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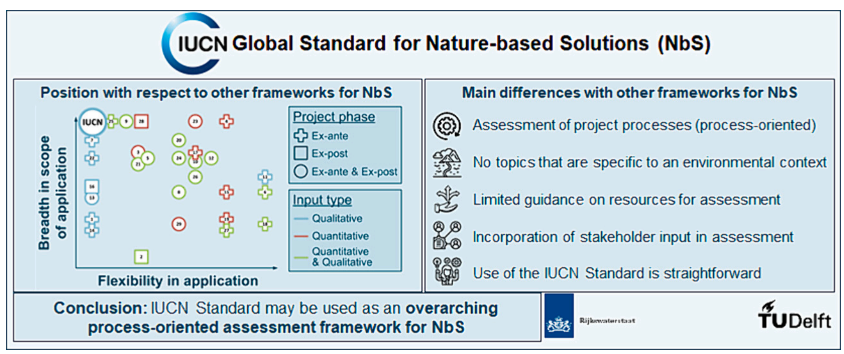
HIGHLIGHTS

- The IUCN Standard may be used as an overarching assessment framework for NbS.
- The IUCN Standard can be used to assess the project processes (process-oriented).
- The IUCN Standard does not allow users to tailor the assessment to a project context.
- The IUCN Standard lacks specific topics and guidance on resources for assessment.
- Use of the IUCN Standard is straightforward and incorporates stakeholder input.

GRAPHICAL ABSTRACT



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ABSTRACT

Nature-based Solutions (NbS) are actions that harness nature to help address major societal challenges. The assessment frameworks for NbS proposed in the literature differ in scope and intended use. In 2020, the International Union for Conservation of Nature (IUCN) introduced their Global Standard for NbS as a framework that can be used by anyone working on different types of NbS. Since research on the applicability of the IUCN Standard remains limited, the aim of this paper is to analyse whether the IUCN Standard may be used as an overarching assessment framework for NbS in river flood management applications and to identify the main differences in content with other NbS-frameworks. This was achieved through a comparison with 29 assessment frameworks for NbS, that are applicable to physical interventions for riverine flood risk reduction. The comparisons showed that the IUCN Standard has the largest breadth in scope of application and may therefore be used as an overarching framework. In addition, we identified a distinction between frameworks for the assessment of project processes (process-oriented) and project results (results-oriented), where the IUCN Standard can be characterized as process-oriented. This implies that the IUCN Standard may be used to assess the processes (e.g. stakeholder engagement and adaptive management) of planned, ongoing or completed NbS projects for a wide variety of environmental contexts and societal challenges. This will help persuade policy makers to consider NbS as one of the solutions in flood management issues, next to or in combination with e.g. engineering solutions or

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changing land use. We also identified that, while the IUCN Standard is straightforward to use and incorporates stakeholder input, the environmental context specificity as well as guidance depth on resources for assessment can be improved.

1. Introduction

Nature-based Solutions (NbS) is an increasingly popular concept referring to actions that harness nature to help address major societal challenges, while simultaneously providing benefits for human well-being and biodiversity. To operationalize the NbS concept, it is important to assess the effectiveness and efficiency of NbS alongside and in comparison to traditional grey interventions. In this context, effectiveness and efficiency can be defined as the extent to which targeted problems are resolved and resources are used, respectively (Sowińska-Świerkosz and García, 2021). Assessment frameworks can be used to objectively assess this by answering specific questions related to design, implementation and/or results (Dumitru and Wendling, 2021a). A large number of assessment frameworks for NbS have been developed over the past decade (de Lima et al., 2022), but these differ in applicability with respect to their scope and intended use. Examples are NbS in urban (e.g. Raymond et al., 2017), rural (e.g. Caroppi et al., 2023), riverine (e.g. Andrikopoulou, 2020) or coastal (e.g. Shafiq et al., 2019) environments and to NbS that address flood risk reduction (e.g. Pagano et al., 2019) or a variety of societal challenges (e.g. Calliari et al., 2019). Assessment frameworks can be designed to be used prior to implementation of a project (ex-ante) (e.g. Sowińska-Świerkosz and García, 2021), during implementation (operational) and/or after implementation (ex-post) (e.g. Watkin et al., 2019). In an effort towards a common understanding and successful application of NbS, there is a need for an overarching framework with global and common applications. Given the broad field of application of NbS and the number of societal challenges, we limit ourselves to NbS in a riverine environment, and with the primary aim of achieving flood reduction.

The International Union for Conservation of Nature (IUCN) appears to provide such an overarching framework with the IUCN Global Standard for NbS (IUCN, 2020a). This framework is intended to be used by anyone working on the design, verification and scaling up of any type of NbS (IUCN, 2020b). The support by the IUCN ensures periodic updates to keep the standard up-to-date (IUCN, 2020c) and enhances the likelihood that a wide body of experience on its application will be established. Recent studies by Seddon et al. (2021), Sowińska-Świerkosz and García (2022) and Dumitru and Wendling (2021a) also acknowledged the IUCN Standard as state-of-the-art, because of its systematic and clear guidance on NbS design and assessment. Since the launch of the IUCN Standard, several applications of the standard to case studies in specific environmental contexts have been published (e.g. Le Gouvello et al., 2023; Châles et al., 2023; Luo et al., 2023; Risna et al., 2022), but research on whether the IUCN Standard may be used as an overarching assessment framework for NbS is lacking. Upon establishment, the increased application of the IUCN Standard will facilitate the uniform assessment of measures. This uniformity enables systematic comparisons, leading to the development of a comprehensive database of findings. Such a database will be instrumental in refining existing Nature-Based Solutions (NbS) and designing new measures for riverine flood management. This will help persuade policy makers to consider also NbS as a possible solution for managing floods, next to or in combination with, for instance, engineering solutions or land use changes. In doing so, policy makers have a broader choice in solving flooding problems. We emphasize that enlarging the range of possible solutions (varying from grey (engineering) to green (NbS), including hybrid solutions) is important. The actual choice of the solution is up to policy makers, and in this choice also considerations with respect to finance, societal embedding and integration in the existing landscape may play a role.

In response to this need, the main objectives of this paper are: (1) to analyse whether the IUCN Standard may be used as an overarching assessment framework for NbS in a riverine environment and with a flood reduction purpose, and (2) to identify the main differences in content between the IUCN Standard and other assessment frameworks for NbS (with the similar limitation as in (1)). To achieve these objectives, we conducted a literature review of assessment frameworks for NbS and compared the IUCN Standard with the selected frameworks.

2. IUCN Global Standard for NbS

The IUCN Standard was developed in response to the “pressing need for greater clarity and precision of what the [NbS] concept entails and what is required for it to be deployed successfully” (IUCN, 2020a). With the IUCN Standard, the IUCN aims to provide a common understanding of NbS and connect application of NbS to a shared vision for a just and sustainable world. Most of the framing of the IUCN Standard originates from the IUCN definitional framework for NbS (Cohen-Shacham et al., 2016), in which NbS is defined as an umbrella concept that covers a whole range of ecosystem-related approaches. After a two-year process in which key missing concepts identified by Cohen-Shacham et al. (2019) (i.e. ecosystem complexity and the need for adaptive management) were incorporated and two rounds of public consultations were held, the IUCN Standard was published in July 2020 (IUCN, 2020b; IUCN, 2019).

The core of the IUCN Standard consists of eight criteria, which are defined as the essential principles to which a (design of) a project must adhere in order to be recognized by the IUCN as an NbS (Fig. 1).The IUCN recognizes seven major societal challenges that can potentially be addressed by NbS (Fig. 1b).

Each of the eight criteria is composed of three to five indicators, which can be used as guiding principles for design, or as qualitative parameters for evaluation. Examples of indicators of the IUCN Standard include: Criterion 3 – Indicator 4 (i.e. Indicator 3.4): *“Opportunities to enhance ecosystem integrity and connectivity are identified and incorporated into the NbS strategy”* (IUCN, 2020a, p. 10). Indicator 7.2: *“A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle”* (IUCN, 2020a, p. 18).

The IUCN Standard (IUCN, 2020a) provides concise and straightforward guidance on the criteria and indicators. The IUCN report is supplemented with an in-depth guidance (IUCN, 2020b) and a self-assessment tool, which is a spreadsheet that allows users to provide a semi-quantitative score of the extent (*strong, adequate, partial or insufficient*) to which a project adheres to the individual indicators. Subsequently, the spreadsheet uses the provided scores to calculate the

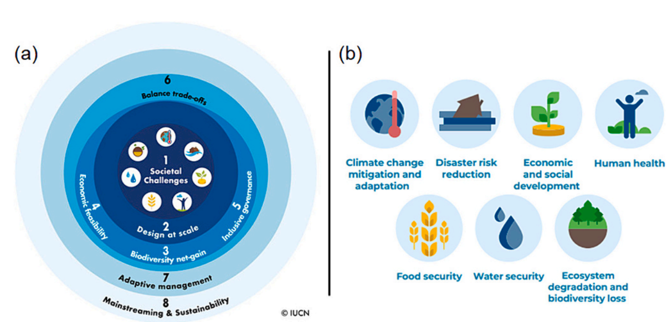

Fig. 1. (a) The eight criteria of the IUCN Standard (IUCN, 2020a), (b) The major societal challenges addressed by NbS, as recognized by the IUCN (Le Gouvello et al., 2022).

percentage match of a project to each of the criteria and to identify whether a project adheres to the IUCN Standard.

3. Methods

3.1. Identification of assessment frameworks for NbS

In preparation for the comparison between the IUCN Standard and other assessment frameworks for NbS, we carried out a literature search for assessment frameworks in search engines Google Scholar and ResearchGate. We limited the literature search to assessment frameworks that are applicable to NbS for riverine flood risk reduction. For the comparison with the IUCN Standard we drafted a list of keywords, focusing on five main categories: a) NbS concept, b) framework elements, c) assessment elements, d) scope – environmental context, and e) scope – societal challenges. In the context of flood risk reduction, the NbS concept is often referred to as "Building with Nature" (BwN) (Slinger, 2021) or "Natural Flood Management" (NFM) (Wren et al., 2022), which are therefore included as keywords together with the term "Nature-based Solutions". As certain documents with relevant guidelines for NbS assessment may not include the term "framework", the keyword "guidelines" was included in the second category (*framework elements*), as well. The keywords "assessment" and "evaluation", separated by boolean operator "OR", were included as the third category (*assessment elements*), because both terms are often used interchangeably (Dumitru and Wendling, 2021a). In addition, the keywords "river" and "fluvial", and "flood risk", "flood safety", "flood protection" and "flood control", both separated by boolean operator "OR", were added as fourth and fifth category, respectively. Given that the research prior to 2016 was focused on positioning and defining the NbS concept (Cohen-Shacham et al., 2016) and that a recent study by de Lima et al. (2022) found that the first framework related to NbS was published in 2017, the literature search was limited to documents published from 2017 until May 2023. The categories of search terms and the combined search string are provided in Table 1.

We selected documents (e.g. scientific papers, technical reports/handbooks or academic theses) that (1) consist of explicit guidance for a multidisciplinary assessment or evaluation of a (potential) project, (2) are explicitly designed for NbS or similar concepts, and (3) are applicable to physical interventions for riverine flood risk reduction. This implies that we excluded (a) documents that solely provide guidance on planning, implementing and monitoring NbS (e.g. Bridges et al., 2021), (b) hydrological assessments of NbS (e.g. Miller et al., 2023), (c) frameworks designed purely for conservation projects (e.g. Dickson et al., 2017) as they do not address societal challenges other than ecosystem degradation (IUCN, 2020b), and (d) frameworks focusing on urban applications without a direct connection to rivers (e.g. Beceiro et al., 2020). We have not selected papers based on specific case studies. Case studies are mentioned in the papers, but they are not relevant for our study. The selection of frameworks was complemented through backward snowballing (i.e. using the references of the selected frameworks to identify additional frameworks) and forward snowballing (i.e. using the "cited by"-function of the search engines to identify additional frameworks that cited the selected frameworks). Forward snowballing did not lead to additional frameworks. All literature is in English.

Table 1
Categories of search terms and the combined search string that is used for the literature search for assessment frameworks for NbS.

Category	Search terms
Concept of NbS	"Nature-based Solutions" OR NbS OR "Building with Nature" OR BwN OR "Natural Flood Management" OR NFM
Framework elements	framework OR guidelines
Assessment elements	assessment OR evaluation
Scope – environments	river OR fluvial
Scope – societal challenges	"flood risk" OR "flood safety" OR "flood protection" OR "flood control"
Publication date	$\geq$ 2017
Combined Search String	
("Nature-based Solutions" OR NbS OR "Building with Nature" OR BwN OR "Natural Flood Management" OR NFM) AND (framework OR guidelines) AND (assessment OR evaluation) AND (river OR fluvial) AND ("flood risk" OR "flood safety" OR "flood protection" OR "flood control")	

3.2. Framework analysis and comparison

To assess whether the IUCN Standard may be used as an overarching framework, we analysed the IUCN Standard and the selected frameworks regarding the following characteristics: project phase (ex-ante, operational and/or ex-post), type of societal challenges (e.g. flood risk reduction, social development and/or food security) and type of environment (urban, rural and/or riverine). We did this by thoroughly studying the papers, and collecting the information about the responsible project or organisation, project phase, data input type, scope (societal challenges as well as environmental context), flexibility and link with the IUCN Standard (see Supplementary Material 1). We consider the IUCN Standard to be overarching with respect to the other frameworks if it is designed to be applicable to all project phases, societal challenges and environmental contexts that are addressed by the other frameworks. In addition, we analysed the selected frameworks and the IUCN Standard regarding the type of required data input (quantitative and/or qualitative) and the flexibility in assessment provided to the user (fixed indicators versus open to interpretation). These are important characteristics for practical usage of a framework. We also checked whether the frameworks that appeared before 2020 (the year the IUCN Standard was published) mentioned IUCN publications related to NbS, like Cohen-Shacham et al. (2016), as this shows awareness of the existence of IUCN.

This method comes with some limitations. First, frameworks that did not use the search terms in Table 1 were excluded. Second, the analysis of the IUCN Standard and its comparison with other frameworks was content-based, whereas applicability requires evaluation of both content and formulation tools (e.g., indicators), which necessitates practical application (see Berg et al., 2024).This was not possible for the complete collection of 29 frameworks and is outside the scope of this paper. Finally, the selection criteria for frameworks were not fully explicit, so frameworks close to meeting the criteria may have been overlooked due to our interpretation.

4. Results

The results of this study are divided into three sections. Section 4.1 lists the assessment frameworks for NbS that follow from the literature search, along with a brief review of their scope and general properties. In Section 4.2, the characteristics of the IUCN Standard and selected frameworks are analysed and used to assess whether the IUCN Standard can be considered overarching. Lastly, Section 4.3 covers the main differences in content between the IUCN Standard and the selected frameworks.

4.1. Selection of assessment frameworks for NbS

The literature search yielded 29 assessment frameworks that meet the requirements mentioned in Section 3.1 (Table 2). The authors do not claim that the inventory is complete, but are confident that the most relevant frameworks are included.

The list consist of scientific papers (1, 4–8, 11, 15, 17–18, 20, 22–25, 27–28), conference paper (14), PhD-thesis (19), MSc-theses (2), European project deliverables (3,12,13), books (21), and guidelines, manuals and handbooks (9, 26, 29). They encompass urban, peri urban and riverine environments, as well as consideration of grey, green and/or hybrid solutions. Almost all note that whilst there is a lot of scientific evidence that NbS work, they are not generally applied due to societal or

Table 2
Assessment frameworks for NbS that followed from the literature search. The italic items (1, 13, 23 and 28) were found by backward snowballing. All other items were the result of the initial search query. Forward snowballing did not lead to new frameworks.

Framework number	Author	Year of publication
1.	*Alves* et al.	*2018*
2.	Andrikopoulou	2020
3.	Autuori et al.	2019
4.	Calliari et al.	2019
5.	Caroppi et al.	2023
6.	Coletta et al.	2021
7.	Croeser et al.	2021
8.	De Lima et al.	2022
9.	Dumitru and Wendling	2021a, Chapter 1–5
10.	Dumitru and Wendling	2021a, Chapter 6
11.	Giordano et al.	2020
12.	Graveline et al.	2017
13.	*Huthoff* et al.	*2018*
14.	Kourtis et al.	2022
15.	Le Coent et al.	2021
16.	Martens	2017
17.	Ommer et al.	2022
18.	Pagano et al.	2019
19.	Pudar	2021
20.	Raymond et al.	2017
21.	Ruangpan and Vojinovic	2022
22.	Ruangpan et al.	2021
23.	*Rödl and Arlati*	*2022*
24.	Shah et al.	2020
25.	Sowińska-Świerkosz and García	2021
26.	van Zanten et al.	2023
27.	Vojinovic et al.	2017
28.	*Watkin* et al.	*2019*
29.	Wishart et al.	2021

governance barriers. Many introduce specific frameworks for implementing NbS in a conceptual way (13, 20, 25, 27), for quantifying co-benefits (1, 2, 5, 17), or provide a review framework (20, 24). A wide variety of tools are employed within the frameworks as part of the assessment of NbS, including multi-criteria (decision) analysis (5, 7, 14, 22), fuzzy logic (6), quasi-dynamic fuzzy logic cognitive map approach (11), analytical hierarchy process (14) and participatory system dynamic modelling (18). Stakeholder analysis and participation is a common theme throughout the frameworks (and explicitly in 5, 6, 22, 27). The frameworks present many case studies demonstrating the effectiveness under consideration, for instance in urban environments (7, 16, 23), on the lower Danube (11), the Nestos River, (shared by Greece and Bulgaria, 14), Tamnava River, Serbia(22) and Nangang River, Taiwan, (22), Ayutthaya Island, Thailand (27) and Rangsit canal area, Thailand (28). A specific comparison of all the frameworks in Table 2 to the IUCN Standard is made in Sections 4.2 and 4.3.

4.2. Comparison of framework characteristics

Fig. 2 graphically compares the frameworks with the IUCN Standard. The x-axis (Flexibility) indicates the scope of flexibility provided to the user of the framework under consideration. From left to right, frameworks provide a greater degree of flexibility, based on how they use indicators for assessment: (a) a fixed number of indicators, not allowing selection of specific indicators relevant to the project context (i.e. tailoring), (b) a fixed number of indicators with the possibility of tailoring, (c) flexible number of indicators, possibly originating from other frameworks or documents, (d) user-defined definition of indicators and/or methods for assessment from other frameworks or documents, and (e) general input from stakeholder meetings and workshops for the identification of the elements to be assessed and the valuation of these elements.

Even though all the selected frameworks are designed to be applicable to riverine flood risk reduction, some have a broader range of application. This is visualized on the y-axis of Fig. 2 (Breadth in Scope which differentiates (from bottom to top) between frameworks that consider: (a) only riverine flood risk reduction, (b) flood risk reduction including co-benefits, (c) other water-related risk reduction like socio-environmental, or drought related, (d) hydro-meteorological

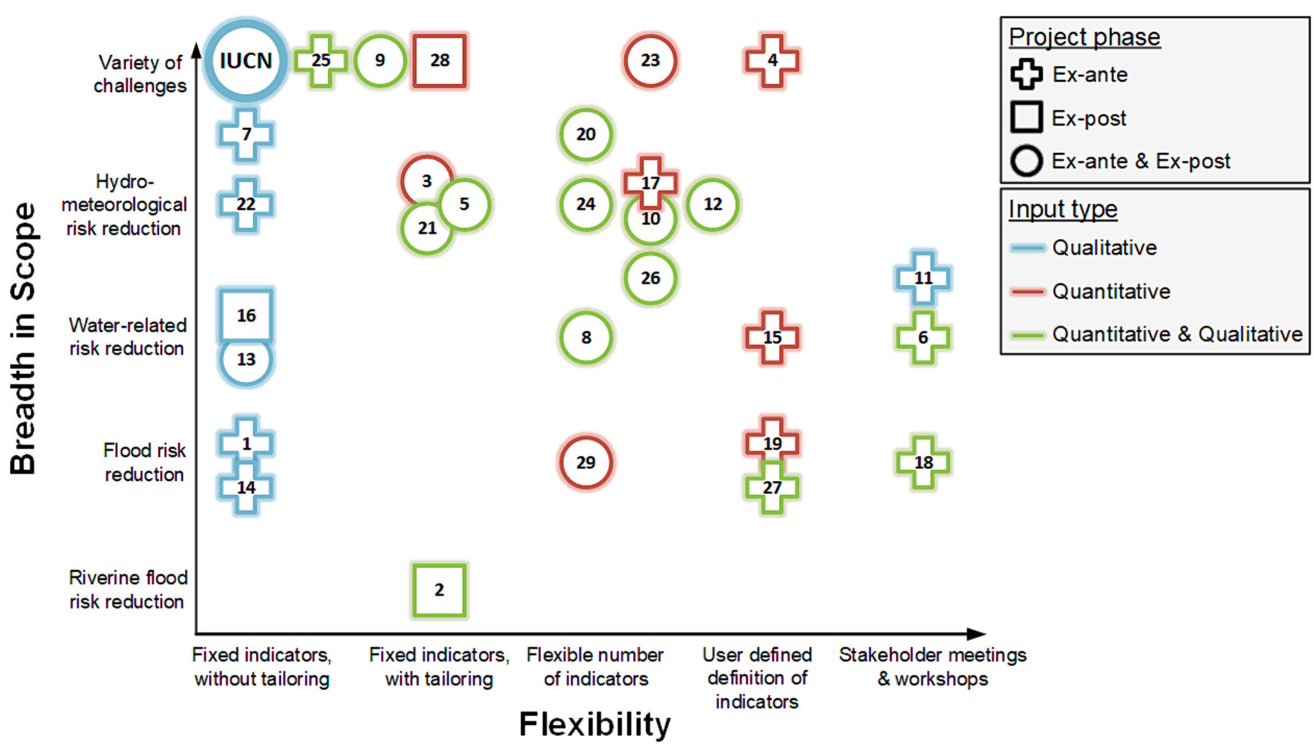

Fig. 2. Flexibility in assessment, Breadth in Scope of application, project phase and data input type for IUCN Standard and other assessment frameworks for NbS. The numbers refer to the framework numbers in Table 2.

(including pluvial and flash flood) risk reduction, and (e) a variety of societal challenges. Recognising potential overlaps in Flexibility and Breadth in Scope, certain frameworks are positioned in between the listed categories in Fig. 2. A more complete description of Flexibility and Breadth in Scope of the IUCN Standard and other assessment frameworks can be found in Supplementary Material 1.

The IUCN Standard does not have limitations as to the environmental context in which it is designed to be applicable, and has a fixed number of indicators that cannot be tailored. This is why it is positioned at the top-left position in Fig. 2. The majority of the frameworks do not have restrictions as to the environmental context, though one framework (nr. 2 – Andrikopoulou, 2020) can solely be applied to riverine NbS

Almost half of the frameworks (45 %) refer to a publication by the IUCN, of which one (nr. 24 – Shah et al., 2020) has a direct link with the IUCN definitional framework and another (nr. 9 – Dumitru and Wendling, 2021a) has a direct link with the IUCN Standard. A complete overview of the framework characteristics and links to the IUCN can be found in Supplementary Material 1.

The comparison reveals that the IUCN Standard is applicable to all of the project phases, societal challenges and environmental contexts that are addressed by one or more of the other frameworks. This indicates that the IUCN Standard meets our definition of an overarching framework for the assessment of Nature based Solutions.

4.3. Differences in outcome and output

By comparing the IUCN Standard and the other frameworks on the characteristics that are mentioned in Section 4.2 (see Supplementary Material 1 for the summary), as well as the position these frameworks have in space spanned by the parameters 'Flexibility' and 'Breadth in Scope' in Fig. 2, we identified five main differences in outcome and output between the IUCN Standard on one hand and the set of other assessment frameworks on the other hand where the differences vary between the 29 frameworks. These are (1) Approach orientation, (2) Context specificity, (3) Guidance detail, (4) Stakeholder engagement and (5) Usability complexity.

1) Approach orientation: Process-oriented versus results-oriented frameworks. We identified a distinction between assessment frameworks that can be used to evaluate the processes throughout a project, defined as process-oriented, and frameworks that can be used to evaluate the results of a project, defined as results-oriented. The IUCN Standard can be used to evaluate the extent to which the essential processes of an NbS (as established by the IUCN) have been incorporated in a project and is therefore clearly a process-oriented framework. These processes include risk management, targeting and monitoring, stakeholder engagement and adaptive management. The deliverables of a process-oriented framework (e.g. Huthoff et al., 2018; Martens, 2017) contain an overview of the extent to which a project has incorporated processes that are of importance to be an (effective) NbS, while the deliverables of a results-oriented framework (e.g. Andrikopoulou, 2020; Caroppi et al., 2023) contain an overview of the project results. This difference can be clarified with the following example of an indicator: Process-oriented indicator: *"Stakeholders who are directly and indirectly affected by the NbS have been identified and involved in all processes of the NbS intervention" (*IUCN, 2020a*, p. 14)*. Results-oriented indicator: *"Number of different stakeholders/disciplines involved" (*Andrikopoulou, 2020*, p. 96)*. There is some ambiguity in terminology. Dumitru and Wendling (2021a) use "solutions-oriented" and Huthoff et al. (2018) use "reflection on design and implementation steps" to denote process-oriented frameworks/indicators. For results-oriented frameworks/indicators, Dumitru and Wendling (2021a) use the term "impact evaluation", while Andrikopoulou (2020) use "performance indicators" and "success indicators" Huthoff et al. (2018) use "success indicators" for results-oriented frameworks/indicators.
2) Context specificity: Specific versus broad topics. The assessment frameworks that are restricted to environmental contexts (all of which can be categorized as results-oriented), include criteria and/or indicators that evaluate project results that are specific to that context. Examples are the "net carbon sequestration by urban forests" for urban environments (Raymond et al., 2017) and "amount of scenic sites and landmarks created" for rural environments (Autuori et al., 2019). In contrast, the criteria and indicators of the IUCN Standard contain relatively broad language and are not specific to an environmental context. We identified the same difference with regard to the societal challenges, where the IUCN Standard recognizes seven societal challenges that are not specific to an environmental context, while the frameworks of Dumitru and Wendling (2021a) and Graveline et al. (2017) include urban-specific societal challenges, such as "green space management" and "place regeneration".
3) Guidance depth: Guidance on resources for assessment. There are differences in the extent to which assessment frameworks provide guidance on possible resources for assessment (e.g. data collection and measurement methodologies). The framework of Dumitru and Wendling (2021a) is complemented by an appendix of methods (Dumitru and Wendling, 2021b) that provides elaborate guidance on possible resources for the completion of each individual indicator. Graveline et al. (2017) include a section on methods for valuation, while Ruangpan et al. (2021) provide case studies with a description of the data collection. The documents of the IUCN Standard, on the other hand, provide very limited guidance on resources for assessment.
4) Stakeholder engagement: Incorporation of stakeholder input. The extent to which the IUCN Standard and other frameworks incorporate stakeholder input in the assessment differs. Several indicators of the IUCN Standard reflect upon the opinions and experiences of affected stakeholders, thereby facilitating the incorporation of stakeholder input (e.g. IUCN Indicator 5.3: *"Stakeholders who are directly and indirectly affected by the NbS have been identified and involved in all processes of the NbS intervention"* (IUCN, 2020a, p. 15)).

There are several other frameworks that, similar to the IUCN Standard, incorporate stakeholder input. Ommer et al. (2022) recommend to align indicator selection with the needs and interests of stakeholders, whilst Giordano et al. (2020) incorporate the level of importance to stakeholders in determining the weight of the criteria. Other frameworks (e.g. Autuori et al., 2019; Andrikopoulou, 2020; Croeser et al., 2021) do not refer to or require input from stakeholders, while the users of the framework of Croeser et al. (2021) recommend including deliberations with stakeholders in revisions of the tool.

5) Usability complexity: Required competences. In contrast to other assessment frameworks, the IUCN Standard is relatively straightforward to use because the indicators are well defined in advance. Frameworks that involve the selection of indicators relevant to the project context (e.g. Watkin et al., 2019) or frameworks that propose structured procedures for selecting appropriate criteria and indicators (e.g. Rödl and Arlati, 2022) require users to think carefully about which indicators are relevant for the assessment. Examples of other frameworks that require such competences include (i) Andrikopoulou (2020), which involves the interpretation of project metadata to identify the project's contribution to the UN Sustainable Development Goals s, (ii) Caroppi et al. (2023) and Autuori et al. (2019), which incorporate mathematical equations in the normalization, weighing and aggregation of indicators, and (iii) Pagano et al. (2019) and Giordano et al. (2020), which contain a methodology based on Fuzzy Cognitive Maps.

5. Discussion

5.1. Overarching framework

With respect to the overarching nature of the IUCN Standard, also, Pakeman et al. (2021) identified the IUCN Standard as the most suitable framework for NbS assessment due to its comprehensiveness even though their method is different and employs a somewhat less stringent approach. Berg et al. (2024) suggests that improvements on the guidance on how to use the IUCN Standard are possible, confirming what is said about usability in Pakeman et al. (2021). We expand on this observation with the differentiation between process-oriented and results-oriented frameworks and with the analysis of the flexibility of the assessment frameworks. Because the scoring approach of the IUCN Standard itself is relatively straightforward, we disagree with the suggestion on usability in Pakeman et al. (2021).

5.2. Process-oriented versus results-oriented

Despite its overarching nature, we found that IUCN Standard cannot be used for the evaluation of project results, whether referring to biophysical or social, institutional and stakeholder outcomes. A way to overcome this is illustrated in Huthoff et al. (2018). This framework is also almost completely process-oriented, but has one results-oriented indicator to evaluate whether the project is answering its objectives. This framework however, has a limited Breadth in Scope compared to the IUCN Standard (see Fig. 1 in which the Huthoff framework is indicated by '13').

The terms "process-oriented" and "results-oriented" are not to be confused with "process-based" and "results-based", which refer to two different types of results-oriented indicators (so within a framework). Process-based indicators can be used to provide information about the results of the planning, design and implementation processes of a project (e.g. number of trees seedlings planted) and results-based indicators can be used to measure the effectiveness of the project (e.g. percentage of CO_2 captured by planted vegetation) (GIZ et al., 2020). The frameworks of Rödl and Arlati (2022) and de Lima et al. (2022) are examples of results-oriented frameworks that distinguish between process-based and results-based indicators.

For an optimal assessment of a NbS projects, it is recommended that a suitable combination of a process-oriented and a results-oriented framework is used. Adherence to the first ensures that (most of the) processes that lead to a successful project have been taken, and that improvement can be achieved on indicators with a low score, whilst adherence to the latter ensures that with respect to outcomes on physical indicators (biodiversity, recreation or general well-being), improvement is gained.

The IUCN Standard can also be used ex-ante, to guide project design or evaluate which essential processes of an NbS have (not) been incorporated in the design. The outcome of ex-ante application of results-oriented frameworks can be used to evaluate which NbS benefits are (not) to be expected given a specific NbS-design (e.g. Giordano et al., 2020) and use this information to adapt the design under consideration (e.g. de Lima et al., 2022).

5.3. Applicability of the IUCN standard

The limited flexibility and the broad language of the IUCN Standard compared to some of the other frameworks may pose challenges in diverse socio-spatial context (de Lima et al., 2022) and environmental contexts. The limited guidance on resources for assessment in the application of the Standard presents another challenge, in that users may encounter difficulties with data collection. The incorporation of data covering stakeholder input in the assessment may also pose a challenge where communication and collaboration with stakeholders presents difficulties. Finally, the required semi-quantitative input may pose a limitation to an assessment with the IUCN Standard as it is more susceptible to human errors (e.g. differences in interpretation of indicators or bias of the user) than an assessment that is based on quantitative input, which inherently requires exact rationale (e.g. measurements). These aspects have been studied in detail by Berg et al. (2024) who applied the IUCN Standard to three case studies in Scotland, The Netherlands and the USA.

The majority of the 29 selected frameworks are also applicable to other environmental contexts (e.g. urban, rural and coastal) and other forms of hydro-meteorological risk reduction (e.g. droughts, storms and landslides). This suggests that our finding that the IUCN Standard can be used as an overarching framework for NbS in river flood management and the difference in characteristics (Section 4.3) may also be valid for frameworks for broader hydro-meteorological risk reduction in other environments.

Only seven of the 29 selected frameworks address societal challenges beyond hydro-meteorological risk reduction. Consequently, comparing the IUCN Standard with assessment frameworks targeting other societal challenges mentioned within it (e.g., food security or economic development) could yield additional insights into its overarching applicability to these challenges. For evidence on both aspects (broader application in hydro-meteorological risk reduction and targeting other societal challenges), further research is needed.

5.4. Connection with the UN Sustainable development Goals (UN-SDG's)

The IUCN Standard has a straightforward connection to the UN SDG's in the 2030 Agenda (UN General Assembly, 2015), through indicator 8.3, which evaluates whether a project has identified relevant national and global targets (e.g. UN SDGs) and whether the contribution to these targets is reported to the relevant platforms (e.g. UN). The SDG's are globally important goals for peace and prosperity for people and planet. Since NbS can contribute to the UN SDG's (possibly increasing the well-being of people which might be specifically interesting for low and middle income countries), it is important that an overarching framework assess the connection therewith. Of the 29 other frameworks reviewed, three refer to the UN SDGs, though with no explicit link, and six incorporate the connection or contribution of the project to the SDGs within the assessment procedure (see also Supplementary Material 1).

6. Conclusion

This study evaluated the applicability of the IUCN Global Standard for Nature-based Solutions (NbS) as a comprehensive assessment framework and compared it with 29 other frameworks focused on riverine flood risk reduction. The findings indicate that the IUCN Standard stands out due to its extensive scope, making it suitable as an robust starting point as overarching framework for diverse NbS projects. This applies to planned, ongoing and completed riverine NbS projects. The IUCN Standard's process-oriented nature enables it to effectively assess project processes, such as stakeholder engagement and adaptive management for river management context but possibly also across various other environmental contexts and societal challenges. The common grouping of terms provided in the IUCN Standard may increase the ease of communication between people working on NbS and contribute to the development of the NbS concept.

The Standard is unable to evaluate project results. Integrating the Standard with a results-based framework would effectively assess both the process and outcomes of an NbS project, enhancing project performance and supporting the advocacy for NbS implementation.

Despite its broad applicability and straightforward use, the IUCN Standard has notable limitations. It lacks specificity in addressing particular environmental contexts and provides limited guidance on resources for assessment. These areas require enhancement to fully meet the needs of practitioners and policymakers working on NbS projects.

Overall, while the IUCN Global Standard offers a robust starting point for assessing NbS processes, further refinements are necessary to improve its environmental context specificity and depth of guidance. Future research should focus on addressing these gaps and exploring the Standard's applicability in more diverse and specific environmental settings. This will ensure that the IUCN Standard not only serves as a comprehensive framework but also meets the nuanced needs of varied NbS initiatives worldwide.

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CRediT authorship contribution statement

Maikel Berg: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Chris J. Spray:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Astrid Blom:** Writing – review & editing, Supervision, Funding acquisition. **Jill H. Slinger:** Writing – review & editing, Conceptualization. **Laura M. Stancanelli:** Writing – review & editing. **Yvo Snoek:** Writing – review & editing. **Ralph M.J. Schielen:** Writing – review & editing, Visualization, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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