Solidago* with the situation before their spreading phase. It would be good to see the scale of *Solidago* invasion during the last decade.

The second part of the PhD thesies is oriented on the habitat resistance for the plant species invasion. It is closely connected with the first part of the study, because the author wants to check why we observe the strong invasion of goldenrods in some places, but some other localisations are completely free from *Solidago*. The research hypothesis of this part of the study is also very interesting, which habitat is more resistance or more competitive against the invasion of goldenrods. The intensive maintained grasslands, special rich vegetation (semi - natural extensive management) and open soil (control) are compared. The experiment was established in 2018 in containers in 3x3 completely randomised design with six replications. The design of the experiment and the soil characteristics are fully understood, but I have some doubts about the terminology. I think that not different habitats were tested, but different types of management (the soil on all treatments was the same and climate conditions were also the same). The different habitats were created by the author during the experiment by using different seed mixtures, introduction of herbs and grass species typical for semi natural meadows in Central Europe. I understand the aim and the idea of the trials established in Swojczyce Research Station, but we should remember that there are still artificial habitats and we should be very careful to draw general conclusions on the basis of only that experiment without the field studies. On the other hand I would like to underline that all measurements which are presented in the third year of the experiment and clearly described in the article (page 877 of the PhD thesis), also the statistical analyses are used in a proper way and we can have the full confidence of the results.

The third article included in the PhD thesis is a paper published in Journal Scientific Report titled "The impact of restoration methods for *Solidago* invades land on soil invertebrates ". That experiment was located on an abandoned arable land dominated by Solidago spp (*Solidago gigantea* and *Solidago candiensis*). That area was surrounded by suburban buildings and extensively used meadows. The goal of that experiment was rather complicated because the author wanted to join three different proposals in one experiment. First one was a problem of habitat restoration using the different method of seed introduction into dense Solidago sward. Different seed mixtures were used, seeds collected from the seminatural meadow and fresh hay from donor habitat. In my opinion there is not enough information about some details connected to the donor habitat. The next factor was different frequencies of mowing (1, 2 or 3 times a year). The soil invertebrates from all combinations were extracted using the Tulgren' method

and identified into taxa using a light microscope. The methodology is correct but I have some doubts about the goal of that experiment and practical meaning of those studies. First of all, I do not think that restoration of typical meadows on arable land is possible, especially in such a short period of time. Secondly, the effectiveness of methods of restoration and their cost could be a problem, also the relationship between soil invertebrates and Solidago sp. is not very clear (which group of taxa is more or less favourable for goldenrods presence and development).

Generally the materials and methods presented in those three articles were selected in the appropriate manner. We can find the full description of each technology, information about the sites of the experiments, also statistical methods and models are used correctly. Probably the author had to spend a lot of time studying the literature and preparing his studies.

Results

One of the basic conclusion from the first article is that *Solidago canedensis* distribution pattern is correlated with proxies of human pressure whereas *Solidago gigantea* mostly with environmental characteristics. It is also logical that distribution of *S. canadiensis* depends on the anthropogenic factors (human population density and share of agricultural land in total tested area). In my opinion the effect of stopping agricultural activity should be also underlined. It was mentioned in the introduction to the first paper that goldenrods species prefer fallow land, roadsides, stream edges, ruderal habitats and abandoned farmland. The abandonment of grassland management is one of the most serious treats of permanent grassland and probably one of the reason of invasion some aggressive species like *Solidago*. I expect some explanations or comments about that during final defence of PhD. I would like also to pay attention to very good maps in the article published in Ecology and Evolution. That material should be a good inspiration for future research works. I appreciate the effort of the author for collection all data and preparation such interesting figures.

The second article published in 2021 in Management of Biological Invasions ended with also very interesting conclusions. One of the most important suggestions is that semi-natural communities as well as species rich urban grassland are rather resistant to *Solidago* invasion. It means that it is not possible to confirm the hypothesis that the community consisting of the highly productive grass species is more resistant to goldenrods invasion than semi-natural extensive grassland. It is true that no significant differences are found between these two plant communities. However, I think that more research is still needed, because the strong

relationships between human activity and environmental factors can decide about the scale of invasion, like it was evidenced in the first part of Mr Chatura Perera thesis.

The article titled "The impact of restoration methods for Solidago invaded land on soil invertebrates" is rather complicated. I think the author wanted to answer to many questions in one experiment. I fully agree that mowing regimes significantly affect the soil invertebrates. It is also logical that the number of soil taxa is higher where the mixture of grass and legumes was sown in comparison with the control. The author of this article shows that greater intensity of mowing has a negative effect on soil organisms (but it depends on the group of soil taxa). I do not fully understand the last sentence in conclusion's part , which is: " (...) the introduction of a mixture of grasses with legumes constitute the most suitable method for restoring Solidago-invaded stands, while also maintaining soil invertebrate abundance." In my opinion that article is interesting as a comparison of different methods of restoration and soil invertebrate abundance, but is only slightly connected with *Solidago sp* presence or control.

Discussion

Discussion should be the chapter, where we can find the summary of the results, but also the confrontation with other results published in the literature. I am sure that discussion placed in chapter 5 of Mr Cathura Perera first-person narrative summary fulfils all those aspects. The author discusses some results and conclusions from three articles, which make up for the PhD thesis. He repeats the most important results from each article and, of course, it is acceptable. It is important to underline the value of the species distributions model assessed by AUC value and by PAB framework. For practice but also for ecological research it is important to show that *Solidago gigantea* recent domination in Carpathian Mountains has been primarily spontaneous whereas the spread of *Solidago candensis* depends mostly on human activity. I think that it should be also explained which factors of human activity are more important for stimulation of goldenrods invasion. The question is which one can be treated as a method of prevention or which one may lead to invasion. It is connected with the second part of the discussion. The results of the study show that resident grassland vegetation under the low-mowing regime significantly reduced the growth of *Solidago* invasion in different parts of Europe. The results suggest that the species rich meadows and the highly productive grassland are able to restrict the long distance spread of *Solidago sp*. The author did not find the significant differences between intensive, highly productive grass species and semi-natural meadows with the high biodiversity. It is very interesting conclusion but maybe is too early to reject the hypothesis about higher resistance of intensive grasslands for goldenrods invasion. I would say

that still more research is needed for that subject. The third part of the discussion is about the changes in soil communities during restoration by different methods. As I have mentioned before it is a very interesting aspect of study and rather new idea to link soil properties with method of restoration. However, it is only slightly connected with goldenrods sp biology. It could be also very interesting to list soil invertebrates, which can have the positive or negative effect on Solidago biology and development.

Finally, I would like to underline that not only the discussion printed in first-person narrative summary is very gripping, but also I read with pleasure the discussion chapters in all articles. It confirms the deep knowledge and ability of critical thinking of Mr Chathura Perera. He also used some modern literature. We can find a lot of very good articles published in English in scientific journals with a high CI. Those articles have been chosen very carefully and they fully correspond with the main subject of the thesis.

Conclusions

The Doctoral thesis is ended by three conclusions which are logical, arise from results and they are the answer to research hypotheses. The conclusions confirm that the main goal and the purpose of the research are fully realised and we can say about the real progress in understanding goldenrods biology and reasons of *Solidago* invasion.

Recapitulation and final remarks

To sum up, I think that the evaluated work of Mr. Peliyagodage Chathura Dineth Perera meets the conditions for doctoral dissertations and I request that the author admitted to the public defence in accordance with the provisions of the Act on the title and degrees.

Due to high scientific value and very carefully prepared PhD thesis I also put forward a motion for special price to Mr Chathura Perera for his excellent work and all his efforts.

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