

**Reponses to first referee's comments on "Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area" by Laddaporn Ruangpan et al.**

The premise of this article is extremely interesting and some of the conclusions of the article, in particular the "Overview of knowledge gaps / potential future research" is a very useful contribution to advancing this topic. The article helps to give an overview of the many concepts and terms associated with Nature based solutions for disaster risk reduction and it attempts to provide a mixed quantitative /qualitative assessment of a number of pre-determined questions that the authors have outlined as the objectives of the review. It therefore merits to be published if some fundamental methodological issues can be resolved.

**Authors' response:** Thank you for your encouragement and comments. Your concerns are addressed in this response letter and the manuscript revised accordingly. Please find our point-by point response below.

**1. Concepts**

**Comments from Referee:** The article provides an interesting historical overview of the different related concepts but there is still a confusion of terms. The abstract in particular is confusing, i.e. Nature based Solutions (NbS) is generally considered to be an umbrella term under which other types of approaches, Eba, Eco-DRR and GI / GBI provide more specific solutions to more specific issues (see various definitions given by IUCN and EU-related). This does not come out clearly in the article.

For example: p. 4/ line 30 NbS is not just about storm water

**Authors' response:** Thank you for pointing out this issue. We agree that terminology was confusing in the Abstract and other instances. This has been clarified in the revised manuscript. Furthermore, Section 3 "Overview of definitions and theoretical backgrounds", has been modified and expanded to better highlight the definition of NBS as an umbrella concept, as the reviewer suggested. This section also has been relocated to section 2 before "Materials and methodology" section as it discusses more on the background of NBS.

P.4 line 30: revised. Now, we specifically refer to SuDs, LIDs and WSUD terms in the sentence.

**Authors' change in the revised manuscript (revised and added text with yellow highlights):**

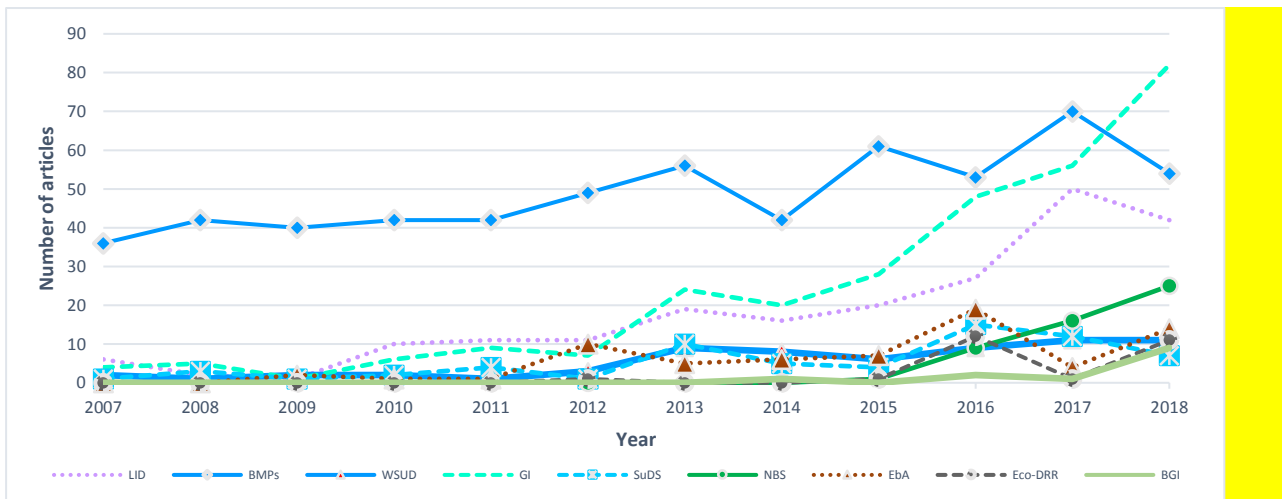
There are several terms and concepts which have been used interchangeably in the literature to date. In terms of NBS, the two most prominent definitions are from International Union for Conservation of Nature (IUCN) and the European Commission. The European Commission defines Nature-Based Solutions as "*Solutions that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions. Nature-based solutions use the features*

*and complex system processes of nature, such as its ability to store carbon and regulate water flows, in order to achieve desired outcomes, such as reduced disaster risk and an environment that improves human well-being and socially inclusive green growth*” (European Commission, 2015). The IUCN has proposed a definition of NBS as “*actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*” (Cohen-Shacham et al., 2016). Eggermont et al., (2015) proposed a typology characterising NBS into three types: i) NBS that address a better use of natural/protected ecosystems (no or minimal intervention), which fully fits on how IUCN frames NBS; ii) NBS for sustainability and multi-functionality of managed ecosystems and iii) NBSs for the design and the management of new ecosystems, which are more representative of the definition given by the European Commission.

NBS is a collective term for innovative solutions that are based on natural processes and ecosystems to solve different types of societal and environmental challenges. Therefore it is considered as an “umbrella concept” covering a range of different ecosystem-related approaches and linked concepts (Cohen-Shacham et al., 2016; Nesshöver et al., 2017), which provide an integrated way to look at different issues simultaneously.

Due to the diverse policy origins, NBS terminology has evolved in the literature to emphasize the different aspects of natural processes or functions. In this regard, nine different terminologies are commonly used in the scientific literature in the context of hydro-meteorological risk reduction: Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SuDS), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR). The timeline of each terminology based on their appearances on literature shown in Fig. 1 and their definitions are given in Table 1.

The analysis of publications sourced from Scopus from 2007 to 2018 shows that only 62 out of 1387 articles (i.e., 5%) explicitly used the term “Nature-Based Solution” for hydro-meteorological risk reduction (Figure xx). This can be explained due to difference in terms used in different countries while the term NBS has been used only from 2008 (MacKinnon et al., 2011) (Fig. 2). However, the significant increase of published articles in recent years testifies how NBS is a rapidly growing research area (Fig.2).



**Figure 2: Number/trend of published articles on Nature-Based Solutions (NBS) for hydro-meteorological risk reduction and its sister terms: Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Green Infrastructure (GI), Sustainable Urban Drainage Systems (SuDS), Nature-Based Solutions (NBS), Ecosystem-based Adaptation (EbA), Ecosystem-based Disaster Risk Reduction (Eco-DRR) and Blue-Green Infrastructure (BGI)**

The commonalities between NBS and its sister concepts (i.e., GI, BGI, EbA, Eco-DRR) is that they take a participatory, holistic, integrated approach using nature to enhance adaptive capacity, reduce disaster risk, reduce the vulnerability, increase the resilience, enhance biodiversity, and improve human well-being. More information on the history, scope, application and underlying principle of terms of SuDS, LIDs, BMPs, WSUD and GI can be found in Fletcher et al., (2015) while the relationship between NBS, GI/BGI, and EbA is described in more detail by Nesshöver et al., (2017).

Although all terms are all based on a common idea, differences in definitions reflect their historical perspectives and knowledge base pertinent for that point in time (Fletcher et al., 2015). The distinguishing characteristic between NBS and its sister concepts is how they address social, economic and environmental challenges (Faivre et al., 2018). Some terms such as SuDS, LIDs, and WSUD refer to NBS that specifically address stormwater management. They use landscape for transforming the linear character of conventional stormwater management into a more cyclic approach where drainage, water supply, and ecosystems are treated as part of the same system, mimicking more natural water flows (Liu and Jensen, 2018). GI/BGI focuses more on technology-based infrastructures by applying natural alternatives (Nesshöver et al., 2017) for solving specific activity (i.e., urban planning or stormwater). EbA focuses more on a long-term change within the conservation of biodiversity, ecosystem services, and climate change, while Eco-DRR focuses more on immediate and medium-term impacts from the risk of weather, climate and non climate-related hazards. EbA is often perceived as a subset of NBS that is explicitly concerned with climate change adaptation through the use of nature (Kabisch et al., 2016; Nesshöver et al., 2017). From the above discussion, it can be concluded that EbA, Eco-DRR and GI/BGI provide more specific solutions to more specific issues. One key distinction is that unlike the sister concepts, the NBS concept is more open to different interpretations. It can be useful as they may be easier to encourage stakeholders to take part in the discussion.

Moreover, features of NBS provide an alternative to work with existing measures or grey infrastructures. Therefore, it is important to note that very often a combination between natural and traditional engineering solutions (a.k.a. “hybrid” solutions) is likely to produce more effective results than any of these measures alone, especially when their co-benefits are taken into consideration (Alves et al., 2019).

Important advances in the science and practice of NBS is provided by the EKLIPSE Expert Working Group, who developed the first version of a multiple-dimension impact evaluation framework to support planning and evaluation of NBS projects. The document includes a list of impacts, indicators and methods for assessing the performance of NBS specifically at the urban scale (EKLIPSE, 2017). Laforteza et al., (2018) has also reviewed different case studies around the world where NBS have been applied from micro-scale to macro-scale. Furthermore, an overview of how different NBS measures can regulate ecosystem services (i.e., soil protection, water quality, flood regulation, and water provision) has been carried out by Keesstra et al., (2018).

**2. Methodology of the review;** This is where this reviewer has the greatest number of questions:

**Comments from Referees 2.1** Good that multiple data bases were used but why assume that just because Scopus has the greatest number of articles, that it is the most comprehensive? You could have merged all three searches and then removed duplicates.

**Authors’ response 2.1** Thank you very much for your comment. The authors have revised the methodology (see also next comment) by including both Web of Science and Scopus databases and merged the two searches together as recommended by the reviewer, and removed duplicates. Note that Google Scholar has been completely excluded from the revised methodology because it has limited metadata and filters which, at present, do not allow to limit results to articles published in peer-reviewed, scientific journals written in English (one of the three selection criteria adopted in our search process).

**Comments from Referees 2.2** Adding missing articles adds a huge bias to your search. Which articles were selected and based on what criteria? That the keywords were there? - Which criteria were used for deleted certain articles - perhaps I missed this?

**Authors’ response 2.2** We agree that the methodology of this review was not clearly explained and had some flaws. Thanks to Reviewer’s comments, our methodological approach has been carefully revised and improved. Specifically:

- 1) Bias introduced by missing articles has been removed, namely those articles are no longer evaluated neither included/added in the analysis. Note that few comments drawn upon this subset of articles have been retained because considered of relevance to our discussion, but they are now included in the new Section 2, which is not part of the “Findings” section
- 2) An analysis of why other papers in the extended list did not appear in the search shows that they were missed because they use the terms ‘green and grey infrastructure’ as

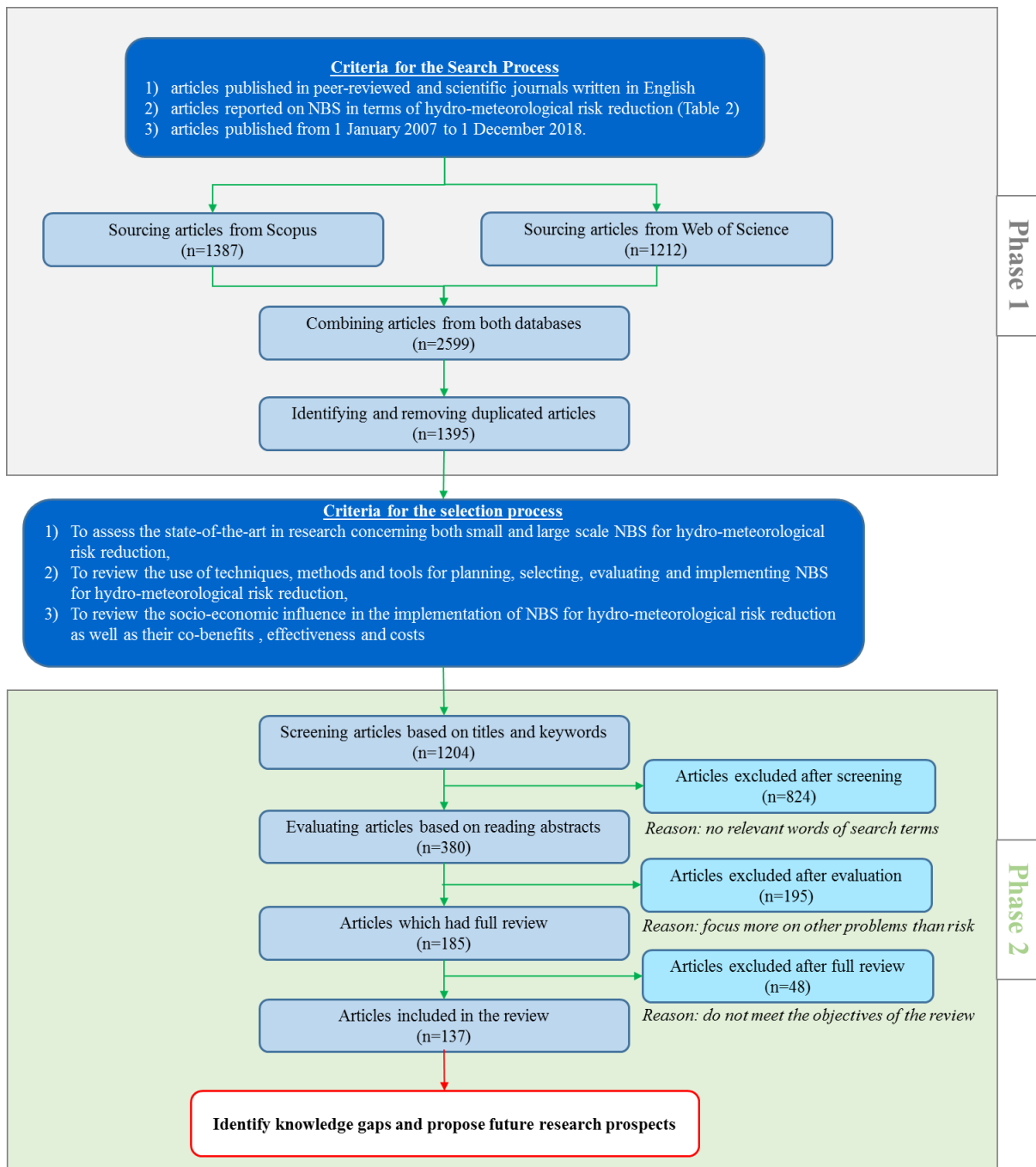
opposed to 'green infrastructure' directly. As this is merely a language issue, the term 'green and grey infrastructure' was added to the search terms.

- 1) As this Reviewer pointed out, the selection process was not clearly explained in the original manuscript. We have now substantially expanded the methodological section, by explicitly stating the objectives of the review and by explaining the criteria used for selecting the literature of relevance with respect to these objectives. This is summarized in the diagram below (included in the new version of the manuscript) which shows that the method consists of two phases. For the search process (phase I) the only selection criteria adopted were that (a) articles are published in peer-reviewed and scientific journals written in English; (b) articles reported on NBS in terms of hydro-meteorological risk reduction (construction of the search query based on the keywords in Table 1); (c) articles were published in the period 2007 to 1 December 2018. The search process resulted in a total of 1204 articles which were then subjected to selection process (Phase II). The selection process involved a set of progressive steps as schematized in Fig.3 and detailed in the following: << *Initially, all articles were analysed on the basis of reading titles and keywords and their relation to the search terms. For example, articles having 'resilience', 'stormwater' or other relevant words in the title or keywords were selected for continued analysis. Secondly, a more in-depth analysis was conducted, based on reading the abstract of each article selected in the previous step. The criteria was that the abstract should discuss about hydro-meteorological risk reduction. For example, if the abstract of the articles focuses more on water quality than risk, then that paper was excluded. This step served to reduce the number of articles from 380 to 185. Finally, reading full articles was undertaken to identify those that were relevant to the review objectives. Any studies appearing to meet the key objectives (dealing with subjects such as effectiveness of NBS, techniques, method and tools for planning, and others which are of relevance for the key objectives) would then be included in the review. As a result, the entire selection process resulted in a total of 137 articles were selected* >> (text extrapolated from the revised Section 2.2 (now Section 3.2)). For sake of completeness and clarity, the new version of the entire methodological section is provided below.

### **Authors' change in the revised manuscript:**

### **3. Materials and methodology**

Explain here that the entire methodology consisted of two phases as schematized in the diagram (Fig.3). The first phase consisted in the identification of all articles satisfying the searching criteria discussed in Section 3.1 Next, all articles were screened and filtered in or out based on the selection criteria discussed in section 3.2.



**Figure 3: Process of article selection on Nature Based Solutions for hydro-meteorological risk reduction. The final number of fully reviewed articles is 137.**

### 3.1 Search strategy

The review analysis concerned articles in peer review and scientific journals written in English. Two main concepts were used in the search: Nature-Based Solutions and hydro-meteorological risk. As the concept of ‘Nature-Based Solutions’ appears under different names (which more or less relate to the same field of research), articles related LIDs, BMPs, WSUD, SuDS, GI, BGI, EbA and Eco-DRR were included in the identification of relevant articles (see Table 2). The review of hydro-meteorological risk included literature on relevant terms (i.e. disaster, review etc.) and different types of risk (i.e. floods, droughts, storm surges and landslides) (Table 2).

During the construction of the queries, the strings were searched only within Index terms and Metadata “titles, abstract, and keywords” in the Scopus and Web of Science database. The search terms for the two concepts were linked with the Boolean operator “AND” while the Boolean operator “OR” was used to link between the possible terms (Table2). An example of a protocol is shown below:

“TITLE-ABS-KEY ( "Nature-based solutions" OR "Nature based solutions" OR "Nature Based Solutions" OR "Nature-Based Solutions" OR "Low impact development" OR "Sustainable Urban Drainage Systems" OR "Water Sensitive Urban Design" OR "Best Management Practices" OR "Green infrastructure" OR "Green blue infrastructure" AND "flood" ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "ch" ) OR LIMIT-TO ( DOCTYPE , "re" ) OR LIMIT-TO ( DOCTYPE , "bk" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) )”.

Based on pre-search process, the number of scientific articles with respect to the concepts of NBS, LIDs, SuDS, WSUD, BMPS, GI, and BGI started increasing significantly from 2007. Therefore, the time window selected for the review process was from 1 January 2007 to 1 December 2018. 1387 articles published in scientific journals have been found in the Scopus database and the same search performed in Web of Science resulted in 1212 articles. The articles from both databased have been combined to 2599 articles. Duplicated articles found from the applied queries were then removed, resulting in a total number of 1395 articles. As consequence, the 1204 articles resulting from the search query.

## **2.2 Selection process**

As stated in the Introduction, this study aims at reviewing the state of art of the research on NBS that specifically address hydro-meteorological risk reduction. In this regard, the key objectives of the present review work were carefully formulated as follows:

- 1) To assess the state-of-the-art in research concerning both small and large scale NBS for hydro-meteorological risk reduction;
- 2) To review the use of techniques, methods and tools for planning, selecting, evaluating and implementing NBS for hydro-meteorological risk reduction;
- 3) To review the socio-economic influence in the implementation of NBS for hydro-meteorological risk reduction as well as their multiple benefits, co-benefits, effectiveness and costs;
- 4) To identify trends, knowledge gaps and proposed future research prospects with respect to the above three objectives.

These key objectives defined for the review with the intention that the results could be both quantitative and qualitative.

The 1204 articles resulting from the search query (Section 2.1) were thus evaluated against their relevance with respect to these objectives, and those found of little or no pertinence with the topic removed. This selection process involved a set of progressive steps as schematized in Fig.3 and detailed below.

Initially, all articles were analysed on the basis of reading titles and keywords and their relation to the search terms. For example, articles having ‘resilience’, ‘stormwater’ or other relevant words in the title or keywords were selected for continued analysis.

Secondly, a more in-depth analysis was conducted, based on reading the abstract of each article selected in the previous step. The criteria was that the abstract should discuss about hydro-meteorological risk reduction. For example, if the abstract of the articles focuses more on water quality than risk, then that paper was excluded. This step served to reduce the number of articles from 380 to 185.

Finally, reading full articles was undertaken to identify those that were relevant to the review objectives. Any studies appearing to meet the key objectives (dealing with subjects such as effectiveness of NBS, techniques, method and tools for planning, and others which are of relevance for the key objectives) would then be included in the review. As a result, the entire selection process resulted in a total of 137 articles were selected as relevant for the objectives of the present review and were obtained for review.

**Comments from Referee 2.3** Search terms you had several search terms from your first column with "urban", this may have included a bias toward urban

**Authors’ response 2.3:** We understand the Reviewer’s concern, but we would like to point out that as mentioned on page 3 line 10, the concept of Nature-Based Solution was historically linked to different names in different countries [e.g. Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SuDS), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR)]. In this cases, there are only 2 search terms that include “Urban” out of the 10 search terms. Therefore, if we do not include search terms like ‘Water Sensitive Urban Design’ (WSUD) and ‘Sustainable Urban Drainage Systems’ (SuDS), we may miss some important articles related to the topic. Furthermore, only 130 of the 1387 papers from Scopus appear due to these terms and only 4 articles out of 137 were included in the review. This means that the word “urban” contributed to only 2.9% of the total 88% urban cases shown in Figure 5.a. Therefore, we concluded that including these 2 terms do not have a significant impact in terms of bias. For sake of clarity, this has been now clarified also in the manuscript (section “Trends, knowledge gaps and future research prospects”).

**Authors' change in the revised manuscript:**

Most of the literature to date is about NBS in urban areas whereas those contexts concerning river and coastal floods, droughts and landslides are the least addressed. 88% of all articles were concerned with runoff reduction or flood risk reduction in urban areas (Fig. 5a). It is worthwhile to notice that two out of the ten search terms in Table 1 contain the word “urban”. This was in order to include two popular concepts linked to NBS for hydro-meteorological risk, which are WSUD and SuDS (cf. the overview of terminology given in Section 2). Nevertheless, the literature sourced using these two search terms only accounts for 2.5% of the total 88% urban cases shown in Figure 5.a. Therefore, no significant bias was introduced in our findings by the inclusion of the word “urban” through these two search terms.



**Comments from Referee 2.4** One of the main objectives of this review was to find trends and patterns, so only section 4.1 Trends, knowledge gaps and future research prospects provides quantitative results, the remaining sections onward are mainly qualitative descriptions to answer your pre-defined research questions: e.g. (2) Effectiveness of multiple NBS sites, etc. It should be clarified that you the review is quantitative but also qualitative based on pre-defined questions. However you do not justify why you selected these topics - again, they did not emerge as trends in the literature, you selected them and then found literature to analyse them. In other words, you combine deductive with inductive research. This should be made more explicit, or you should choose one or the other.

**Authors' response 2.4:** We thank you the reviewer for this comment which really helped us to re-shape the manuscript in a much more coherent form. As discussed earlier (comment 2.2), we have now explicitly stated that the literature material was selected to answer our pre-defined research questions. Trends, knowledge gaps and proposed future research prospects were mainly evaluated with respect to these pre-defined objectives - something that should have been evident from Table 3 but that we anyway missed to comment on in text, thus leading to confusion. For each given topic embedded in our key research questions, this Table specifies the number of articles found that deal with it and it summarizes the knowledge gaps and future research prospects drawn upon them. Trends and path - as emerging from those articles – are therefore discussed not in general, but with respect to each of these topics, which was the criterion based on which Section 4 was divided into subsections. The different sub-sections are meant to reflect the key objectives defined for the review with the intention that the results could be both quantitative and qualitative

In the revised manuscripts, we will also slightly modify the titles and contents of some subsections of Section 4 to better highlight the correspondence between them and the research questions of this review. Furthermore, we will move Section 4.1 “Trends, knowledge gaps and future research prospects” to end of Section 4, as we feel this will better clarify the logic of the paper. Here we also plan to include a paragraph to explicitly comment on Table 3 and to better highlight the quantitative results emerging from our analysis. Finally, we will expand the “Introduction” Section to better motivate our research questions’ choice.

### **3. Other**

**Comments from Referees 3.1** Some paragraphs appeared to be more a promotion of author’s projects rather than related to the literature review ?? They might belong in the conclusions but not as part of the analysis.

**Authors' response 3.1** We apologize if some paragraphs appeared to be more a promotion of author’s projects. Paragraph on page 10, line 12 has been relocated to conclusion.

**Comments from Referees 3.2** The manuscript needs to be redrafted by a native English speaker. e.g. p8, line 27 "desiderative" ;)

**Authors' response 3.2** Thank you for suggestion. The revised manuscript has been reviewed by a native English speaker.

**Comments from Referees 3.3** The table on websites related to the topic is good but excludes a few important sites, namely IUCN's data base on EbA projects and the Partnership for Environment and Disaster Risk Reduction (PEDRR) website.

**Authors' response 3.3** We apologize for the missing site lists. IUCN's database on EbA projects and the Partnership for Environment and Disaster Risk Reduction (PEDRR) website have been included in Table 4.