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The IUCN Global Standard for Nature-based Solutions™ as a tool for enhancing the sustainable development of marine aquaculture

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This paper applies the IUCN Global Standard for Nature based Solutions™ self-assessment tool (published in 2020) to two aquaculture case studies. Data from the case studies were compiled by the authors. In Zanzibar, secondary data were obtained through a previous project, which included a stakeholder workshop in Zanzibar (in 2019) and one deliverable published by the IUCN on Zanzibar of their catalogue "Aquaculture and Marine Conservation". In Indonesia, the original data were provided by the Blue Natural Capital Funding Facility (BNCFF) and the associated local teams. The analysis of the data, the information provided, and the scoring itself were done by the authors, in association with local teams in both areas. The results of the two assessments, discussed in the paper and presented in detail in the Supplementary materials, can be considered original research, never previously published in a scientific journal. The concept of Nature-based Solutions (NbS) was proposed by the International Union for Conservation of Nature (IUCN) to protect, restore, and sustainably manage natural and modified ecosystems for achieving a variety of societal benefits. The IUCN released the IUCN Global Standard for NbS™ to help design, assess, strengthen, and upscale NbS interventions. In the current context of growing uncertainties for the future of coastlines and oceans, aquaculture has been recognized as a positive activity for achieving sustainable development in coastal communities; supporting food security, poverty alleviation, and economic resilience; and contributing to the conservation of marine ecosystems in some cases. However, the sustainability of aquaculture systems has often been criticized. Aquaculture initiatives in coastal areas can achieve both nature conservation and sustainable development objectives, but reflection on the conditions under which this would happen is needed. This article examines aquaculture systems through the lens of the NbS concept and the IUCN Global Standard for NbS™, along with other sustainability concepts and instruments currently used in the context of aquaculture. The application of the IUCN Global Standard for NbS™'s to two case studies is explored: seaweed farming in Zanzibar in marine conservation areas and shrimp farming coupled with mangrove restoration in Indonesia. The results show that the NbS concept underpinning the IUCN Global Standard for NbS™ could help in the overall assessment of aquaculture systems and improve their sustainability by highlighting both their positive outcomes and issues requiring further examination in relation to marine biodiversity benefits, socio-economic development, and/or governance. The IUCN Global Standard for NbS™ could provide an operational framework to implement existing concepts, such as the Ecosystem Approach to Aquaculture, contribute to clarifying critical issues in aquaculture development, and provide guidance for the development of a new type of aquaculture project, specifically designed as NbS. This finding advocates the context-dependent exploration and promotion of aquaculture projects as NbS.

KEYWORDS

Nature-based Solution (NBS), IUCN Global Standard for NbS™, Ecosystem approach to aquaculture (EAA), sustainable mariculture, coastal social ecological system

1 Introduction

Climate change and biodiversity crises are looming (Crutzen and Stoermer, 2021; Steffen et al., 2015; Ripple et al., 2017; IPBES, 2019; IPCC, 2022). The Intergovernmental Panel on Climate Change (IPCC) (Pörtner et al., 2019) and the United Nations (United Nations, 2021a; United Nations, 2021b) are warning of the impacts of climate change on ocean and coastal ecosystems and their consequences on coastal populations. In total, 23% of the world's population is concentrated in coastal areas, which are deemed particularly vulnerable to climate change effects and biodiversity losses (Goussard and Ducrocq, 2017) and whose populations are particularly reliant on seafood production, fisheries, and aquaculture for their present and future food supply and security (Salz and Macfadyen, 2007; Barange et al., 2018; Costello et al., 2020). In addition, significant deoxygenation is occurring in deep seas and coastal waters, further threatening the future of marine systems, both socially and ecologically (Laffoley and Baxter, 2019; United Nations, 2021a; United Nations, 2021b). As a result, conserving oceans is now urgent (Laffoley and Baxter, 2016; Le Gouvello et al., 2017; Laffoley and Baxter, 2019), as is the adaptation of coastal social-ecological systems to respond to these growing threats.

Global fish production from aquaculture and fisheries peaked at approximately 178 million tons in 2020, with aquaculture representing 49% (88 million tons) of the total fish volumes (FAO, 2022). Approximately 1/3 of marine fish stocks remain listed as overfished. As the world's population is expected to reach 9.7 billion by 2050, global fisheries will continue to be under pressure to meet future demands for seafood (UnitedNations, 2015). Attention is increasingly turning to aquaculture as a key factor in meeting this shortfall, given its impressive continuing growth to supply fish for human consumption. It is estimated that edible food from the sea could increase by 21–44 million tons by 2050 (+36–74% compared to current yields), with a major increase in the potential of marine aquaculture (Costello et al., 2020), although there have been words of caution over such aquaculture "over-optimism" and its potential consequences (Sumaila et al., 2022).

Aquaculture plays an important role in the sustainable development of coastal communities, contributing to food security, poverty alleviation, and economic resilience, while enhancing marine ecosystem services in some cases, such as carbon sequestration, nutrient mitigation, and habitat creation (Alleway et al., 2018; Custódio et al., 2019). Sustainable aquaculture can also contribute to the Sustainable Development Goals (SDGs) (Hambrey, 2017; Brugere et al., 2018; Troell et al., 2023 (in press)). However, over the past decades, questions around the poor sustainability of some aquaculture systems have been frequently raised (Soto et al., 2012; Edwards, 2015; Alleway et al., 2018; Aubin et al., 2019), as aquaculture's rapid growth has also been dampened by significant negative environmental impacts, leaving social and economic conflicts in its wake in some parts of the world (Alleway et al., 2018). While ecosystem-based approaches to aquaculture development have gained momentum in responding to these challenges, it could be accelerated if regulatory impediments and management constraints were lifted, and if a thorough economic valuation of the ecosystem services provided by aquaculture systems was undertaken (Alleway et al., 2018). Aquaculture can support marine and coastal conservation and local community resilience under some conditions and situations (Le Gouvello et al., 2017). This indicates the complementarity between nature conservation and sustainable development while implementing aquaculture projects in marine areas, therefore requiring further examination of the conditions enabling their mutual and reciprocal benefits.

NbS are defined by the IUCN as "actions to protect, sustainably manage, and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016). NbS are gaining momentum around the world, given their potential to address today's major societal challenges. In coastal areas for example, NbS interventions, such as a combination of restoration of wetlands, marshes, and dune systems and the creation of protected areas, are being deployed to address coastal erosion, risk of submersion, and marine biodiversity loss (Bauduceau et al., 2015; Châles et al., 2022; O'Leary et al., 2022). While the conceptual and operational frameworks for NbS are being adopted and show promise in coastal, urban, and agricultural systems (Nesshöver et al., 2017; Raymond et al., 2017; IUCN, 2020b), they have very rarely been considered in the case of aquaculture systems. In principle, the NbS concept and the IUCN Global Standard for NbS™ could support the sustainable development of aquaculture, within "blue economy" goals (Hughes, 2021). le Gouvello et al. (2022) reviewed the NbS concept and the IUCN Global Standard for NbS™ in relation to existing and prevailing sustainability concepts and approaches for aquaculture. Riisager-Simonsen et al. (2022) analyzed their potential in marine interventions including aquaculture (Riisager-Simonsen et al., 2022). All these authors concur on the complementarity of the NbS concept and the IUCN Global Standard for NbS™, with existing approaches aimed at making aquaculture more sustainable. Le Gouvello et al. (2022) further argued that the IUCN Global Standard for NbS™, which has emerged out of discussions around the operationalization of the NbS concept, could even enhance potential synergies between aquaculture and marine conservation.

This paper further unpacks how the IUCN Global Standard for NbS™ can steer marine aquaculture development toward greater sustainability while simultaneously supporting marine conservation and coastal communities' resilience to climate change. To do this, it uses: 1) a semi-review of how the IUCN Global Standard for NbS™ criteria apply to social-ecological systems, incorporating aquaculture and the challenges that it raises (Section 2), and 2) a practical test application of the IUCN Global Standard for NbS™ in cases of seaweed farming in the Zanzibar archipelago (IUCN, 2020c) and the Kalimantan Mangrove Shrimp Program (KMSP) in Kalimantan, Indonesia (BNCFF, unpublished) (Section 3). Section 4 discusses the findings, including future research questions. Section 5 concludes. While this paper discusses the links between NbS and aquaculture, it does not attempt to demonstrate that aquaculture is an NbS since data is still lacking to do so robustly.

2 The IUCN Global Standard for NbS™ applied to aquaculture

2.1 Eight criteria and a self-assessment tool

The NbS concept has been actively promoted by the IUCN since 2009 as a new approach to achieving sustainable development (Eggermont et al., 2015; Cohen-Shacham et al., 2016; Cohen-Shacham et al., 2019). In 2020, the IUCN launched the IUCN Global Standard for NbS™, with a set of eight interconnected criteria and their associated indicators, to help design, assess, implement, strengthen, and upscale NbS interventions (IUCN, 2020a) (Table 1).

Each of the eight criteria has a set of 3-5 associated indicators, totaling 28 (Table 1) (IUCN, 2020a; IUCN, 2020b). The IUCN Global Standard for NbS™ also proposes a self-assessment tool, currently in an Excel computation tabular format, with a 4-level scoring system for each indicator: 'Insufficient' (red); 'Partial' (orange); 'Adequate' (light green); 'Strong' (dark green). The scoring must be justified in the 'Rationale' column. Links to relevant references, publications, and data sources must be provided in the 'Means of verification' column. The scores obtained are then aggregated and a final evaluation of the overall adherence of the assessed intervention to the IUCN Global Standard for NbS™ is provided through a table and a radial diagram.

Some assessed interventions may end up with one or several criteria having an insufficient score, in which case, they are not considered in adherence with the IUCN Global Standard for NbS™. However, this self-assessment tool is not intended for certification but to help define how an intervention can be improved to more closely match NbS criteria. In the following sections, each criterion is reviewed in the context of marine aquaculture. We highlight and discuss specific issues that need to be scrutinized or that could contribute to aquaculture systems for these to be considered an NbS and meet the IUCN Global Standard for NbS™ criteria.

2.2 What is aquaculture's relevance to key societal challenges?

Criterion 1 of the IUCN Global Standard for NbS™ requires the identification of the specific societal challenge(s) that an intervention is addressing, of the seven proposed by Criterion 1 (Table 2). Identifying the societal challenges to address may bring new perspectives to aquaculture developments or interventions, as well as raising debate over prioritization and benefits. The effects of aquaculture regarding the listed IUCN societal challenges can be positive or negative. For instance, how aquaculture development can best fulfill its promise in terms of contribution to food security and economic growth (Costello et al., 2020) requires reconsideration of the assumptions behind its continued growth and, therefore, also the type of aquaculture that needs to be promoted to address specific societal challenges (Sumaila et al., 2022). Another example is that of climate mitigation and adaptation, which may require specifically-designed aquaculture systems (Hughes, 2021), such as a "climate-smart aquaculture" system (Dabbadie et al., 2018; Soto et al., 2018; Galappaththi et al., 2020) that is also oriented toward improved community well-being (Campbell et al., 2021), or one that pays greater attention to human rights and the labor rights of its workers (Brugere et al., 2023) for it to be considered as satisfying Criterion 1.

TABLE 1 The eight criteria of the IUCN Global Standard for Nature-based Solutions™ and some keywords from each of the 28 indicators (for indicators' full titles and explanations, see IUCN (2020a and 2020b).

The criteria of the IUCN Global Standard for Nature-based Solutions™	
Criterion 1	NbS effectively address societal challenges (Societal challenges)
	1.1 Identification and prioritization of societal challenges
	1.2 Documented societal challenges
	1.3 Identified human well-being outcomes
Criterion 2	Design of NbS informed by scale (Design at scale)
	2.1 Interactions between economy, society, and ecosystems
	2.2 Complementarity and synergies
	2.3 Risk identification and management
Criterion 3	NbS result in a net gain to biodiversity and ecosystem integrity (Biodiversity net gain)
	3.1 Ecosystem state and drivers of degradation and loss
	3.2 Biodiversity conservation outcomes
	3.3 Unintended adverse consequences
	3.4 Enhancement of ecosystem integrity and connectivity in NbS strategy
Criterion 4	NbS are economically viable (economic feasibility)
	4.1 Direct and indirect benefits and costs
	4.2 Cost-effectiveness study
	4.3 Alternative solutions to test effectiveness
	4.4 Resourcing options
Criterion 5	NbS are based on inclusive, transparent, and empowering governance processes (Inclusive governance)
	5.1 Grievance resolution mechanism
	5.2 Indigenous people involvement
	5.3 Stakeholders identification and involvement
	5.4 Stakeholders involvement in decision making
	5.5 Decision-making beyond jurisdictional borders
Criterion 6	NbS equitably balance trade-offs between the achievement of their primary goal(s) and the continued provision of multiple benefits (Balance trade-offs)
	6.1 Costs and benefits of associated trade-offs
	6.2 Rights, usage of, and access to land and resources
	6.3 Periodic review of safeguards
Criterion 7	NbS are managed adaptively, based on evidence (adaptive management)
	7.1 NbS strategy
	7.2 Monitoring and evaluation plan
	7.3 Framework for adaptive management
Criterion 8	NbS are sustainable and mainstreamed within an appropriate jurisdictional context (sustainability and mainstreaming).
	8.1 Information sharing for transformative change
	8.2 Policy, regulations, and laws
	8.3 National and global targets

2.3 Are aquaculture systems informed by scale

The "Ecosystem Approach to Aquaculture" (EAA) has long been recognized as the scientific basis for sustainable aquaculture (Soto et al., 2008; IUCN, 2009). Ecosystem-based Approaches are incorporated under the NbS umbrella (Cohen-Shacham et al., 2016; Cohen-Shacham et al., 2019). A direct link exists between the requirement of NbS Criterion 2 for informing scales and interactions in the design of NbS and the EAA's defined scales (i.e., the aquaculture farm, the water body in which the farm is located, and the watershed/aquaculture zone), over which regional, national, global, and market-trade scales are imposed (Soto et al., 2008). Some recent tools for spatial planning of aquaculture, such as the establishment of aquaculture management zones and/or Allocated Zones for Aquaculture (AZAs) are now proposed for the implementation of EAA and, thus, could specifically inform Criterion 2 of the Global Standard for NbS™ (Brugere et al., 2010; Aguilar-Manjarrez et al., 2017; Gimpel et al., 2018; Lester et al., 2018; le Gouvello et al., 2022).

2.4 Is aquaculture contributing to a net gain in biodiversity and ecosystem integrity

Nowadays, most sustainable aquaculture developments aim at having as little environmental impact as possible, based on robust Environment Impact Assessments (EIA) conducted using the EAA (Troell et al., 2013). Such assessments should be carried out considering various spatial and temporal scales, including far-field and near-field effects and short-, mid-, and long-term effects (Ottinger et al., 2016; Weitzman et al., 2019). However, the NbS Global Standard for a net biodiversity gain (Criterion 3) goes beyond the first requirement to pass the EAA and to reduce negative impacts, since it clearly states that "a positive net gain on biodiversity and ecosystem integrity must be achieved and demonstrated to validate the NbS", referring to the Ecosystem Services (ES) concept. While aquaculture provisional services are straightforward to value in monetary terms, others are more difficult to quantify and are typically under-valued, even though they are often badly impacted by aquaculture itself (Muir et al., 1999). Stronger or more robust methods of assessing the biodiversity gain of aquaculture are under development (Filgueira et al., 2015; Le Gouvello et al., 2017; Alleway et al., 2018; Aubin

TABLE 2 Examples of the potential ways in which aquaculture development could address or have a negative impact on societal challenges.

IUCN Societal challenges addressed by NbS in Criterion 1	Potential positive contributions related to aquaculture development	Potential negative impacts related to aquaculture development
Climate change mitigation and adaptation Disaster risk reduction,	Positive functions associated with aquaculture are now evidenced by seaweed and shellfish farming in climate change mitigation (Craig, 2022). Some species of algae are very effective in reducing methane emissions from ruminants (Alleway, 2023). Shellfish reefs could help reduce submersion risks (Smaal et al., 2019).	Mangrove degradation by shrimp farming in coastal areas has significantly contributed to impairing their capacity to buffer against climate-induced disasters (tsunami, storms, etc.) and reduce their carbon absorption function for climate change mitigation (Barbier et al., 2008; Queiroz et al., 2013; Troell et al., 2013; Davies et al., 2019).
Economic and social development Human health Food security	Aquaculture production typically contributes to food security, economic social development, and human health (Stentiford et al., 2020; FAO, 2022).	Large quantities of seafood produced in emerging countries (from fisheries and aquaculture) are exported to rich industrialized countries (Gephart and Pace, 2015; Watson et al., 2017; FAO, 2022), depriving local access and rights to healthy food (FAO, 2003) and degrading local livelihoods (Belton et al., 2018).
Water security	The potential role of earthen aquaculture ponds in addressing water scarcity needs to be further investigated (Aubin et al., 2019).	Freshwater aquaculture requires large volumes of freshwater that can affect water quality and water security in inland areas, where fish farming is practiced on large scales (Troell et al., 2013; Aubin et al., 2014; Aubin et al., 2019).
Environmental degradation and biodiversity loss	Positive effects of aquaculture production on biodiversity are documented (Mascorda Cabre et al., 2021; Theuerkauf et al., 2021; Bridger et al., 2022). Aggregations of transient and resident fish and marine mammals are observed around open sea cage facilities (Dempster et al., 2006; IUCN, 2021). Aquaculture offshore platforms could be assimilated by Other Effective area-based Conservation Measures (Le Gouvello et al., 2017; IUCN-WCP, 2019; Appiott et al., 2021) as demonstrated in a mussel farm in the UK (Bridger et al., 2022).	Examples of biodiversity degradation are numerous. Mangrove degradation caused by shrimp farming in coastal areas has significantly contributed to biodiversity loss (Barbier et al., 2008; Queiroz et al., 2013; Troell et al., 2013; Davies et al., 2019). Sea-cage systems have often been considered very detrimental to surrounding ecosystems, in particular, to Posidonia seagrass fields in the Mediterranean regions (Bolognini et al., 2019) or to benthic flora and fauna in Scottish lochs (Mente et al., 2010; Bloodworth et al., 2019).

et al., 2019; Custódio et al., 2019; Smaal et al., 2019; Weitzman, 2019; Theuerkauf et al., 2021; Bridger et al., 2022; le Gouvello et al., 2022). The level at which Criterion 3 is met by an aquaculture intervention would largely depend on the type, species, and farming practices that the aquaculture system involves. Some types of aquaculture production (e.g., integrated multitrophic aquaculture) and cultivation of extractive species (e.g., low trophic species, algae, and certain bivalves) can have a direct positive effect on strengthening not only the provision of ES but also regulating and supporting services and, potentially, cultural services. Initiatives of "restorative mariculture", which associate seaweeds and/or shellfish cultivation in opened water systems are emerging, indicating natural habitat benefits for other wild species (Theuerkauf et al., 2021).

2.5 What is the economic viability of aquaculture operations

Economic viability is a prime concern for aquaculture producers and is integral to the sustainability of their operations. However, as proposed by Criterion 4's indicators, economic viability and feasibility assessment must rely on the critical evaluation of how economic benefits are obtained and shared among the stakeholders involved. NbS Criterion 4 brings up the discussion of what may be considered a truly viable economic aquaculture system that considers social issues (Hughes, 2021), although the terms "inclusiveness" and "equity" are not explicitly mentioned in the Criterion's indicators. Criterion 4 also implies that positive and negative externalities must be fully identified and measured despite the difficulty of doing so due to insufficient economic data, in particular at a sub-national level (Mikkelsen et al., 2021). This also means going beyond conventional micro- and macro-economic and financial indicators (e.g., gross and net incomes, accountable added value, and Gross Domestic Profit (Costanza et al., 2016)). Yet, indicators reflecting social benefits and people's well-being in the context of aquaculture are seldom used, in the large part because our understanding of the human and social dimensions of aquaculture, and the extent to which the sector can contribute to greater equity, human rights, and well-being is considerably lagging behind (Brugere et al., 2021; Brugere et al., 2022; Brugere et al., 2023 (in press)). Ongoing studies are addressing the choice of relevant social and economic indicators (Krause et al., 2020; Mikkelsen et al., 2021), sustainable aquaculture value chains (Bush et al., 2019a), gender issues (Kruijssen et al., 2018), the development of inclusive business models in aquaculture (Kaminski et al., 2020), Community-based or Community-oriented Aquaculture (Bradford, 2017; Ateweberhan et al., 2018; Campbell et al., 2021), and policy coherence and benefit sharing for greater equity in aquaculture development (Brugere et al., 2021) – all of which are central to the future sustainability of aquaculture and to meet the SDGs (Hambrey, 2017; Brugere et al., 2018; Eriksson et al., 2018). They could all help assess economic viability as defined by Criteria 4, along with complementary tools to broaden the economic analysis to encompass equity issues in aquaculture, such as the equity diagnosis evaluation tool for mariculture developed by (Eriksson et al., 2018).

2.6 Are aquaculture governance systems inclusive, transparent, and empowering

Many failures in the development of aquaculture and associated detrimental effects on surrounding social-ecological systems have been associated with a lack of solid governance systems and appropriate regulations (Brugere, 2006; Davies et al., 2019) a situation that could make critical the adherence to the Criterion 5 (Inclusive governance). For example, conflicts are even more prevalent in coastal areas, where there are variety of practices, multiple types of rights, contested accesses and weak institutions influences (Brugere, 2006; IUCN, 2007). Local communities have also been disconnected from local aquaculture development (Krause et al., 2015) and numerous examples exist of poor acceptability of aquaculture developments in local communities, owing to a lack of dialog between aquaculture producers, shareholders, and other stakeholders (Vince and Haward, 2017; Mather and Fanning, 2019; Raux et al., 2020; Brugere et al., 2023 (in press)) and insufficient consideration of "social license" and "social acceptability" by the aquaculture industry (Baines and Edwards, 2018; Mather and Fanning, 2019). To date, the uptake of integrated coastal management (ICM) to address sustainable coastal development and adaptation objectives has not met expectations (Stephenson et al., 2019), nor has aquaculture been able to take its real position in ICM initiatives. For marine aquaculture development to comply with Criterion 5, the activity needs to be seen as an integral part of the wider coastal social-ecological system within which it is embedded (Soto et al., 2012; Brugere et al., 2018).

The participation and integration of all aquaculture actors within a broader governance system, as part of improved governance, has been investigated and demanded for decades (Rey-Valette et al., 2008; Soto et al., 2008; Brugere et al., 2010; Lazard et al., 2014; Brugere et al., 2018; Jolly et al., 2022). Improved governance is also required for the development of aquaculture on larger scales (Davies et al., 2019; Costello et al., 2020) as well as on a community level (Bradford, 2017; Ateweberhan et al., 2018). However, governance situations vary from one area to another depending on national political and administrative systems and the organization of value chains (Bush et al., 2019b). Therefore, characteristics of inclusiveness, transparency, and empowerment in aquaculture governance, as laid out in Criterion 5, will depend on the context (type of aquaculture, institutions and policies in place, organization of the sector, etc.) and will need to be assessed on a case-by-case basis.

2.7 To what extent does aquaculture enable equitably balancing trade-offs between the achievement of their primary goal(s) and the continued provision of multiple benefits

Constraints associated with complex systems make trade-offs (in policies, space, time, benefits, etc.) inevitable, and the equitability of these trade-offs is dependent on how decisions are made (Hughes, 2021), i.e., on "good governance" (Cf. Criterion 5). Addressing Criterion 6 is likely to be challenging for all stakeholders involved in a potential NbS-aquaculture intervention. The IUCN provides guidance (IUCN, 2020b) on the data and tools that can be used to provide evidence on the equitability of trade-offs (Table 1) and to identify necessary safeguards or corrective actions. Answering Criterion 6 may therefore require specific investigations to be conducted on a case-by-case basis.

2.8 Does aquaculture enable adaptive management

The promotion of the adaptative management (Criterion 7) and adaptative capacity of aquaculture systems was embedded in the EAA (Soto et al., 2008; IUCN, 2009). Adaptive management has since been applied in the context of specific aquaculture systems but would require further exploration. For instance, participatory and iterative consultations involving adaptive management based on a "conception loop" involving the wide aquaculture stakeholder community (local communities, local authorities, regional and national representatives of the sector, value chain actors, non-profit and non-governmental organizations, etc.) were introduced in various aquaculture projects and enabled the design and adoption of corrective actions to manage risks and make the system move on an adaptive and progressive trajectory (Aubin et al., 2019). Risk identification and risk management cut across the evaluations proposed in Criteria 2, 6, and 7.

2.9 Is aquaculture sustainable and mainstreamed within an appropriate jurisdictional context

Aquaculture as a sector often straddles administrative jurisdictions and different ministries with their own laws and policies, which results in both gaps and complexity in the legal frameworks for the sector. This situation has significantly impaired its development in many places (IUCN, 2009; Cavallo et al., 2020; Cavallo et al., 2021). Consequently, the extent to which aquaculture-related policies are integrated within a broader policy context needs to be considered to assess the compliance of aquaculture systems with Criterion 8. The existence and the development of aquaculture systems must be considered in accordance with various planning tools, policy instruments dealing with water, ocean, and coastal management; natural resources management; SDGs; and international and national policies (Macias et al., 2019; le Gouvello et al., 2022).

3 Applying the IUCN Global Standard for NbS to case studies in Zanzibar and Indonesia

Two case studies were selected to explore the application of the IUCN Global Standard for NbS™ in the context of aquaculture: one of a seaweed farming system in East Africa, and one of a shrimp farming system in Southeast Asia. The intention was to assess the extent to which these forms of aquaculture comply with the Global Standard's criteria but not to compare them, given their different locations and contexts. These two case studies use data from published or unpublished works in which the authors were involved (IUCN, 2020c; BNCFF, unpublished) as a primary source for testing the self-assessment tool of the IUCN Global Standard for NbS™ (IUCN, 2020b) in its first application to aquaculture systems. The scoring itself was conducted by the authors and locally associated teams. COVID-19 restrictions prevented the implementation of the scoring exercise with local stakeholders.

3.1 Could seaweed farming in Zanzibar qualify as an NbS according to the IUCN Global Standard for NbS™?

3.1.1 Description of the social-ecological system involved in Zanzibar

The first social-ecological system examined was located in the Zanzibar archipelago, in the Indian Ocean, as a semi-autonomous territory, under the authority of the Revolutionary Government of Zanzibar (RGoZ), forming a political union within the United Republic of Tanzania (Lange, 2015; Khamis et al., 2017; Hugé et al., 2018; IUCN, 2020c). The Zanzibar economy is largely based on tourism (accounting for 35% of Gross Domestic Product, GDP), fisheries and aquaculture, spices, and raffia.

Zanzibar is the main producer of seaweed in East Africa (103,200 t in 2018 in Tanzania wet weight) (FAO, 2020). Seaweed farming was introduced from the Philippines in 1989 (Lange and Jiddawi, 2009; Hedberg et al., 2018; IUCN, 2020c). It is practiced mostly by women in intertidal zones and close to mangrove forests and coral reefs. It is an extensive form of artisanal aquaculture, with low inputs. The sun-dried seaweeds are collected in the villages and exported to Europe by a few export traders, with little or no local value addition. The seaweed sector has helped raise the economic status of rural women, given its significant role in contributing to the provision of ecosystem services (e.g., income), as identified by Lange and Jiddawi (2009), and has led to positive impacts on the quality of life in coastal communities (Lange and Jiddawi, 2009; Valderrama et al., 2013; Lange, 2015; Ateweberhan et al., 2018; IUCN, 2020c). These benefits have, however, been disputed (Bryceson, 2002), most notably because of the negative impacts that seaweed farming has on women's health (Fröcklin et al., 2012; Brugere et al., 2020b). Furthermore, the international market is very competitive, and difficulties in accessing it are compounded by the lack of organization of women seaweed producers and the strong bargaining power of seaweed buyers. Higher-valued cultivated species *Kappaphycus alverezii* (commercially known as 'Cottonii') have been suffering from the impacts of climate change (through higher water temperature and variations in salinity), while the production of lower-valued species (*Euchema denticulatum*, commercially known as 'Spinosum') that constitutes the bulk of production and exports is earning little income for farmers (Msuya et al., 2007; Brugere et al., 2019). Consequently, the production of seaweed has been declining over the past years and does not look as attractive and does not look as attractive to coastal communities as it used.

The islands of Zanzibar are experiencing rapid changes, with population growth, immigration, urbanization, growing tourism, and the increasing demand for fisheries increasing demand for fisheries, agricultural and forestry products. This situation is resulting in higher pressures on coastal ecosystems and marine resources, impairing the overall resilience of the population in coastal areas, which are already affected by climate change. In response to these threats, the Revolutionary Government of Zanzibar has promoted the establishment of multiple-use marine protected zones known as Marine Conservation Areas (MCAs) since the early 1980s (IUCN, 2020c). Approximately 80% of the seaweed production in Zanzibar is practiced in these conservation areas. Zanzibar MCAs aim at protecting critical marine habitats while enhancing sustainable artisanal fisheries and mariculture and their practices. However, effective management of these MCAs remains a challenge. The Revolutionary Government of Zanzibar has recently embarked on the development of a blue economy strategy, in which the importance of such seaweed production for coastal communities is acknowledged (RGoZ, 2020). Seaweed farming in Zanzibar is embedded in the overall management concept of marine conservation, blue growth, blue economy, integrated coastal management, and marine spatial planning in Zanzibar.

3.1.2 Assessment of the case in Zanzibar

We summarise here the original findings from the detailed assessment of the 'Seaweed farming in Zanzibar' against the eight criteria of the IUCN Global Standard for NbS™. The assessment and case study analysis were carried out based on inputs from the authors and other IUCN NbS team members (unpublished data, Supplementary materials) and were complemented by secondary information (Brugere et al., 2019; Brugere et al., 2020a; Brugere et al., 2020b; IUCN, 2020c) collected prior to and during the COVID-19 pandemic (2020-2021). The self-assessment tool Excel scoring system was used (IUCN, 2020b). The overall results are presented in Table 3 and the full results are presented in the Supplementary Materials.

The results (Table 3) indicate that the strengths of Seaweed farming in Zanzibar, as an NbS, are in addressing key social challenges (Criterion 1; 44% adherence), its scalability potential (Criterion 2; adherence of 44%), its economic feasibility (Criterion 4; adherence of 42%), and its overall sustainability policy framework (Criterion 8; 44%). These are nonetheless rather moderate scores (<50% adherence), which indicate room for improvement. For instance, better economic viability (Criterion 4) could be expected if more added value was generated through post-harvest activities favored in this aquaculture value chain, such as locally processing seaweeds for use in cosmetics or food products. Local women have started producing artisanal soap made with seaweed and plants, which is sold to tourists (IUCN, 2020c), but this is still embryonic. The degree of inclusiveness of the current aquaculture business

TABLE 3 Overall result of the assessment of Zanzibar seaweed farming, according to the IUCN Global Standard for NbS™'s self-assessment tool (results were discussed and refined with the NbS IUCN team).

Criterion	Criterion Score	Maximum Criterion Score	Normalized criterion	FINAL OUTPUT Overall adherence (%)
1. Societal challenges	4	9	0.44	44
2. Design at scale	4	9	0.44	44
3. Biodiversity net-gain	2	12	0.17	17
4. Economic feasibility	5	12	0.42	42
5. Inclusive governance	5	15	0.33	33
6. Balance trade-offs	2	9	0.22	22
7. Adaptive management	3	9	0.33	33
8. Sustainability and mainstreaming	4	9	0.44	44
Total				40

Legend:

Key				Output
(dark green)	4	≥75	Strong	Intervention adheres to the IUCN Global Standard for NbS.
(light green)	3	≥50 & <75	Adequate	
(orange)	2	≥25 & <50	Partial	
(red)	1	<25%	Insufficient	Intervention does not adhere to the IUCN Global Standard for NbS.

model is also questionable (Eriksson et al., 2018; Kaminski et al., 2020; Brugere et al., 2021), in particular with regard to the benefits drawn by women seaweed farmers as most of the benefits are shared among a limited number of actors, i.e., the traders and export agents. The up-scaling potential (Criterion 2) of such a solution must therefore be carefully considered, as seaweed farming very much depends on external drivers such as export markets. Local tourist-based markets driving demand for seaweed-based products may also be risky, given the potential negative impacts on the Zanzibari social-ecological system that may result from excessive touristic local developments (Benansio et al., 2016).

Two of the criteria were scored overall as "Insufficient" (in red) for Biodiversity and Trade-offs (Criteria 3 and 6: 17% and 22% adherence respectively). The biodiversity net gain criterion is evaluated with a very low score, as no clear evidence of biodiversity monitoring was provided in the secondary data used. Actions to improve aspects referred to by this criterion could include the establishment of adequate measures to reduce, control, and mitigate any negative impacts of seaweed farming on biodiversity (including seagrass beds) and to reduce waste (IUCN, 2020c). Similarly, information was lacking to provide evidence for equitable trade-offs.

The governance and adaptative management criteria (Criteria 5 and 7 respectively, both with 33% adherence) also scored low, partly because of the top-down nature of the governance system, monitored by the national and local authorities, and under-representation of key stakeholders, such as the women seaweed farmers and local communities, at various governance levels.

This first assessment of seaweed farming in Zanzibar, as an NbS, clearly places this solution in the "partial" scoring group, with 40% adherence to the IUCN Global Standard for NbS™ (Table 3). Among the eight criteria's 28 associated indicators, eight (28%) of them would need to be further discussed and rationalized. According to the IUCN Global Standard for NbS™ guidance, the scoring of any one criterion as "Insufficient" would disqualify an intervention as NbS (IUCN, 2020b). Such a lack of adherence with the IUCN Global Standard for NbS™, however, would seem here unduly severe and should prompt further investigation and validation of the IUCN Global Standard for NbS™ self-assessment tool on the one hand, as well as further investigation on the ground and validation by local stakeholders on the other. It would be even more necessary that the assessment's results reflect a situation at a particular moment in time. The institutional context has evolved since the COVID-19 pandemic (2020-2021), notably with the acknowledgment of the importance of seaweed farming for socio-economic development and gender equality in the government's recent Blue Economy strategy (RGoZ, 2020), and this would need to be accounted for. Thus, the proposed operational framework provided by the IUCN Global Standard for NbS™ may help to generally improve the seaweed farming sector in Zanzibar to address sustainable development challenges, while identifying corrective actions and, thus, consolidating the positioning of seaweed farming in Zanzibar.

Based on this case study, we may conclude that Zanzibar seaweed farming presents many assets to be considered as an NbS, enabling the provision of local income to coastal communities, while being integrated into the general management framework of marine conservation areas and the blue economy strategy (RGoZ, 2020). However, even in this case, which could seem rather straightforward at first glance, many questions would need to be further addressed to ensure that it is a true NbS.

3.2 Could shrimp farming coupled with mangrove restoration in Indonesia qualify as an NbS according to the IUCN Global Standard for NbS™?

3.2.1 Description of the social-ecological system involved in Indonesia

The second case study considers the Kalimantan Mangrove Shrimp Project (KMSP) implemented in the Sesayap River Delta in Kalimantan, Indonesian Borneo using SELVA SHRIMP, a zero input (no feed, no fertilizers, no antibiotics) and certified sustainable silvofishery model, which promotes mangrove restoration in shrimp ponds (BNCFF, unpublished). The initiative is privately managed by Blueyou, a Swiss seafood trading and consulting company, operating with a local partner in Indonesia to contract farmers, to process, to export shrimps, and to conduct mangrove restoration in a selected area.

This farming area of Tarakan, bordering central Borneo, is part of a global biodiversity hotspot (De Bruyn et al., 2014). It covers approximately 150,000 ha of mangrove habitat. The latter provides major ecosystem services (Arifanti et al., 2022) including provisioning services, climate mitigation, protection against disaster (submersion, erosion…), cultural services, and essential habitats for numerous species, including endangered species. Degradation of mangroves associated with shrimp farming has been well documented and remains a crucial environmental issue related to shrimp farming (Boone Kauffman et al., 2017). In addition, there is a common belief that mangroves negatively impact shrimp health in this Indonesian region, which makes it challenging for farmers involved in the KMSP.

Silvofishery practices in mangrove areas refer to extensive shrimp polyculture systems in ponds that include mangrove trees that can be situated in the farming area or integrated within the ponds, or that are adjacent to the ponds (Bosma et al., 2016). These farming models show promising results regarding mangrove state, shrimp yield productivity, and subsequent additional income for the farmers, although these practices need to be implemented carefully. The planned KMSP intervention will provide improved natural mangrove habitats for Black Tiger shrimp (*Penaeus monodon*) and other commercially important species, such as mud crab (*Scylla* spp.), thus increasing the yield of aquaculture products in the farming area (BNCFF, unpublished). The wild juveniles of these two commercial species are collected and trapped in farming ponds, and no other input is added and no other input is added to this simple low-tech system. According to the project manager, "mangrove forests are maintained and preserved in order to provide habitat and food for the animals that are raised in small channels and ponds within the forest".

Although still in its early stages, the KMPS project builds upon the successes of a similar intervention in Ca Mau province in Southern Vietnam, which encompasses 15,000 ha of silvofishery, for a production of 3,200 tons of Black Tiger shrimp (Bridson, 2013), conducted under the SELVA Shrimp program and based on three functional pillars: (1) improved market access and up-side value through Fair Trade, Aquaculture Stewardship Certification (ASC), and specific consumer marketing; (2) increased resilience and productivity of farms and ecosystems through reforestation of mangroves; and (3) facilitated funding for mangrove reforestation and monitoring of conservation efforts by third-party verification under the existing SELVA SHRIMP auditing scheme. In addition to increasing ecosystem resilience, it is anticipated that restored mangrove forest areas will provide the opportunity to access carbon offsets and Blue Carbon investment programs to finance further mangrove restoration and ensure the program's sustainability.

The KMSP local partner works closely with local, small-scale shrimp farmers encompassing approximately 30,000 ha of traditional ponds (*Tarakan*) situated in the delta. The project includes successive phases, with the first of these targeting 2,000 ha of the farming area producing 500 t of Black Tiger shrimp yearly (plus live mud crabs), with a mangrove reforestation potential of 400 ha (20% of total surface).

3.2.2 Assessment of Kalimantan Mangrove Shrimp Program in Indonesia

The evaluation of the KMSP as an NbS was conducted with the support of the Blue Natural Capital Funding Facility (BNCFF) (https://bluenaturalcapital.org/), which is managed by the IUCN and serves as a re-granting mechanism to support the development of financially sustainable investment opportunities based on blue natural capital (BNCFF, unpublished). Approximately four people were involved in the evaluation exercise, consisting of members of the Blueyou team, as well as IUCN NbS and BNCFF representatives.

The overall evaluation process of the KMSP project (see Supplementary Materials) according to the IUCN Global Standard for NbS™'s self-assessment tool revealed that the project adheres to most of the criteria, although weaknesses could be identified through the exercise (Table 4). This is primarily because the project is in its early stages and local data from the initiative are lacking. The level of adherence to each criterion varied from 33% on Adaptive Management (Criterion 7) to 56% each on Addressing societal challenges (Criterion 1) and Sustainability and mainstreaming (Criterion 8). Overall, the project score is 46%.

The societal challenges (Criterion 1; 56% of adherence) are multiple and are addressed under the overall umbrella of the SELVA SHRIMP program, e.g., improving livelihoods through higher incomes for farmers, and improving the ecological state of the mangrove, although progress could be made in collecting present and future information to monitor specific indicators.

Criterion 2, focusing on the upscaling potential and complemented by other types of solutions and risks (Criterion 2; 44% adherence), was demonstrated in the aforementioned Vietnamese project (Ca Mau) (Bridson, 2013). A similar implementation is anticipated in the KPSM project, with the first

TABLE 4 Overall result of the assessment of Kalimantan Mangrove Shrimp Program in Indonesia, according to the IUCN NbS Global Standard™'s self-assessment tool (results were discussed and refined with the BNCFF team).

Criterion	Criterion Score	Maximum Criterion Score	Normalized criterion	FINAL OUTPUT Overall adherence (%)
1. Societal challenges	5	9	0.56	56
2. Design at scale	4	9	0.44	44
3. Biodiversity net-gain	5	12	0.42	42
4. Economic feasibility	6	12	0.50	50
5. Inclusive governance	6	15	0.40	40
6. Balance trade-offs	4	9	0.44	44
7. Adaptive management	3	9	0.33	33
8. Sustainability and mainstreaming	3	9	0.56	56
Total				40

Legend:

Key				Output
(dark green)	4	≥75	Strong	Intervention adheres to the IUCN Global Standard for NbS.
(light green)	3	≥50 & <75	Adequate	
(orange)	2	≥25 & <50	Partial	
(red)	1	<25%	Insufficient	Intervention does not adhere to the IUCN Global Standard for NbS.

3-year phase project that targets 10% of the shrimp farming area, and will be up-scaled on the same basis. Biodiversity net gain (Criterion 3, 42% adherence) is a strong asset of the project as direct biodiversity benefits are purposely and specifically targeted through mangrove conservation and restoration tools. The underlying assumption here is that improved mangrove health and increased habitat will be associated with benefits for birds, reptiles, and other species, but robust local data (and appropriate funding) are needed to test this assumption.

The project scored 50% on the criterion related to economic feasibility (Criterion 4) due to its design seeking to increase the economic viability of shrimp farming in the target area. It is important to reemphasize that the assessment is based on the results obtained elsewhere, due to insufficient local evidence at this time. It is, however, anticipated that the organization of the KPMS project with local partners of the value chain, involving direct agreements with the farmers inspired by Fair Trade principles, would enable economic feasibility as well as some equity in the system. Other economic benefits may also be anticipated through blue carbon credits linked to mangrove restoration. These assumptions will be tested as data are generated by the project.

The project only scored 40% on Criterion 5, focusing on inclusive governance, reflecting a trend that can often be observed in aquaculture private projects (Bush et al., 2019b). The relatively low score for this criterion reflects the limited scope of the stakeholder engagement processes in the private sector. Direct stakeholders (shrimp farmers and the shrimp processing plant) were consulted and will continue to be engaged during the project. But other direct (middlemen, traders) or indirect (other representatives of the local communities, government officers, MPA managers, NGO representatives, etc.) stakeholders were not included, nor were their interests and concerns documented. Further, broadening stakeholder engagement would help the project identify marginalized groups who would benefit from inclusion in the project.

The project received a score of 44% (Partial) for Criterion 6 on Trade-offs. The project identifies and documents direct financial costs and benefits. The cost-effectiveness of the intervention was analyzed, accounting for the financial costs and benefits and evaluating these against an alternative business-as-usual scenario, for instance, the silvofishery model vs. conventional shrimp farming using inputs. This financial analysis, however, fell short in accounting for trade-offs, which are more complex to value in economic terms.

The lowest score among all criteria was observed for Criterion 7, based on adaptative management (score of 33%). While the KMSP includes some baselines against which progress will be monitored and evaluated, these are not robust, and there are gaps in the integration of lessons during the project cycle. It was also rated partial in incorporating risk identification and management beyond the intervention site.

Criterion 8 on Sustainability and Mainstreaming scored 56% (Adequate). The strong role that the IUCN and the Blue Natural Capital Funding Facility will play in aggregating lessons and best practices from this field implementation in national and global policy is evident. The project contributes to Indonesia's Nationally-Determined Contributions through the restoration of mangroves and by capturing emissions, and to SDGs 13, 14, and 15 (UnitedNations, 2015). The project was rated adequate for the systematic capture of lessons and the accessibility of these to strategic audiences, primarily through the BNCFF. Nevertheless, it was ranked partial in informing and influencing policy and regulatory frameworks due to the nature of the private sector or the non-integration of the indirect stakeholders in the intervention (Criterion 5). BNCFF has encouraged the project manager to apply for third-party certification through Fair Trade and ASC certification as a way of incorporating policy, regulations, and law into project implementations. The BNCFF and the IUCN play a key role in working to capture lessons, and these will be shared to support the uptake and mainstreaming of this NbS approach beyond the site level.

To conclude, this case study is an encouraging example of a project that links ecosystems, the economy, and society. Project baselines were collected from a similar initiative in Vietnam rather than the current project sites; therefore, the project score, at present, will not reflect this case study with 100% accuracy until its own baselines have been established. Furthermore, as is common in the private sector, the project primarily consulted direct beneficiaries rather than a broader range of stakeholders, and this is likely to influence the overall scoring. This notwithstanding, the KMSP mariculture intervention performed relatively well, partly due to the targeted biodiversity benefits (Criterion 3) that are expressed and placed at the same priority level as the usual socio-economic benefits targeted in aquaculture systems. Project buy-in and long-term sustainability would benefit from the inclusion of indirect stakeholders in the project design (Criterion 1), ensuring inclusive governance processes (Criterion 5) and better accounting for project trade-offs (Criterion 6). In addition, the project should broaden its landscape and temporal considerations of costs, benefits, and knock-on effects as well as incorporating socio-political risks (Criteria 2, 4, 6). Nevertheless, in this case, it must be emphasized that doing the assessment during the early/planning phase of an intervention may be highly optimistic as it will naturally reflect what people want it to be like. However, the exercise, conducted at this early stage, helps to identify future work to ensure that the intervention is stronger.

4 Discussion

4.1 Relevance and applicability of the IUCN Global Standard for NbS™ to context-specific aquaculture developments

The self-assessment tool of the IUCN Global Standard for NbS™ revealed, for the two analyzed case studies, that most indicators are rated "moderate" to "adequate". This means approximately 40-50% adherence to the IUCN Global Standard for NbS™. In the case of Zanzibar, two criteria were scored as "Insufficient" due to a current lack of adherence to the IUCN Global Standard for NbS™ (Biodiversity and Balance trade-offs). However, in both locations, the evaluation process should be seen as part of their own project improvement cycle. The projects should be revised, with appropriate local consultation in Zanzibar, and with local data produced and connected over time in both cases. At this stage, the NbS exercise through the IUCN Global Standard for NbS™'s self-assessment tool revealed weaknesses in the aquaculture systems assessed but also pointed out ways to strengthen their sustainability through specific future actions. The exercise also showed the importance of considering the contextual and temporal characteristics of the aquaculture system under consideration when applying the IUCN Global Standard for NbS™.

The societal challenges of addressing social and economic development—through improved livelihoods, increased economic incomes, and contribution to economic life—are also translated in high scores for Criterion 4 (economic feasibility). This higher score is based on rather strong assets, in both case studies, on economic targets and feasibility aspects. The results of the application of the IUCN Global Standard for NbS™ indicate critical issues that would have to be further addressed at different stages of each project's implementation. For instance, as underlined through the Zanzibar case's assessment, it is important to consider whether an economic model strictly depending on a fluctuating export market is a long-term, viable project. Similarly, the Kalimantan project is based on the high-value shrimp market for exports.

On inclusiveness, governance, trade-offs, and adaptability (Criteria 5 to 7), both case studies performed rather poorly. This is due to weaknesses in the design, monitoring, and governance of the projects, as well as a lack of relevant data informing these criteria. Interestingly, the cases reflect two different situations for governance. Seaweed farming in Zanzibar is a private family business, but the sector is managed in a top-down manner, with limited representation for women seaweed producers. The Kalimantan project is also private but appears limited in its degree of involvement of other stakeholders beyond direct interested parties. In Zanzibar, the challenge is to better include key stakeholders (women producers) in decision-making processes and the overall governance of the sector, whereas in the Kalimantan project, the challenge is to enlarge the stakeholder platform, which is currently restricted to farmers, the local processor-partner, and the foreign export company. This illustrates that the application of the IUCN Global Standard for NbS™ can shed light on ways forward with issues that are typically acknowledged as problematic in aquaculture developments.

The main practical outcome provided by the IUCN Global Standard for NbS™ is also that the self-assessment tool exercise tool exercise frames and highlights the complexity of assessing coastal social-ecological system sustainability (including the aquaculture component) in practice. The importance of recognizing the complexity of coastal issues (O'Leary et al., 2022) was made evident in the evaluation of the two case studies. Concrete observations and potential corrective actions could be drawn up from the self-assessment. For instance, the IUCN Global Standard for NbS™ encouraged both presented projects to perform better and improve their net gain outcomes.

4.2 Application and relevance of the IUCN Global Standard for NbS™ to aquaculture development more generally

In terms of methodological innovations, the IUCN Global Standard for NbS™ brings a new vision that aggregates existing concepts for framing aquaculture sustainability (Hughes, 2021; le Gouvello et al., 2022). Its eight criteria and 28 indicators present the necessary methodological detail to answer specific questions. The EAA (Soto et al., 2008) encompasses the NbS principles and most of the IUCN Global Standard for NbS™'s criteria (Hughes, 2021). The IUCN Global Standard for NbS™, if applied more regularly for aquaculture projects, may contribute to the overall EAA "reinvigorating" process that Brugere et al. (2018) advocate (le Gouvello et al., 2022). It may also help in developing a more operational Sustainable Blue Economy that includes aquaculture (Hughes, 2021).

However, the application of the IUCN Global Standard for NbS™ also raises some fundamental questions regarding what may be considered a 'natural', ecosystem-based versus an 'engineered, artificialized aquaculture system (Cohen-Shacham et al., 2016; Nesshöver et al., 2017; Cohen-Shacham et al., 2019). Human-technological interventions in aquaculture blur the limit to the "*naturalness*" acceptation of the NbS in aquaculture, for example, in relation to the use of compounded feeds, sea cages like finfish net-pen farms, or reliance on triploid, genetically selected strains of exotic species (e.g., Pacific oysters in Europe). It also raises practical questions about the feasibility of the production expansion ambitions of major producers. For example, how the NbS approach could actually contribute to improving the overall sustainability of shrimp farming in major producing countries like Indonesia and Ecuador, which are both aiming to produce over one million tons of shrimp per year (Boyd et al., 2021). The assumption that the combined and simultaneous requirements of Criteria 3 and 4 for biodiversity gain and economic viability may exclude from NbS qualification industrial, large-scale, high input-output aquaculture systems, in favor of artisanal, extensive, local, or niche aquaculture production systems would require further investigation on a case study basis (le Gouvello et al., 2022).

Regarding marine biodiversity, some forms of aquaculture, such as "restorative aquaculture" (Theuerkauf et al., 2019) could meet some of the criteria of the IUCN Global Standard for NbS™. However, in line with the IUCN NbS principles (Cohen-Shacham et al., 2016; Cohen-Shacham et al., 2019), the use of aquaculture as an "ecosystem engineer" should be handled with caution, and all options and alternative actions, such as the preservation or restoration of natural habitats (seagrasses, mangrove areas, etc.), should be considered before deciding upon the implementation of an aquaculture production as a solution. In that sense, the IUCN Global Standard for NbS™ may help as it introduces criteria and indicators to validate the solution, and, for instance, to run relevant cost-benefit analyses in addressing the questions raised in Criteria 3, 4, and 6 (biodiversity gain, economic viability, and trade-offs). But the IUCN Global Standard for NbS™ does not explicitly address rights, equity, well-being, and benefit sharing, and this constitutes a weakness in the standard itself in our view, unless a specific evaluation of these issues is conducted in parallel, using appropriate tools (such as value chain sustainability, social sustainability, and inclusiveness assessments) (Eriksson et al., 2018; Bush et al., 2019a; Krause et al., 2020; Brugere et al., 2021).

Despite the positive outlook that the NbS concept and the IUCN Global Standard for NbS™ offer in the analysis of aquaculture development, many questions remain regarding their operationalization in the aquaculture context of aquaculture. The case studies have shown that some IUCN Global Standard for NbS™ criteria may be more important to meet in some contexts and aquaculture systems than in others. However, this may change over time, since context-dependent priorities and perceptions also evolve, suggesting that there is no universality over the IUCN Global Standard for NbS™ (hence the importance of its regular revisions), even though NbS principles themselves aren't supposed to change and can be considered 'universal'.

There is, therefore, a need to document additional cases of potential aquaculture-related NbS to clarify and further refine both the limits and potential of the NbS concept and the IUCN Global Standard for NbS™ in their application to aquaculture. Future research questions could also tackle its complementarity with other types of assessments, such as cost-benefit analysis, certification audits, environmental and social impact assessments at the farm level, and the adherence to wider sustainability principles (such as those of the EAA at the institutional level) to inform holistic decision-making and appropriate prioritization of aquaculture developments. How mitigation actions are promoted and those responsible for aquaculture systems that did not score well on some criteria being made accountable should also be integral to future research into the application of the IUCN Global Standard for NbS™. Addressing and providing guidance on these issues would alleviate the risk of discouraging the use of a standard potentially perceived as too strict, especially if no support is provided to comply with it, or if the rewards of an "NbS qualification" are unclear to aquaculture producers and policymakers.

Finally, it should be noted that, although the IUCN Global Standard for NbS™'s self-assessment tool implemented in the analysis of the case studies has a set of guiding questions and four assessment levels, its results depend on and are therefore subjective to the person conducting the assessment. It is therefore important that different stakeholders involved in a certain initiative work together as a group to discuss and agree on the most accurate assessment, reduce partiality, and assess the initiative as objectively and precisely as possible. The NbS's self-assessment tool for the Global Standard is a first step in an educative process intended to draw a roadmap for the progression of all NbS initiatives.

5 Conclusion

The NbS concept and the IUCN Global Standard for NbS™ provide opportunities to refine analyses and document the sustainability of aquaculture systems; to reinforce the implementation of guiding principles, such as those of the Ecosystem Approach to Aquaculture (EAA); and to further contribute to entangling the place and role of aquaculture production systems and aquaculture development more generally within social-ecological systems. Our review of the applicability of the NbS concept and the IUCN Global Standard for NbS™ in the aquaculture context suggests that there are as many nuances of NbS compliance as there are aquaculture systems. Piloting the IUCN Global Standard for NbS™'s self-assessment tool in two case studies of aquaculture development highlighted the weaknesses while providing pointers for corrective actions as part of a roadmap toward greater sustainability. Despite complementarities between the NbS concept and other sustainability concepts, not all aquaculture systems may comply with the IUCN Global Standard for NbS™, even though they comply with other sustainability concepts. This notwithstanding, the NbS concept and the IUCN Global Standard for NbS™ could inspire and provide operational guidance for the development of a new generation of aquaculture initiatives specifically designed as NbS. Thus, our findings advocate pursuing the context-sensitive promotion of aquaculture developments as NbS.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not provided for this study on human participants because No direct field individual data were used in the study, no requirement for an ethical approval. The study was done in agreement with local and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

The work was conceived and undertaken by the authors. The corresponding author coordinated the whole work with two main reviewers, the second author (EC-S) and the last author (CB). The information on Zanzibar case were collected and analyzed by the first author (RL), in collaboration with AS, FS and CB while the study case in Indonesia was provided by the work of DH and discussed with all the other authors. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The author RL is a self-employed person, under a consultancy firm STERMOR, and consulted as expert by the IUCN team for this work and this publication. The author CB is under the same status, self-employed by her consultancy firm Soulfish, and consulted as expert.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1146637/full#supplementary-material

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