



Review

Synthesising ecological, socioeconomic, and governance guidelines for designing Marine Protected Areas

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ABSTRACT

Designing successful, equitable, and just marine protected areas (MPAs) requires integrated consideration of ecological, socioeconomic, and governance dimensions. Such an integrative approach to MPA design is critical as countries establish more MPAs in line with the 30 × 30 initiative. We reviewed and synthesised 574 design guidelines across 62 peer-reviewed and grey literature publications to assess the extent to which ecological, socioeconomic, and/or governance guidelines are integrated in current MPA design. We identified a total of 26 broad guidelines (i.e., 9 ecological, 12 socioeconomic, and 5 governance) across a variety of MPA objectives. We found that documents that included only ecological guidelines were the most frequently used (60%), followed by socioeconomic (3%) and governance guidelines (3%). Almost 20% of the documents combined ecological guidelines with socioeconomic guidelines, while only 8% combined ecological guidelines with governance guidelines. Fewer than 7% of documents combined all three to achieve MPA objectives. *Adequacy* often co-occurs with *Connectivity*, *Comprehensiveness*, and/or *Ecological Importance* among the ecological guidelines. Similarly, *Equity* frequently co-occurs with *Cultural Identity* and/or *Social Context* in papers reporting socioeconomic guidelines. Such a pattern could not be established for governance guidelines due to the low number of documents with governance guidelines. While our results reveal an imbalance and a lack of integrative MPA design, with the prevailing MPA design guidelines being ecologically driven, our synthesis of MPA design guidelines across different MPA objectives provides opportunities for integrating these guidelines towards a holistic MPA design that benefits both nature and people.

1. Introduction

Marine protected areas (MPAs) are increasingly used as tools to conserve marine biodiversity and improve fisheries and tourism (Cabral et al., 2025; Lester et al., 2009; Sala et al., 2021). Currently, MPAs cover 8.3% of the global ocean, with a third of these areas being highly or fully protected (Marine Protection Atlas, 2024). Many nations plan to expand their MPAs to cover 30% of their exclusive economic zones by 2030 as part of their commitment to the Convention on Biological Diversity (2030 CBD Target 3, also known as ‘30 × 30’) (The Secretariat, n.d.). Such expansion could generate substantial benefits when properly designed.

The design and planning processes of MPAs are important determinants of MPAs' success. An MPA is considered successful or effective when its establishment objectives are achieved (Giakoumi et al.,

2018). Pomeroy et al. (2004) defined MPA objectives as “a measurable statement of what must be accomplished” and provided a comprehensive list of ecological, socioeconomic, and governance MPA objectives. Determining the MPA objectives is important for evaluating how the MPA performs in practice and whether it achieved its intended ecological, socioeconomic, and/or governance outcomes. For example, the Cabo de Palos-Islas Hormigas MPA in Spain successfully achieved its objective of biodiversity conservation, resulting in an increase in fish biomass and density (Rojo et al., 2021). However, despite the ecological gains, the MPA establishment led to negative social impacts on some local stakeholders, including artisanal fishers who felt excluded from the decision-making process and experienced restricted access to the fishing grounds, even though the development and support of artisanal fishing were one of the MPA's stated objectives (Hogg et al., 2019). While the implementation of MPAs has mostly aimed to protect marine

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ecosystems, it has often done so without adequately accounting for the impacts on resource users (Ban et al., 2013). There is an increasing recognition that a successful MPA must also be equitable and just, which necessitates a holistic integration of ecological, socioeconomic, and governance guidelines in the MPA design process (Précoma-de La Mora et al., 2021; Green et al., 2020, 2019).

Guidelines are used to inform MPA design towards achieving its goals. Design guidelines are directions deliberately created to manage uncertainties and risks in designing MPAs when there is a lack of scientific knowledge, ecological processes, and current and future threats (The Ecology Centre, The University of Queensland, 2009). Due to the breadth of literature on existing MPA design guidelines, terminology is often inconsistent, and these are often also referred to as principles or criteria, depending on the level of specificity. For example, many documents in both peer-reviewed and grey literature refer to the CAR principles - 'comprehensiveness', 'adequacy', and 'representativeness' principles - each providing a list of recommendations on 1) inclusion ('comprehensiveness'), 2) size, configuration, replication ('adequacy'), and 3) representation ('representativeness') of MPAs (Beaver and Llewellyn, 2009). However, in a few instances, the terms guidelines, criteria, and principles have often been used interchangeably. For example, the early paper by Ballantine (1997) lists 'replication' (which is more a rule of thumb) and 'precautionary principle', with 'replication' being part of the broader category of 'adequacy' - often referred to in the literature as a principle. Similarly, more recently, the paper by Thomas and Shears (2013) lists 'replication' and 'adequacy' as separate principles rather than the former being part of the latter. Finally, another example by Airamé et al. (2003) that lists the criteria 'incorporating connectivity' and 'ecological linkages', where the latter could be incorporated under the umbrella term of 'connectivity'. In the context of systematic conservation planning, Kukkala and Moilanen (2013) reviewed 12 'core concepts' to provide clear definitions and reduce linguistic uncertainty for their application; however, much terminology inconsistency still remains in the literature. Given these inconsistencies in terminology for referring to and categorising design guidelines, we use the term design guidelines as a unifying term that captures the range of directions provided in the literature, regardless of how they were originally categorised.

Little is known about the extent to which socioeconomic and governance guidelines have been developed and integrated into the current MPA design guidelines. A few reviews have synthesised MPA design guidelines focusing primarily on ecological guidelines (Burns et al., 2023; McLeod et al., 2009; Halpern and Warner, 2003; Abelson et al., 2016; Roberts et al., 2003a), with little to no information on socioeconomic and governance guidelines. The most comprehensive review to date was conducted by Burns et al. (2023), who synthesised common MPA design features such as size, shape, and location (i.e., design features associated with improving the ecological effectiveness of MPAs). Similarly, earlier studies only provided ecological guidelines for specific MPA objectives (Ballantine, 1997; Abelson et al., 2016; Botsford et al., 2003; Asaad et al., 2017). For example, the study conducted by McLeod et al. (2009) provided ecological guidelines for designing MPAs that mitigate the impacts of climate change, while the study by Mesnildrey et al. (2013) provided ecological guidelines for MPAs used as a fisheries management tool. Furthermore, other documents discuss the combination of only a few ecological guidelines, such as the review by Halpern and Warner (2003), which solely discusses MPA size and spacing. Given the specific scope of these reviews, a gap remains in the integration of socioeconomic and governance guidelines into MPA design.

In response to the lack of synthesis on ecological, socioeconomic, and governance guidelines, we synthesise design guidelines from peer-reviewed and grey literature. Our systematic review sought to: (i) collect MPA design guidelines from documents that explicitly included ecological, socioeconomic, and/or governance guidelines; (ii) explore how these guidelines align with a range of ecological, socioeconomic,

and governance MPA objectives; (iii) assess which combination of guidelines is most often used for different MPA objectives; and (iv) quantify the extent to which ecological, socioeconomic, and governance guidelines are integrated into current MPA design. Our goal is to provide an integrative synthesis of design guidelines that support the design of ecologically successful, socially just, and equitable MPAs.

2. Methods

2.1. Database search and inclusion criteria

We searched for publications from the peer-reviewed and grey literature that listed and/or described design guidelines of established, planned, or proposed MPAs, and listed the objectives set to achieve. We used Web of Science and Scopus to search for papers using, respectively, the Boolean keywords combinations 'marine protected area*' AND ('principle*' OR 'criteri*' OR 'guideline*') and 'marine' AND 'protected' AND 'are*' AND ('principl*' OR 'criteri*' OR 'guideline*') as a starting point for collecting literature. We considered papers published from 1 January 1980 until 30 November 2024. To broaden the scope of this review, we used the Boolean keyword combination 'marine protected area*' AND ('principle*' OR 'criteri*' OR 'guideline*') on Google and Google Scholar to search for government reports (e.g., Guidelines from the Department of Biodiversity to design MPAs in Western Australia) and Non-Governmental Organisation (NGO) regional reports (e.g., USAID Asia and design guidelines for MPAs in the Coral Triangle). The advanced searches in Google and Google Scholar returned a large number of results. To ensure relevance, we considered the first 50 entries, as results beyond this range were found to be less relevant to the research topic. Finally, we examined the reference list of papers or reports that reviewed design guidelines for additional publications that met the paper inclusion criteria. In total, we retrieved 62 relevant publications.

Publications were reviewed for ecological (e.g., replication, connectivity, size), socioeconomic (e.g., social context, equity, complementarity), and governance (e.g., knowledge integration, accountability, legitimacy) guidelines. Each document was also reviewed for MPA objectives, which were either explicitly stated in the main text or were derived from the document context (see Supplementary material 1 Table S1 for a detailed categorisation of MPA objectives). The retained publications covered design studies in specific locations, guidelines reviews or frameworks, objective-specific guidelines documents, and design proposals for MPAs not yet established.

2.2. Categorising design guidelines and MPA objectives

MPA objectives and guidelines were categorised into ecological, socioeconomic, and governance. The categorisation of guidelines was based on the guideline definition in the original source. Guidelines with shared characteristics were grouped under the same overarching guideline (e.g., all guidelines discussing the use of resources, economic and non-economic, and distribution of costs and benefits were categorised under *Equity*). A similar approach was adopted to categorise MPA objectives. Furthermore, we used the MPA goals reported in Pomeroy et al. (2004) as a foundational work to guide our MPA objective categorisation (Table 1). Where appropriate, we modified the terminology to reflect more recent usage, as some MPA objectives have evolved in recent literature and practice. Ecological MPA objectives were grouped into the four broad sub-categories "*biodiversity conservation*", "*assisting the maintenance of ecological processes*", "*marine conservation*", and "*building resilience to climate change*" based on MPA objective definitions. Similarly, socioeconomic and governance MPA objectives were grouped respectively into four (i.e., "*ongoing ecologically sustainable use*", "*maintain or improve livelihoods*", "*ensure food security*", and "*cultural value*") and two (i.e., "*community-centred conservation governance*" and "*effective legal structures*") broad sub-categories.

2.3. Data analysis

Data were visually summarised and analysed in R (R Core Team, 2025; ver. 4.4.1). From each paper, unique guideline-objective combinations (e.g., “Adequacy” guideline combined with the “biodiversity conservation” objective) were extracted. For documents with multiple MPA objectives, each guideline was categorised under the relevant MPA objectives (e.g., if the document had both “marine conservation” and “biodiversity conservation”, the guidelines was counted once under each objective). These unique guideline-objective combinations were used to conduct a presence/absence matrix analysis to highlight which design guidelines are used in published records in the design process for each MPA objective. The analysis was used to identify frequent combinations of design guidelines used together for each MPA objective. A frequency matrix was used to determine the relationship between each design guideline and MPA objective. Based on this analysis, we produced a heatmap that displays the frequency of unique guideline-objective combinations for ecological, socioeconomic, and governance categories.

3. Results

3.1. Documents profile

Of the 62 documents that were reviewed, we found over 60 % were peer-reviewed articles (journal articles) and around 40 % were grey-literature reports (Fig. 1A). When examining different jurisdictional

scales, we found that nearly 20 % of the documents focused on site-specific study areas (e.g., Great Barrier Reef, Raja Ampat), around 15 % on state/province (e.g., California, South Australia), over 20 % on country level (e.g., Mexico, New Zealand), 13 % on regional level (e.g., Coral Triangle, Mediterranean Sea), and over 30 % of the documents were categorised as “other” - primarily including review articles as well as theoretical frameworks and habitat/species MPAs (Fig. 1B). These documents span across the six continents, with no study included for Antarctica (Fig. S1, see Supplementary material 1).

We found 574 guidelines for MPA design from 62 publications. These were categorised into 26 broader subcategories (i.e., 9 ecological, 12 socioeconomic, and 5 governance guidelines subcategories) (Table 2). We found that documents that included only ecological guidelines were the most frequently used (60 %, $n = 37$), followed by socioeconomic (3 %, $n = 2$), and governance guidelines (3 %, $n = 2$) (Fig. 1). Almost 20 % ($n = 12$) of the studies combined ecological guidelines with socioeconomic guidelines, while only 8 % ($n = 5$) combined ecological guidelines with governance guidelines. Fewer than 7 % ($n = 4$) of the documents combined all three to achieve MPA objectives. When examining the combination of categories across different jurisdictional scales, we observed that documents focusing on regional, state/provincial, and site-specific (i.e., documents reporting specific sites or MPAs) levels provided ecological and/or socioeconomic design guidelines and MPA objectives (Fig. S4, see Supplementary material 1). Documents at the national level or those without a specified scale (categorised as ‘other’; e.g., reviews) integrated governance design guidelines and MPA

Table 1

MPAs objectives modified from Pomeroy et al. (2004) and their definitions. We found inconsistencies in the literature regarding how different resources categorise/define ‘fisheries management’. In this review, any impacts of MPAs underwater are categorised as ecological (e.g., protecting targeted species), while any impacts of MPAs above water are categorised as socioeconomic (e.g., reducing fishing efforts).

MPA objective	Definition
<i>Ecological objectives</i>	
(OE1) Biodiversity conservation	Ensures that ecologically important values are protected to conserve biodiversity, ecological integrity, and ecosystem functioning for the future (Department of Biodiversity, 2023). More specifically, this MPA objective aims to protect rare or endemic species, areas critical for life history stages, reduce or remove human threats, protect at the hierarchical level (i.e., ecosystems, communities, habitats, species, and gene pools), and maintain ecosystem functions.
(OE2) Marine conservation	This includes preventing loss of biodiversity and ecosystem functions, ensuring populations of target species (for extractive or non-extractive use) are sustained at desired reference points and are protected during vulnerable life stages, and reducing or prohibiting the extraction of living and/or non-living resources. This incorporates fisheries management goals (e.g., increase fish biomass) as design guidelines that favour conservation compatible with fishery management (Roberts and Hawkins, 2000).
(OE3) Assisting the maintenance of ecological processes	Sustain the health and integrity of marine systems and their ability to maintain ecological functions, which includes: the rehabilitation of ecosystems, habitats, and populations of focal or protected species (Green et al., 2020, 2019), protecting, recovering, and maintaining connectivity (McCook et al., 2009), and ecological viability (Kremen et al., 1999).
(OE4) Building resilience to climate change	Design MPAs to help build strong resilience to potential climate and ocean changes on marine systems, impacts include: an increase in sea surface temperature, ocean acidification, changes to rainfall patterns, and intensification in the severity of cyclonic events (Fernandes et al., 2012; Arafeh-Dalmau et al., 2023; Green et al., 2014; Brock et al., 2012).
<i>Socio-economic objectives</i>	
(OS1) Ongoing ecologically sustainable use	Design a multiple-use marine park that provides social and economic benefits to local communities and provides for the sustainable use of resources. Use activities (extractive and non-extractive) are: recreational and commercial fisheries (e.g., catch yield, maximising yield (Botsford et al., 2003), aquaculture, tourism, recreation, education, research, and protection of natural, historic, and heritage values.
(OS2) Maintain or improve livelihoods	This includes: improving the financial well-being of local communities and resource users, contributing to economic variability, decreasing dependency on marine resources, and improving the health of local communities (Pomeroy et al., 2004).
(OS3) Ensure food security	This includes meeting and maintaining the nutritional needs of local coastal communities and improving access to locally caught sources for public consumption (Pomeroy et al., 2004).
(OS4) Cultural value	Protect and support local knowledge, values, and resources through a network of Marine Protected Areas (Mangubhai et al., 2015), protecting areas for spiritual and recreational opportunities (cultural, ecological, and derived values) (Aíramé et al., 2003).
<i>Governance objectives</i>	
(OG1) Community-centred conservation governance	Conservation initiatives led by local and Indigenous communities for the safeguarding of natural resources and biodiversity. This involves multilevel governance that respects rights and builds on trust-based relationships and customary practices among local communities, supportive state agents, and civil society participants, including conservation organisations, business, and industry partners. It is recognised that these community-centred conservation initiatives can be carried out by Indigenous rights holders, organisations, governments, the private sector, and/or other society actors (Armitage et al., 2020). This aims to encourage active involvement and support of the community in the management of the MPAs/MPA Network (Green et al., 2020).
(OG2) Effective legal structures	Strategies for management are maintained, which include: ensuring adequate legislation, maximising and ensuring formal and informal arrangements, and ensuring that arrangements are enforced (Pomeroy et al., 2004).

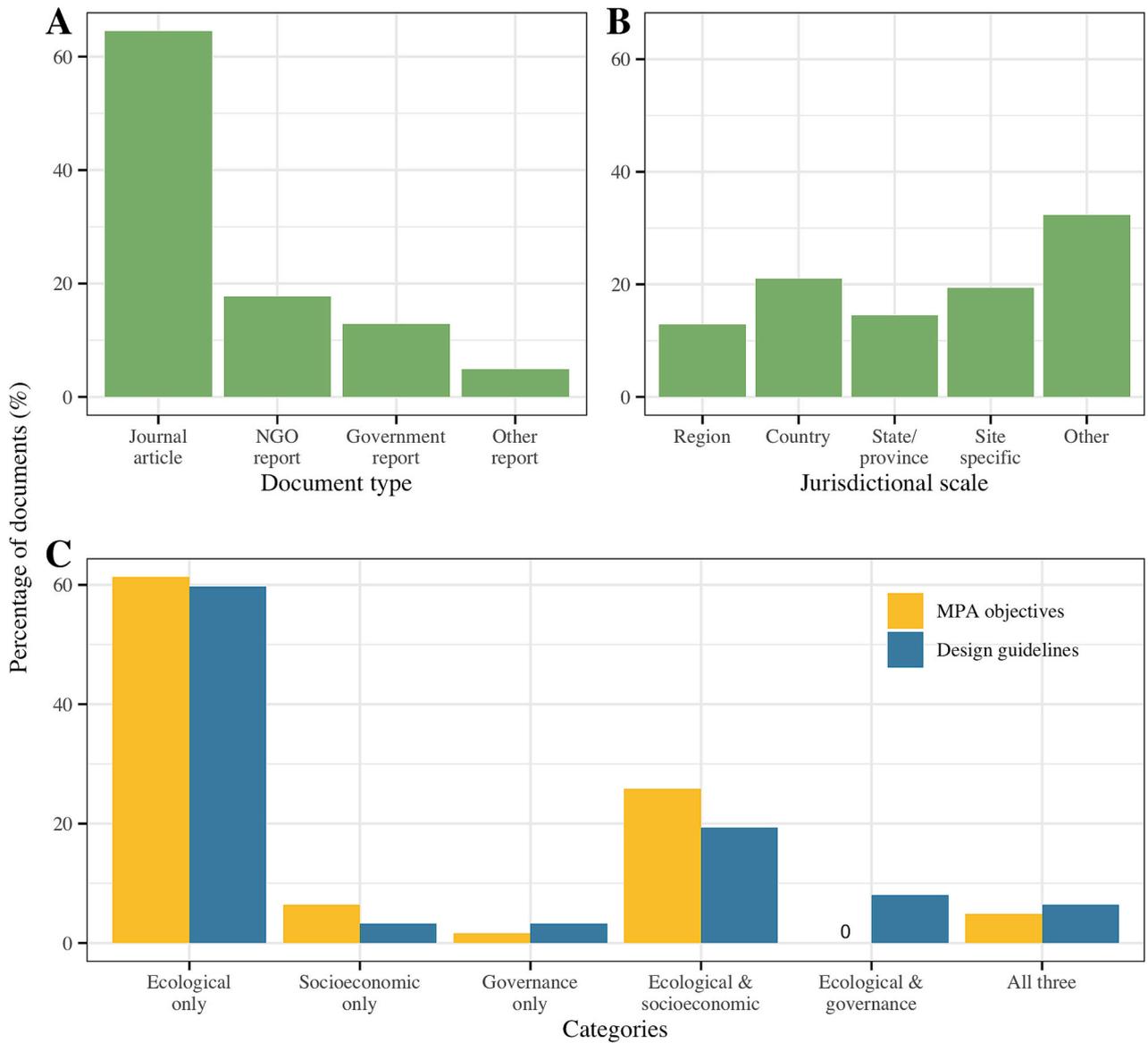


Fig. 1. Profile of collated literature ($n = 62$) expressed as percentage (%): (A) document type; (B) jurisdictional scale discussed in the document (where 'site-specific' are documents that discuss specific MPAs or sites, and 'other' refers to documents where jurisdiction was not specified, such as reviews); and (C) documents that reported an ecological, socioeconomic, or governance objective (orange) and design guidelines (blue) for marine protected areas (MPAs). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Definitions of guidelines for the design of MPAs and MPA Networks.

Guideline	Abbreviation	Definition
<i>Ecological</i> (GE1) Comprehensiveness		The MPA should comprise the entire range of ecosystems, habitats, and communities found within and across each bioregion (Department of Biodiversity, 2023), characteristic of the region's marine environment (Kirkman, 2013). The reason behind this guideline is to consider linkages between habitats and ecosystems to increase the opportunity of securing a comprehensive range of linkages, especially connections that have not yet been identified (McCook et al., 2009). This can refer to the simplistic approach of systematically including instances of present features, such as geographic gradients (e.g., latitude, depth, inshore to offshore areas) and influences (e.g., upwelling zones, river runoffs; McCook et al., 2009). Within the literature on systematic conservation planning, comprehensiveness frequently refers to including all known elements of biodiversity of the bioregion within highly protected areas (e.g. Sala and Giakoumi, 2018; Claudet et al., 2008). The key recommendation is to map the ecosystems within the bioregion and clearly define "include" to determine the MPA configuration and the amount of ecosystems to be "included" (Beaver and Llewellyn, 2009).
(GE2) Adequacy		Adequacy refers to a network's capacity to contribute to long-term biodiversity protection in a bioregion (Beaver and Llewellyn, 2009). Adequacy guarantees ecological sustainability within the network, promotes connectivity, and preserves the integrity of ecological processes (Day et al., 2002). The MPA should include each biodiversity component to achieve a functioning ecosystem (Department of Biodiversity, 2023). To achieve adequacy are to be considered the following key features (Department of Biodiversity, 2023): <ul style="list-style-type: none"> – size and shape (Ballantine, 1997; Laffoley, 2013; Department for Environment and Heritage, 2008; Kirkman, 2013; Fernandes et al., 2012, 2005, 2009; Ohayon et al., 2021; Horta et al., 2022; Day, 2017; Gill et al., 2017; Wedding et al., 2013), – avoid habitat fragmentation (Department of Biodiversity, 2023), – replication (Précoma-de La Mora et al., 2021; Ballantine, 1997; Airamé et al., 2003; McLeod et al., 2009; Laffoley, 2013; Kirkman, 2013; Fernandes et al., 2012; Munguia-Vega et al., 2018; Department of Biodiversity, 2023; Green et al., 2009, 2014; Arafteh-Dalmau et al., 2023), – permanence, – network connectivity (McCook et al., 2009), – fully protected areas (Précoma-de La Mora et al., 2021).
(GE3) Representativeness		Represent biodiversity across genetic and biological ranges of diversity and variability (e.g., across a range of depths and/or temperatures) (Laffoley, 2013; Horta et al., 2022; Department of Biodiversity, 2023; Wedding et al., 2013; Department of Conservation, Ministry for the Environment, Ministry for Primary Industry, 2019; Alonso et al., 2021). Protect the species diversity inhabiting different areas and species that move across different habitats at different life stages. Because much information regarding biodiversity is uncertain or unknown (The Scientific Peer Review Panel for the National Representative System of Marine Protected Areas, 2006), ecosystems or habitats can be used as surrogates (Department for Environment and Heritage, 2008; Kirkman, 2013; Fernandes et al., 2005, 2009) because species assemblages will be unique in each (Ballantine, 1997; Airamé et al., 2003; Asaad et al., 2017; Roberts et al., 2003b). The guideline acknowledges heterogeneity in marine systems and ensures that the full ecological and biophysical characteristics and processes are represented (Beaver and Llewellyn, 2009; McCook et al., 2009).
(GE4) Precautionary principle		Adopt a proactive (rather than reactive) approach to plan MPAs that are presently in relatively good conditions to ensure future protection (Department of Biodiversity, 2023; Christiansen, 2007). The MPA design should be informed by the best available information, and uncertainty should not be a reason to delay protection measures (Thomas and Shears, 2013; Laffoley, 2013; Department of Biodiversity, 2023). However, decision-making can be problematic when there is a lack of available information (Lundquist et al., 2015) or high uncertainty (Beaver and Llewellyn, 2009). A precautionary approach uses proxies when (or where) there is insufficient knowledge (Ballantine, 1997), limited data, or uncertainty (Department of Biodiversity, 2023). Furthermore, this supports the decision-making process when there are unknown risks (Department for Environment and Heritage, 2008; Kirkman, 2013). It is unlikely that our knowledge is sufficient to identify all these problems and are able to solve them, and potentially the most serious have not happened yet (Ballantine, 1997).
(GE5) Ecological importance, vulnerability, and resilience	Ecological Importance	MPAs should be designed to help maintain the course or state of natural areas. This includes areas that have more vulnerable areas (i.e., provide more protection to critical areas or species) and the highest integrity (i.e., to ensure more resilience to future threats) should be included in the MPA (Kirkman, 2013). Specifically, all available environmental information should be used to define the arrangement of fully protected areas to establish functional networks (Roberts et al., 2001; Fernandes et al., 2005). Furthermore, areas of particular importance to the marine environment should be considered for inclusion in the MPAs (Department of Biodiversity, 2023). Key features to consider are: <ul style="list-style-type: none"> – Areas important for life history stages (e.g., breeding, spawning, nursery, nesting, feeding, foraging areas) (Précoma-de La Mora et al., 2021; Department for Environment and Heritage, 2008; Roberts et al., 2001; Chiappone and Sealey, 2000); – Highly productive areas are placed permanently in no-take areas (Wedding et al., 2013); – Aggregation areas for endemic, rare, threatened, vulnerable, critical, or protected species placed in no-take areas (Précoma-de La Mora et al., 2021; McLeod et al., 2009);

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Table 2 (continued)

Guideline	Abbreviation	Definition
(GE6) Connectivity		<p>Department for Environment and Heritage, 2008; Fernandes et al., 2012, 2005; Munguia-Vega et al., 2018; Roberts et al., 2001);</p> <ul style="list-style-type: none"> – Ecological/biodiversity hotspot (Munguia-Vega et al., 2018; Department of Biodiversity, 2023); – Areas with high levels of naturalness and integrity (Asaad et al., 2017); – Habitats that are important to productivity and ecosystem functioning, and more vulnerable to human threats (Airamé et al., 2003; Department of Biodiversity, 2023; Roberts et al., 2001); – Areas likely to be more resistant or resilient to climate change (McLeod et al., 2009; Fernandes et al., 2012; Munguia-Vega et al., 2018; Arafeh-Dalmau et al., 2023; Green et al., 2014). <p>MPA design should consider how marine ecosystem components are connected (Department of Biodiversity, 2023), identifying and maximising (Laffoley, 2013) the connectivity network within and between ecosystems (Green et al., 2009). It should be considered:</p> <ul style="list-style-type: none"> – Dispersal ranges for marine organisms (Précoma-de La Mora et al., 2021; McLeod et al., 2009; Botsford et al., 2003; Munguia-Vega et al., 2018; Horta et al., 2022; Roberts et al., 2001; Chiappone and Sealey, 2000; Fernandes et al., 2005; Saarman et al., 2013); – Distance between and within MPAs and marine reserves (Précoma-de La Mora et al., 2021; Fernandes et al., 2012; Munguia-Vega et al., 2018; Department of Biodiversity, 2023; Green et al., 2014); – Benthic-pelagic linkages between species/functional groups and material movement (McLeod et al., 2009; Department of Biodiversity, 2023; Roberts et al., 2001); – Oceanography (i.e., tides, currents, upwelling, coastal topography) (Department of Biodiversity, 2023); – Migration routes (e.g., cetaceans, seabirds) (Department of Biodiversity, 2023); – Transport of material and nutrients (from land and within MPA sites) and land-based impacts of pollution and sediments (Department for Environment and Heritage, 2008; Kirkman, 2013; Department of Biodiversity, 2023); – Localise more protection upstream of currents (Fernandes et al., 2012; Munguia-Vega et al., 2018; Green et al., 2014); – Consider the impacts of climate change on ecosystem dynamics and implications for the design process (Munguia-Vega et al., 2018; Arafeh-Dalmau et al., 2023).
(GE7) Sustainable use		<p>Manage the use of marine resources within the MPA, allowing time for recovery, permanently placing access limits, prohibiting destructive gear, and establishing no-take areas (Précoma-de La Mora et al., 2021; Fernandes et al., 2012; Green et al., 2014).</p>
(GE8) Ecosystem services		<p>Consider ecosystem services. Ecosystem services are benefits provided to humans from the functioning of natural ecological systems (e.g., mangroves and coral reefs that provide physical protection from wave action, habitats for commercially important fish and crustacean species (Roberts et al., 2003b; Alonso et al., 2021). Placing valuable sites in MPAs also allows for the study of marine ecosystems without the impacts of fishing pressure (Airamé et al., 2003; Chiappone and Sealey, 2000).</p>
(GE9) International borders		<p>Locate fully protected areas near international borders, where there is strong transboundary connectivity that can improve national conservation measures (Arafeh-Dalmau et al., 2023).</p>
<i>Socio-economic</i>		
(GS1) Integrating social context, local aspirations, and human-environment interactions	Social context	<p>Assess the social context: manage MPAs to maintain and promote social wellbeing (Précoma-de La Mora et al., 2021), protect resources that are important for the livelihoods of local communities (Green et al., 2009; Jaya et al., 2022), and ensure that MPAs support small-scale subsistence fisheries (in time and value (Green et al., 2009).</p>
(GS2) Considering economic and non-economic uses, an equitable distribution of costs and benefits	Equity	<p>MPAs and the zoning system should consider the diverse uses of marine resources (Kirkman, 2013; Department of Biodiversity, 2023), present and future (Mangubhai et al., 2015), and their efficient, ongoing, sustainable use (Kirkman, 2013; Department of Biodiversity, 2023). More specifically, the guideline aims to assess the implications of MPAs for stakeholders and their use rights, and encourage economic mechanisms that maximise socioeconomic and environmental benefits (Précoma-de La Mora et al., 2021). Key aspects to consider when designing the zoning system (Department of Biodiversity, 2023):</p> <ul style="list-style-type: none"> – Arrangement of multiple-use zones (e.g., exclude placing in no-take zones sites targeted by multiple activities (Horta et al., 2022); – Users with economic or resource extraction interests, current management strategies, and their use patterns (e.g., seasonal fluctuations; Kirkman, 2013; Fernandes et al., 2009); – Access to sustainable and locally caught fish, and assign privileged access to selective fisheries and local community fishers (Horta et al., 2022); – Access to safe fishing grounds and safety considerations for small vessels (Department of Biodiversity, 2023); – Socioeconomic information on existing activities and their cumulative impacts (Department of Biodiversity, 2023); – Ecosystem services and their economic value (Department of Biodiversity, 2023); – Minimise negative impacts on local livelihoods (Mangubhai et al., 2015; Wedding et al., 2013) and maximise sustainable opportunities for alternative revenue (Fernandes et al., 2009).

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Table 2 (continued)

Guideline	Abbreviation	Definition
(GS3) Respecting and maintaining cultural identity	Cultural identity	Prioritise protecting and promoting sites of natural, historic, scientific, social, and maritime importance, nationally or globally significant (Department of Biodiversity, 2023). It acknowledges and respects local resource owners, traditional fisheries management approaches, and conservation practices (Green et al., 2009). This inclusion in the design process also extends to guarantee that the decision-making process keeps local resource owners involved (Green et al., 2014). This also considers sites or areas that are officially recognised or listed on, for example, the World Heritage List, or the National Heritage List (Department for Environment and Heritage, 2008; Kirkman, 2013).
(GS4) Seek synergies with existing protected areas	Synergies	Recognise the contribution of current protected areas (marine and/or terrestrial) and avoid unnecessary duplication of restricted areas and/or additional restrictions on the community (Department for Environment and Heritage, 2008; Kirkman, 2013).
(GS5) Seek to complement existing terrestrial and marine management practises and conservation agreements	Complementarity	Complement existing management practices to achieve consistency with any existing terrestrial or marine management, such as policies or conservation agreements (Department of Biodiversity, 2023). Seeking to complement existing MPAs can aid with connectivity, providing links across zones, and can decrease restrictions for the community by avoiding overlapping of MPAs (Department of Biodiversity, 2023). Key points to consider are (Department of Biodiversity, 2023): <ul style="list-style-type: none"> – Existing protected areas or other forms of spatial management (e.g., exclusion zones, marinas, fisheries spatial closure areas, indigenous protected areas, adjacent terrestrial parks, etc.); – Conservation agreements (i.e., national and/or international, e.g., Ramsar) (Department for Environment and Heritage, 2008; Kirkman, 2013; Wedding et al., 2013); – Management plans for species of concern. Under this definition, the guideline also aims to minimise conflict among users, for example, by incorporating the option for future use in the zoning system and regulations (Mangubhai et al., 2015), by separating conflicting uses (Department for Environment and Heritage, 2008; Kirkman, 2013).
(GS6) Ensure ease of identification, compliance, and enforcement	Compliance	Ensure MPA sites and their zones are easy to identify for users, such as boundary shape (Department for Environment and Heritage, 2008; Kirkman, 2013). This guideline also aims to maximise enforcement and compliance. This includes placing enforcement resources closer to no-take zones, identifying and employing stakeholders that can act as a deterrent (e.g., place no-take zones in sites used by dive operators), communities' attitude towards and awareness of MPAs (and conservation practices more broadly), and their willingness to contribute to conservation (Chiappone and Sealey, 2000; Mangubhai et al., 2015).
(GS7) Provide for education, appreciation, and recreation	Education	Design MPAs that provide a range of opportunities that improve the community's appreciation of the marine environment (Department for Environment and Heritage, 2008; Kirkman, 2013). This includes improving recreational activities (e.g., tourism), creating accessible areas for education, research, and monitoring activities (present and/or future (Department of Biodiversity, 2023).
(GS8) Support sustainable subsistence fisheries to improve food security	Sustainable subsistence fisheries	Include zones designated to support artisanal subsistence fisheries prioritised by the local community and develop regulations that specify permitted and prohibited fishing gear for the artisanal subsistence fisheries (Mangubhai et al., 2015). This includes the prohibition of destructive fishing practices (Green et al., 2009), cease subsidies for unsustainable fisheries (Jaya et al., 2022), and support community-based, environmentally friendly fisheries and aquaculture (Green et al., 2020; Gaines et al., 2010).
(GS9) Give special consideration to species vulnerable to over-exploitation	Over-exploited species	Conserve marine resources for local communities by paying particular attention to species that are susceptible to over-exploitation (e.g., fisheries targeted species and their aggregation or nursery sites) (Mangubhai et al., 2015), and banning unsustainable commercial fisheries that overexploit targeted species (Green et al., 2009).
(GS10) Protect high-priority tourism sites	Tourism sites	Protect high-priority tourism sites from conflicting (extractive or destructive) uses (Green et al., 2009).
(GS11) Avoid highly protected areas in the vicinity of shipping infrastructure	Shipping infrastructures	Consider and accommodate current infrastructures such as channels, wharves, and shipping facilities (Green et al., 2009).
(GS12) Precautionary approach for uncertainty and limited data	Precautionary approach	In complex fisheries and when there is limited, inconsistent data on the fisheries status (which leads to uncertainty), a precautionary approach aids the decision-making process (Jaya et al., 2022). The greater the uncertainty, the more conservative the approach should be (Jaya et al., 2022).
<i>Governance</i>		
(GG1) Establishing and ensuring legitimacy and institutional continuity	Legitimacy	Engage all stakeholders in every step of establishing the MPAs/MPA Networks, prioritising placing protected areas in sites supported by stakeholders (i.e., increasing the likelihood of the MPA effectiveness (Green et al., 2020, 2019)); Establish a legal framework founded on a collective vision to direct actions across different scales, promoting integrity, consistency, and transparency from all involved actors (i.e., stakeholders (Précoma-de La Mora et al., 2021). This guideline ensures the involvement of local communities and vulnerable groups (i.e., women, youth, and indigenous groups often underrepresented in collaborative management (Précoma-de La Mora et al., 2021) by respecting tradition, customs, and rights and promoting gender equality (Précoma-de La Mora et al., 2021; Armitage et al., 2020).
(GG2) Implementing collaborative and adaptive management	Adaptive management	Ensure the establishment of monitoring and evaluation programs (Précoma-de La Mora et al., 2021) that promote coproduction of knowledge and solutions (Armitage et al., 2020), promoting timely and updated communication of results and progress (Précoma-de La Mora et al., 2021). Encourage policies, spaces, and structures that recognise and respect stakeholders' needs and aspirations (Précoma-de La Mora et al., 2021) and position communities as central to conservation input (Armitage et al., 2020). Ensure and integrate

(continued on next page)

Table 2 (continued)

Guideline	Abbreviation	Definition
(GG3) Promoting effective management	Effective management	consistent and impartial regulations and competent authorities to enforce them to guarantee conservation without damaging third parties (Précoma-de La Mora et al., 2021). To ensure the maintenance and improvement of ecosystem services for local communities (Green et al., 2020; Green et al., 2019), secure transparency in the decision-making and accountability of stakeholders (Précoma-de La Mora et al., 2021) and rightsholders (Armitage et al., 2020) through mechanisms to resolve, manage, and minimise conflicts (e. g., clear procedures, consensual plans, periodical reviews of agreements and performance indicators; Précoma-de La Mora et al., 2021; Lundquist et al., 2015). Furthermore, a clear strategy should be developed to define how goals and objectives will be accomplished, detailing what will be achieved, how, and in what timeframe (Dickinson et al., 2010). Include local communities in compliance and enforcement (Green et al., 2020; Bennett et al., 2020).
(GG4) Knowledge integration and adaptability	Knowledge integration	Governance processes should promote stakeholder dialogue and integration of knowledge and should remain adaptable as new information becomes available (Lundquist et al., 2015).
(GG5) Leadership and accountability	Leadership	Responsibility for the implementation of MPAs needs to be clearly defined and outlined, and leadership for advancing the marine planning should be held at the highest levels of government (Dickinson et al., 2010).

objectives as well as ecological and socioeconomic.

Documents were summarised by year of publication (grouped by decade) to observe temporal trends in the integration of ecological, socioeconomic, and governance design guidelines and MPA objectives (Fig. 2). We find that, while there is a predominance of ecological guidelines and MPA objectives across all decades, recent years see an increase in socioeconomic and governance categories. Specifically, more variation in MPA objectives and design guidelines is observed to start in the decade 2000–2009. The highest variation, with the integration of ecological and socioeconomic or ecological and governance

combinations, is observed in the decade 2010–2019. These two decades, 2000–2009 and 2010–2019, have also had the highest number of documents published, with 25 documents each.

3.2. Ecological, socioeconomic, and governance MPA design guidelines and objectives

If we zoom in on ecological MPA objectives, the design guideline that is the most frequently used across all is *Adequacy* (92.2 % of documents reporting ecological MPA objectives) (Fig. 3). For the MPA objective of

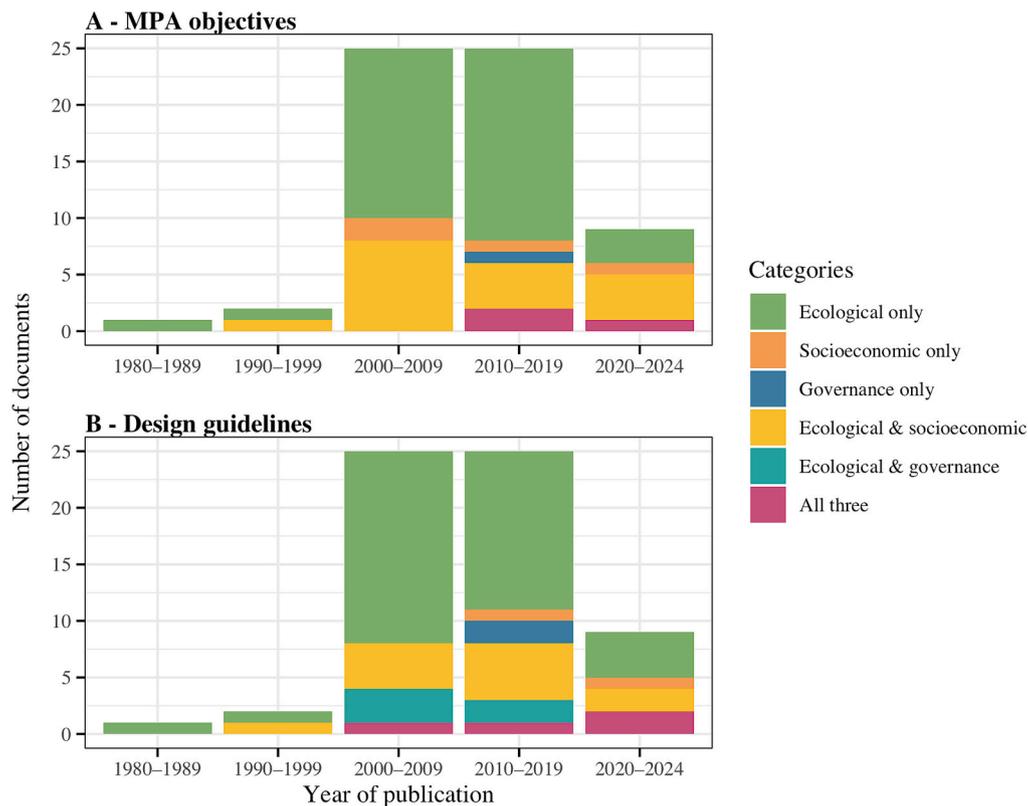


Fig. 2. Temporal variation of (A) MPA objectives and (B) design guidelines. Both MPA objectives and design guidelines are color coded based on the three overarching categories of ecological, socioeconomic and governance and their combination: ecological only in green, socioeconomic only in orange, governance only in blue, combination of ecological and socioeconomic in yellow, combination of ecological and governance in teal, and when ecological, socioeconomic, and governance are combined (i.e., all three) in magenta. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

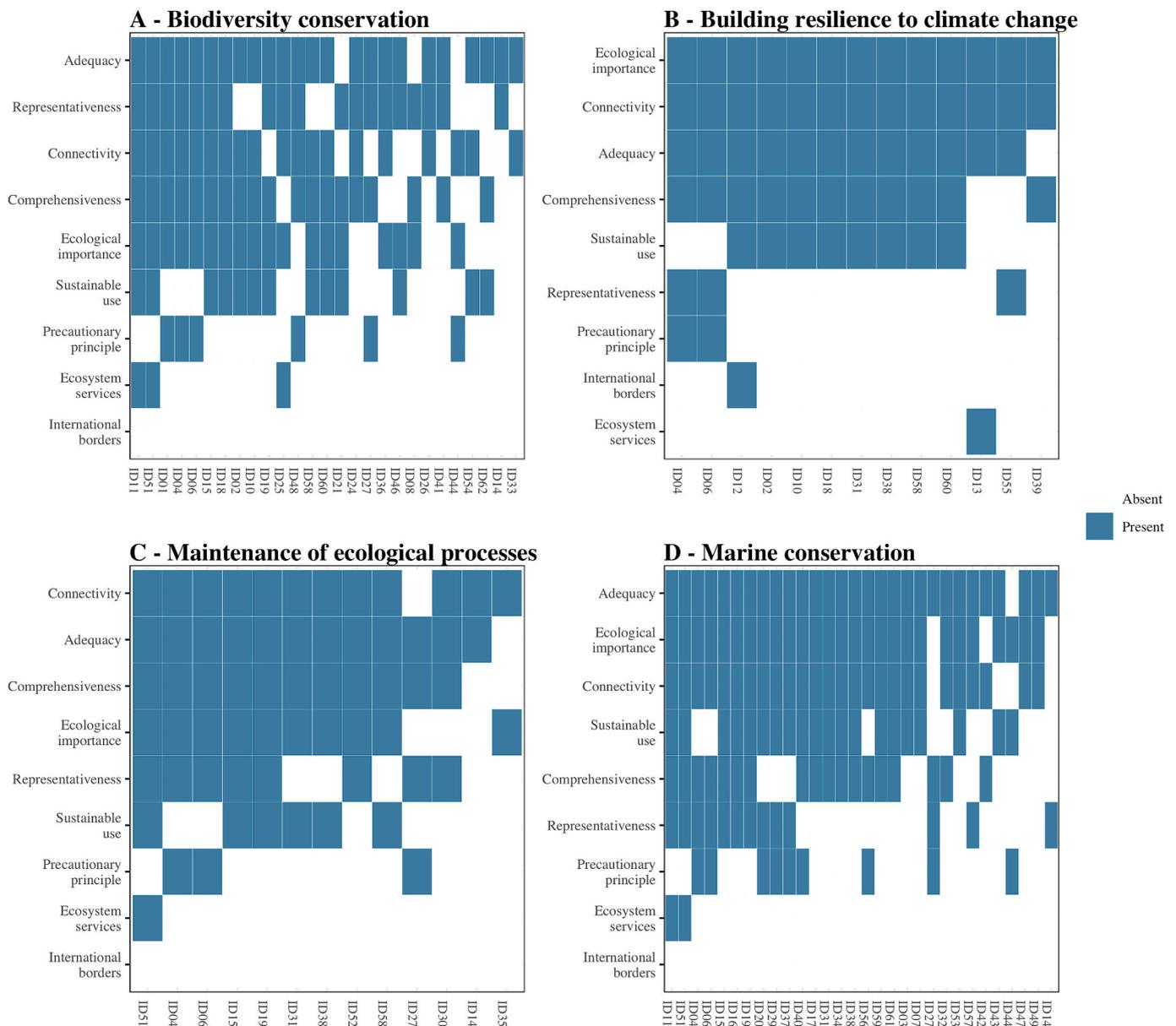


Fig. 3. Presence/absence matrix of the ecological guidelines used to achieve ecological MPA objectives: (A) “*biodiversity conservation*”, (B) “*building resilience to climate change*”, (C) “*assisting the maintenance of ecological processes*”, and (D) “*marine conservation*”. The x-axis shows the paper IDs (see Supplementary Material 1 Table S1 for ID details), while the y-axis presents the design guidelines. The presence of the design guidelines is indicated in dark blue. Data are ordered based on the subcategory with the highest number of design guidelines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

“*biodiversity conservation*”, the ecological guidelines most frequently combined in the design process are *Adequacy* (89%), *Connectivity* (74%) and *Comprehensiveness* (68%). When the MPA objective is “*marine conservation*”, the prevalent combination of guidelines is *Adequacy* (95%), *Ecological Importance* (91%), and *Connectivity* (86%). The most frequent ecological guidelines used for the MPA objective “*assisting the maintenance of ecological processes*” are *Connectivity* (91%), *Adequacy* (91%), and *Comprehensiveness* (82%) (Fig. 3).

The least occurring ecological guidelines are *International Borders* (i.e., fully protected areas located near international borders), occurring in one record with the MPA objective “*building resilience to climate change*”, and *Ecosystem Services* (i.e., benefits to humans from functioning of natural ecological systems) occurring in one record with MPA objectives of “*biodiversity conservation*” and “*marine conservation*”. In the MPA objective “*building resilience to climate change*”, the guidelines *Precautionary Principle* (i.e., protection of sites that are in relatively good

conditions to ensure future protection) and *Representativeness* (i.e., representation of genetic and biological ranges) are the least used (15%).

The design guideline that is the most frequently used across socioeconomic MPA objectives is *Equity* (95% of documents reporting socioeconomic MPA objectives; i.e., consideration of the diverse use of marine resources and encouragement to economic mechanisms that maximise economic and environmental benefits) (Fig. 4). Furthermore, for the MPA objectives “*ongoing ecologically sustainable use*”, *Equity* and *Cultural Identity* are frequently occurring with *Social Context* guideline (respectively 92%, 67%, and 50%, i.e., protecting resources that are important for local communities). The least frequent guideline is *Precautionary Approach* (i.e., precautionary protection when there is limited fisheries data), only used in one document with the MPA objective “*ongoing ecologically sustainable use*”. Only one document had the MPA objective “*cultural value*” with socioeconomic guidelines *Equity* and *Cultural Identity*. The *Tourism Sites* (i.e., protection of high-priority

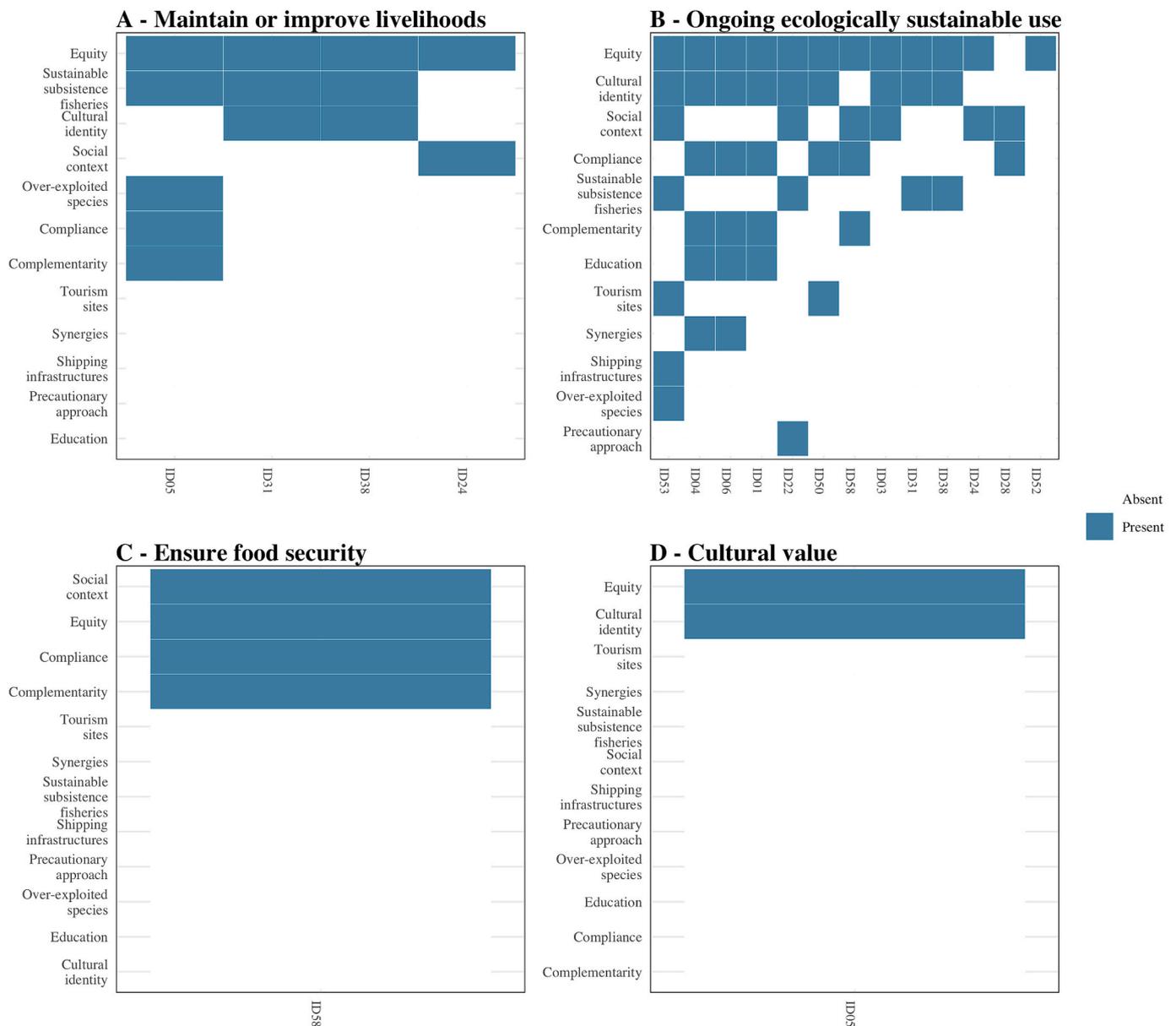


Fig. 4. Presence/absence matrix of the socioeconomic guidelines used to achieve socioeconomic MPA objectives: (A) “maintain or improve livelihoods”, (B) “ongoing ecologically sustainable use”, (C) “ensure food security”, and (D) “protect cultural value”. The x-axis shows the paper IDs (see Supplementary material 1 Table S1 for ID details), while the y-axis presents the design guidelines. The presence of the design guidelines is indicated in dark blue. Data are ordered based on the subcategory with the highest number of design guidelines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tourism sites) and *Shipping Structures* (i.e., protection away from shipping infrastructures) guidelines were only used in the “ongoing ecologically sustainable use” objective, 17 % and 8.3 % respectively.

We found only four documents that had governance MPA objectives (i.e., “community-centred conservation governance” and “effective legal structures”) and governance design guidelines (Fig. S4, Supplementary material 1). *Effective Management* (i.e., transparency in the decision-making process) and *Legitimacy* (i.e., stakeholders' engagement during every planning step) guidelines were used in all four documents, while *Knowledge Integration* (i.e., integration of knowledge to remain adaptable to new information) was not used in any document. The *Adaptive Management* (i.e., promotion of coproduction of knowledge and solutions) guideline was used in one document with the MPA objective “community-centred conservation governance” and the only document for “effective legal structures”. The *Leadership* guideline (i.e., clearly define whose responsible for the MPA implementation) was solely used in

“effective legal structures” objective.

3.3. Combination of guidelines across MPA objectives

We categorised MPA objectives into ten broad subcategories (i.e., 4 ecological, 4 socioeconomic, and 2 governance) (Table 1). We find that 34 documents had “marine conservation” as MPA objective, followed by “biodiversity conservation” (28 documents), and “ongoing ecologically sustainable use” (19 documents) (Fig. S4A, see Supplementary material 1). Many documents combined two or more MPA objectives; however, 36 documents only had one MPA objective (Fig. S4B, see Supplementary material 1).

A frequency heatmap was produced to visualise which guidelines are consistently used in the design process across different MPA objectives and to produce a synthesis of design guidelines to help MPA planners prioritise guidelines to facilitate the design process. Fig. 5 describes the

MPA Objectives

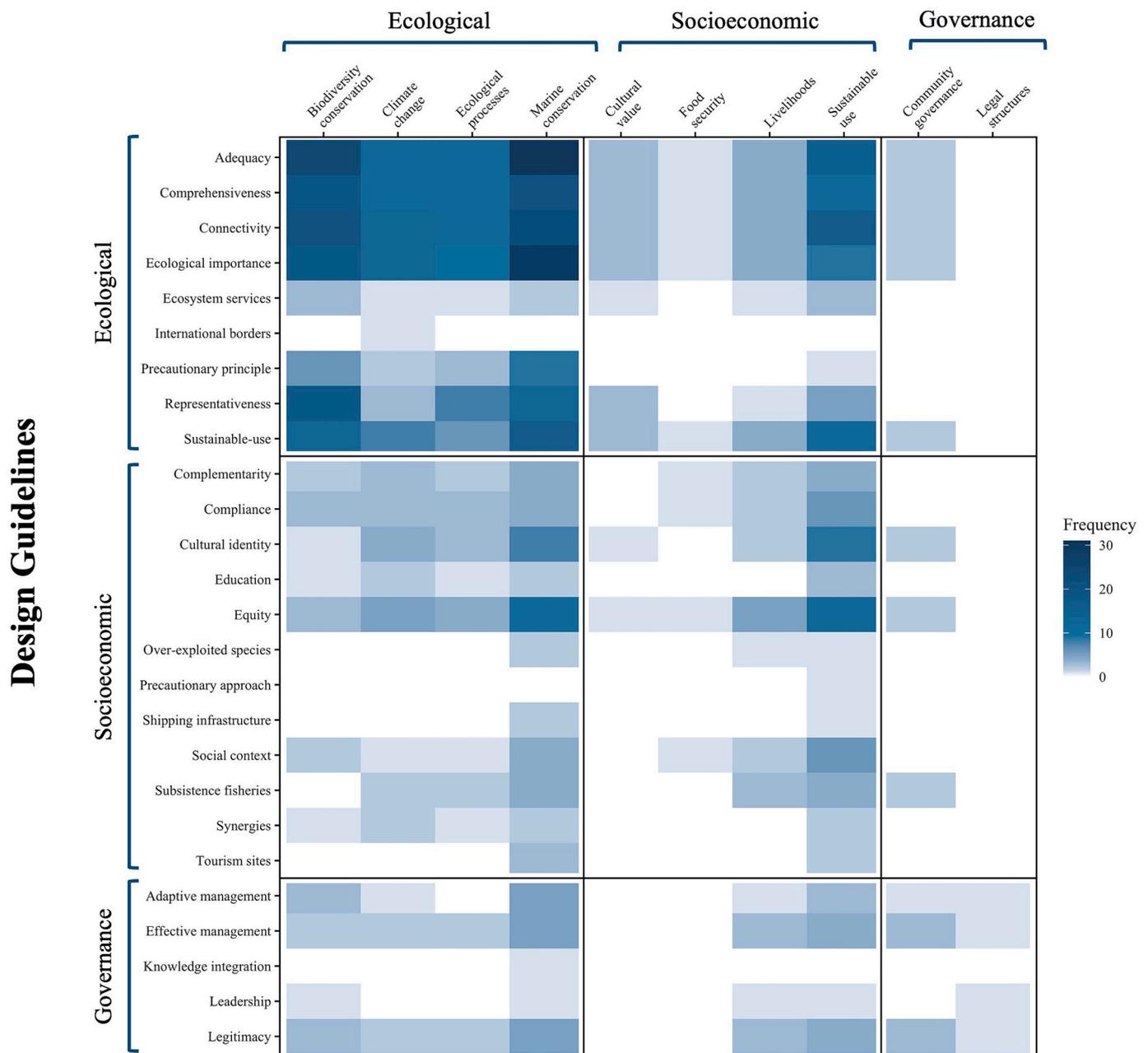


Fig. 5. Heatmap summarising the use of design guidelines across MPA objectives reported in the literature. MPA objectives are shown on the x-axis and design guidelines on the y-axis, grouped into ecological, socioeconomic, and governance categories. The shading represents the frequency of guideline use, ranging from white (absent) to dark blue (frequently used). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

frequency of use of ecological, socioeconomic, and governance design guidelines among an array of MPA objectives. When comparing the use of design guidelines among MPA objectives, ecological objectives have a higher frequency of ecological guidelines than socioeconomic objectives. Furthermore, socioeconomic design guidelines are more frequently used in ecological MPA objectives than in socioeconomic MPA objectives, likely due to the lower number of MPAs that aim to achieve socioeconomic objectives. Overall, there was a lack of ecological and socioeconomic design guidelines used to achieve governance MPA objectives, as well as a lack of governance design guidelines to achieve ecological and socioeconomic MPA objectives.

Ecological design guidelines that have the highest frequency are

Adequacy, Comprehensiveness, Connectivity, Ecological Importance, Representativeness, and Sustainable Use, used mostly to achieve ecological MPA objectives (e.g., “biodiversity conservation” and “marine conservation”) as well as for a few socioeconomic MPA objectives (e.g., “ongoing ecologically sustainable use”). Similarly, socioeconomic design guidelines that have the highest frequency are *Equity, Cultural Identity, and Compliance* to achieve both ecological and socioeconomic MPA objectives. Finally, governance design guidelines were the least frequent in the literature; however, of the five governance design guidelines found, three were more frequently used across all MPA objectives (i.e., *Adaptive Management, Effective Management, and Legitimacy*).

The high frequency of some ecological and socioeconomic design

guidelines suggests these are priority guidelines in MPA design. However, many of these design guidelines are almost absent when addressing governance MPA objectives. Even though ecological guidelines are the most used, our synthesis shows that some socioeconomic and governance guidelines have been used in the literature to address some MPA objectives.

4. Discussion

We synthesise existing MPA design guidelines to assess the extent to which ecological, socioeconomic, and/or governance guidelines are integrated in current MPA design. Our analysis revealed that current design approaches favour ecological guidelines, with considerably less attention given to socioeconomic and governance guidelines. Although there is increasing recognition of the need for integrated design approaches, this is not consistently reflected in current practice. We discuss use patterns in design guidelines and their integration in the literature and in practice.

4.1. Ecological guidelines across ecological MPA objectives

The most frequently used ecological guideline among ecological MPA objectives is *Adequacy*. *Adequacy* refers to an MPA network's capacity to contribute to long-term protection (Beaver and Llewellyn, 2009); it assures ecological sustainability within the network, promotes connectivity, and preserves the integrity of ecological processes (Day et al., 2002). More specifically, *Adequacy* ensures that MPAs are adequately sized, shaped, and replicated, habitat fragmentation is avoided, and connectivity is considered.

Size is a critical component of *Adequacy*; the MPA should be sufficiently large to achieve its ecological objectives (Laffoley, 2013). Larger areas are considered to be ecologically better than smaller areas in achieving biodiversity conservation (Department for Environment and Heritage, 2008; Kirkman, 2013). Compact MPA shapes, such as circular, are preferred ecologically as they minimise protected species movements to unprotected areas (Fernandes et al., 2012; Munguia-Vega et al., 2018; Ohayon et al., 2021). However, circular shapes are harder to identify in navigation charts and on-site (Horta et al., 2022); consequently, shapes such as squares or rectangles are preferred, as they still minimise edge effects (McLeod et al., 2009; Day, 2017). In terms of replication, MPAs should include a sufficient number and connectivity of each habitat type to facilitate the movement of protected species from propagules to adults, and spread the risk from natural and anthropogenic impacts (Ballantine, 1997; McLeod et al., 2009; Laffoley, 2013; Kirkman, 2013; Fernandes et al., 2012; Munguia-Vega et al., 2018; Department of Biodiversity, 2023; Green et al., 2009, 2014; Cinner et al., 2010; Agardy et al., 2011; Jaya et al., 2022; Arafeh-Dalmau et al., 2023).

This review finds *Adequacy* and *Connectivity* frequently co-occurring. In general, *Connectivity* is related to the adequacy of MPAs in size, number, and spacing, especially in fully protected areas (or marine reserves). The recommended size of a fully protected area depends on the dispersal potential of protected species, population growth rate, and fishing pressure (Roberts et al., 2001). Alternatively, fully protected areas can be smaller but numerous if they are part of an MPA network; these areas are connected through the dispersal of adults and larvae (Hastings and Botsford, 1999). A variety of sizes (Chiappone and Sealey, 2000) and spacing can be applied to the network to achieve connectivity (Roberts et al., 2003b) based on the targeted species, their movement extent, and other management beyond the MPA network (Green et al., 2014).

Comprehensiveness and *Ecological Importance* are the guidelines that are combined the most with *Adequacy* and/or *Connectivity* in MPA design. The *Comprehensiveness* guideline is often included in the design process to ensure that linkages between habitats and ecosystems are considered to secure a wide range of connections (McCook et al., 2009). On the other hand, *Ecological Importance* ensures the protection of

ecologically important (Précoma-de La Mora et al., 2021; Department for Environment and Heritage, 2008; Department of Biodiversity, 2023; Roberts et al., 2001; Chiappone and Sealey, 2000), vulnerable, critical, or endangered species and/or habitats (Fernandes et al., 2012), ecological hotspots (Précoma-de La Mora et al., 2021; McLeod et al., 2009; Department for Environment and Heritage, 2008; Fernandes et al., 2012, 2005; Munguia-Vega et al., 2018; Roberts et al., 2001), and resilient areas (Department of Biodiversity, 2023; Roberts et al., 2001; Armitage et al., 2020). *Comprehensiveness* and *Ecological Importance* guidelines complement the aims of *Adequacy*, which promotes sustainability within the network and preserves the integrity of ecological processes (Beaver and Llewellyn, 2009), and *Connectivity*, which ensures all linkages and connections are considered in the design process (McLeod et al., 2009; Laffoley, 2013; Fernandes et al., 2012; Munguia-Vega et al., 2018; Arafeh-Dalmau et al., 2023; Green et al., 2014). MPAs should include self-sufficient, widely spaced areas that enable ecosystem continuity (Laffoley, 2013). The area selected as ecologically important can support rapid growth of ideal habitats, maintain ecological processes, support rare and/or endangered species, support species or other systems that rely on it, and contain whole ecological units (Department for Environment and Heritage, 2008). Adopting a guideline that aims to designate natural areas in MPAs underscores the importance of balancing conservation efforts with extractive activities (Kirkman, 2013).

The least used guideline across all MPA objectives is *International Borders*, used in one record with the MPA objective of “building resilience to climate change”. *Connectivity* guidelines recommend considering dispersal ranges for marine organisms, migration routes, and species movement patterns (Table 2). These movement patterns are expected to be significantly affected by environmental changes, hence potentially driving a shift in species distribution (Poloczanska et al., 2013; Pinsky et al., 2020), often crossing international borders. Therefore, the *International Borders* guideline recommends locating fully protected areas near international borders, where there is strong transboundary connectivity that can enhance national conservation measures (Arafeh-Dalmau et al., 2023). The placement of MPAs near international borders allows the protection of migratory and shifting species as these move across borders (Gaines et al., 2010).

The guideline *Sustainable Use* is most frequently used in the MPA objective “marine conservation”. *Sustainable Use* guidelines restrict marine resources access within the MPA (Fernandes et al., 2012), especially habitats sensitive to natural or human-induced threats (Asaad et al., 2017). *Sustainable Use* suggests that to allow time for recovery (Green et al., 2020), management measures such as no-take areas, prohibition of destructive gear, and access limits should be in place in the long term, preferably permanently (Précoma-de La Mora et al., 2021; Fernandes et al., 2012; Munguia-Vega et al., 2018; Green et al., 2014; Lopera et al., 2023). To further ensure that biodiversity is protected from human activities and its integrity is maintained as much as possible, placing MPA boundaries at habitat edges is recommended to reduce the movement of protected species to fished areas (Fernandes et al., 2012; Gaines et al., 2010).

Two key factors to achieve *Sustainable Use* are: 1) Consider the current and future uses of the area, especially the vicinity of threats and other protected areas (e.g., areas adjacent to terrestrial National Parks probably have more biological integrity than heavily exploited areas) (Roberts et al., 2001; Fernandes et al., 2009); 2) Assess whether community patterns are a consequence of natural processes or human influence (Green et al., 2009). The *Sustainable Use* guideline also has a strong link with the “biodiversity conservation” objective. Establishing an MPA with biodiversity objectives should also aim to reduce impacts to existing users of the marine environment, which includes both compatible (e.g., education, research, tourism) and incompatible activities (e.g., recreational and commercial fishing, dredging, mining) (Lundquist et al., 2015). The *Sustainable Use* guideline ensures this balance.

The *Precautionary Principle* and *Representativeness* were frequently co-occurring guidelines in records with “*building resilience to climate change*” as an MPA objective. The *Precautionary Principle* guideline should be applied when there is a lack of scientific knowledge, unknown current and future threats, and a lack of certainty (Ballantine, 1997; Department for Environment and Heritage, 2008; Kirkman, 2013), thus making this guideline a proactive approach to the protection of the marine environment (Department of Biodiversity, 2023). While the *Ecological Importance* guideline prioritises more resilient and resistant areas in fully protected areas (Munguia-Vega et al., 2018), a precautionary approach that prioritises less resilient or heavily damaged areas in MPAs (Antrim, 2019) can decrease other human-induced impacts and can help build resilience to climate change (Roberts et al., 2017). Similarly, the *Representativeness* guideline ensures that biodiversity is represented across biological and genetic diversity and variability (Department of Biodiversity, 2023). As much information regarding biodiversity is still uncertain or unknown, ecosystems or habitats can be used as surrogates (Department of Biodiversity, 2023) based on the best available information. The integration of the *Precautionary Principle* and *Representativeness* ensures that MPAs can anticipate and mitigate risks associated with uncertainty, therefore aiming to improve the resilience of marine ecosystems to climate change.

4.2. Socioeconomic guidelines across socioeconomic MPA objectives

We find *Equity* the most frequently used guideline across all socioeconomic MPA objectives (Fig. 4). The *Equity* guideline encourages the development of economic mechanisms that maximise socioeconomic and environmental benefits (Précoma-de La Mora et al., 2021), considering the diverse uses of marine resources (Kirkman, 2013; Department of Biodiversity, 2023), current and future (Mangubhai et al., 2015). Furthermore, this guideline is used to assess the implications of MPA establishment for the stakeholders and their use rights, promoting equitable distribution of costs and benefits (Précoma-de La Mora et al., 2021). With these key considerations in mind, the MPA should be designed to minimise avoidable disruption to livelihoods while still upholding the MPA objectives (Kirkman, 2013). The *Equity* guideline particularly aligns with the MPA objective “*maintain or improve livelihoods*”. By aiming to “*maintain or improve livelihoods*”, MPAs are intended to protect natural resources while sustaining local communities' economic activities (e.g., Cinner et al., 2010; Charles and Wilson, 2009; Pollnac et al., 2001). This approach also ensures that conservation measures do not undermine the economic stability of those who rely on marine resources. Similarly, the integration of *Cultural Identity* guidelines acknowledges and respects local resource owners, traditional fisheries management approaches, and conservation practices (Green et al., 2009). Identifying cultural values is particularly important in areas with a significant number of indigenous communities since placing MPAs in these areas can limit access to marine resources, disrupt economic stability, and cause conflicts between users who are competing for the same limited resource (Agardy et al., 2011). Therefore, linking livelihoods with equitable use and cultural value can incentivise local communities to support conservation measures, especially when there are tangible results (e.g., increased tourism revenue or improved fisheries).

The counterpart of the ecological *Precautionary Principle*, the socioeconomic *Precautionary Approach* was used in one record with the MPA objective “*ongoing ecologically sustainable use*”. In this MPA objective, the *Precautionary Approach* aids the decision-making process in complex fisheries or when there is limited/inconsistent data on the fisheries status, both of which lead to uncertainty (Jaya et al., 2022). The greater the uncertainty, the more conservative the approach should be. In fisheries management, key considerations to manage uncertainty include maintaining conservative levels of allowable catch guidelines and strengthening the role of science in management decisions to increase confidence levels (Jaya et al., 2022). Furthermore, “*ongoing*

ecologically sustainable use” is closely associated with *Over-exploited Species* guidelines (Tables 1 and 2). However, our records show that the *Over-exploited Species* guideline was not used to achieve the “*ongoing ecologically sustainable use*” objective. MPAs that are established with the objective of “*ongoing ecologically sustainable use*” aim to provide social and economic benefits and sustainable use (extractive and non-extractive) of marine resources. The *Over-exploited Species* guideline focuses on paying particular attention to species that are susceptible to over-exploitation, protecting key sites (e.g., aggregation sites, nursery sites) from exploitation (Mangubhai et al., 2015). This guideline suggests the banning of unsustainable commercial fishing, especially the export trade of live fish for food and other fisheries that overexploit targeted species (Green et al., 2009).

4.3. Governance guidelines in MPA design

This review found only four studies that included governance guidelines in the design of MPAs. The gap is notable, particularly considering the growing evidence that governance is a significant factor in MPA success (Hogg et al., 2017; Chaigneau and Brown, 2016; Bennett et al., 2019, 2020). Particularly, equitable enforcement has been shown to enhance MPA effectiveness (Jones and Long, 2021), underscoring the need for greater attention to governance in both the planning and maintenance processes. Thus, the decisions made on how MPAs are governed are crucial.

Non-inclusive marine spatial planning has often led to conflicts among its users and between government bodies (Katsanevakis et al., 2011; Frazão Santos et al., 2021). An integrated planning approach addresses these conflicts by adopting a comprehensive approach that considers ecological and socioeconomic factors as well as promoting the enforcement of governance structures (Crowder and Norse, 2008). In published records, we found only two governance MPA objectives: “*community-centred conservation governance*” and “*effective legal structures*”. A “*community-centred conservation governance*” recognises that conservation initiatives can be (and should be) led by any stakeholder, including rights holders and protected areas, or other effective management approaches, are supported by local resource users while providing positive social and ecological outcomes (Armitage et al., 2020). Similarly, the objective “*effective legal structures*” aims to ensure adequately designed and enforced legislation/rules and promotes governance structures that balance the needs of the resource users while coordinating efforts across different authorities and stakeholders (Dickinson et al., 2010). While we found a paucity of ecological and socioeconomic guidelines for governance goals, we infer that this is likely due to the paucity of studies reporting governance goals. We expect a more prominent role of ecological and social guidelines than what our synthesis currently shows given the explicit or implicit links of governance goals to ecological and social dimensions, i.e., “positive social and ecological outcomes” is an intended outcome of “*community-centred conservation governance*” MPA objective, and achieving the “adequately designed and enforced legislation/rules” definition of “*effective legal structures*” MPA goal depends on the local ecological and social attributes.

Five key guidelines should be considered in MPA governance (adapted from Précoma-de La Mora et al. (2021), Lundquist et al. (2015), and Dickinson et al. (2010)):

1. Establishing and ensuring legitimacy and institutional continuity – stakeholder engagement should be conducted during every step of the planning process, prioritising the protection of areas that are supported by the stakeholders (Green et al., 2020, 2019). This ensures the involvement of local communities and vulnerable groups and the development of a legal framework of collective vision (Précoma-de La Mora et al., 2021).
2. Implementing collaborative and adaptive management – monitoring and evaluation programs should be established to promote

coproduction of knowledge and timely communication of results (Précoma-de La Mora et al., 2021; Armitage et al., 2020), with the obtained information potentially leading to alternative management actions. Competent authorities should be integrated to enforce consistent and impartial regulations, ensuring conservation without harming third parties (Précoma-de La Mora et al., 2021).

3. Promoting effective management – ensure transparency in the decision-making process and accountability of stakeholders by setting up clear procedures, consensual plans, and periodical reviews of agreements (Précoma-de La Mora et al., 2021; Lundquist et al., 2015).
4. Knowledge integration and adaptability – maintain the governance processes adaptable to the rise of new information and promote dialogue between stakeholders involved in the conservation approach (Lundquist et al., 2015).
5. Leadership and Accountability - the responsibility for implementation needs to be clearly defined and outlined, and leadership should be held at the highest government levels (Dickinson et al., 2010).

While the number of studies on MPA effectiveness is growing, empirical assessment on governance, equity, and justice is still in the early development stages (Jones and Long, 2021). Given the importance of governance and justice in the success of MPAs, there is also an increasing need to assess and address the inequities that derive from unjust and exclusionary governance of MPAs (Jones, 2009; Hampton-Smith et al., 2024; Bennett, 2018).

4.4. Towards developing an operational framework for MPA planners

As MPA design guidelines are continuously being published in the literature for various habitats, our synthesis of design guidelines could aid MPA planners in their selection of design guidelines. Previous reviews have often summarised design guidelines in terms of ecological requirements for achieving conservation objectives in MPAs, and have highlighted inconsistencies in their guidelines (e.g., size, number of replicates) (Burns et al., 2023). These inconsistencies often reflect variations in spatial scale and context across MPAs reported in the literature (Burns et al., 2023). As a result, guidelines developed for different scales (i.e., large versus small MPAs) should not be compared (e.g., guidelines for Kimbe Bay, Papua New Guinea, and guidelines for the Great Barrier Reef, Australia; Green et al., 2009; Fernandes et al., 2005; Fernandes et al., 2009; Green et al., 2007). In this review, design guidelines are simplified and synthesised beyond their scale. Our design guidelines synthesis is to be used as a general, indicative suggestion of what scientific information is needed to achieve various MPA objectives, not just limited to conservation efforts.

The synthesis of design guidelines can inform an MPA design tool, facilitating the establishment of effective MPAs. All MPAs require objectives to achieve; our design guidelines synthesis pinpoints these objectives and the design guidelines commonly used to achieve them. Given an MPA objective, frequently used design guidelines (as indicated by the darker shading in Fig. 5) reflect those that are more extensively studied and could be prioritised in MPA design. Although frequency alone should not determine priority, it can provide insight into which guidelines are more empirically and theoretically grounded. Importantly, prioritisation of more frequently used design guidelines should not exclude the selection of less frequently used design guidelines; rather, it should encourage a more integrative MPA design. While ecological design guidelines are often central in MPA planning, many socioeconomic and governance design guidelines (e.g., *Equity*, *Social Context*, *Legitimacy*) can contribute to fairly selecting sites to protect and should therefore be included in the early stages of MPA planning.

Our design guidelines synthesis was developed as a need due to the lack of an integrative MPA design we initially observed in the literature, and confirmed by this review. Only a few recent records simultaneously included ecological, socioeconomic, and governance design guidelines

in MPA design. For example, the study conducted by Précoma-de La Mora et al. (2021) included ecological, socioeconomic, and governance guidelines to achieve marine conservation and sustainable use ('fisheries management' in the literature, Table 1) MPA objectives in three regions of Mexico. Similarly, the reports by Green et al. (2020, 2019) for designing MPAs in Indonesia focused on providing biophysical, socioeconomic, and cultural goals as well as biophysical, socioeconomic, and cultural guidelines to achieve such MPA goals. Few other records have combined ecological and socioeconomic aspects in their planning and design processes. For instance, Kirkman (2013) developed socioeconomic design guidelines in addition to ecological (or biophysical) guidelines for South Australia MPAs. Here, socioeconomic guidelines aimed to recognise the diverse uses and users of the marine systems and ensure that they would align with MPAs to support continued and sustainable future uses (Kirkman, 2013). MPAs are complex management tools often involving multiple jurisdictions and comprising intricate ecological processes; therefore, integrative MPA design is necessary to achieve MPA success and effectiveness (Horta et al., 2022).

Our consolidated design guidelines for MPA planners can be very useful during the MPA design stage, helping to harmoniously meet the needs of all stakeholders involved. In many countries, MPAs are established ad hoc, resulting in ecologically unsustainable MPAs due to inadequate planning of management needs (e.g., in Sri Lanka; Perera and De Vos, 2007). Because the identification of areas for protection includes analysing criteria that affect their ecological and socioeconomic processes (Fernandes et al., 1999), this identification procedure requires the integration of various scientific (i.e., ecological), socioeconomic, and political factors (as part of governance) (Stevens, 2002). Basing plans solely on one single criterion is often an unsuccessful strategy, as these plans are unable to address the complexity of the problem effectively (Fernandes et al., 1999). Considering the complexity of marine systems and their adjacent social communities, there is a need to better incorporate socioeconomic and governance information in the planning and design processes.

4.5. Limitations and future directions

We found a few potential limitations to our review and points for future research. Of the 62 documents that were included in our review, only 12 focused on specific MPAs, MPA networks, or sites. Kimbe Bay MPA Network and the Great Barrier Reef Marine Park recorded two documents each, implying that by summarising information by documents, some guidelines referencing the same site might have been included twice, which may affect the results of the frequency heatmaps. Due to the low number of case studies, the relationship between overarching network-level guidelines and site-level guidelines within the same network could not be explored further. Further investigation should focus on collecting documents from both the MPA network and MPAs within the network to compare site-specific design guidelines to the network's overarching design guidelines. Furthermore, due to the low returned documents discussing specific MPAs, other aspects, such as the status of the MPAs (e.g., implemented, actively managed, etc. following the MPA guide) or the location of the MPAs (i.e., remote, inshore, offshore), could not be further investigated.

We also note that there is a chance that our findings on the low number of governance design guidelines and MPA objectives could be potentially due to a biased literature search. Specifically, social science databases were not included in the literature search, nor were databases with a wider collection, such as ProQuest. Broadening the search could have returned a wider variety of documents and more documents that include the use of governance guidelines. Similarly, the combination of database and Boolean keywords syntax chosen to retrieve literature might not have returned all peer-reviewed and grey literature documents that are published. Although our systematic review search has returned a good representation of peer-reviewed and grey literature documents, we are aware that a few peer-reviewed and grey

publications focusing on MPA networks in some countries and regions were not returned in our document search. For example, our search retrieved [Ardron et al. \(2015\)](#), which includes ecological guidelines and one socioeconomic guideline for MPA Network planning in Canada's Northern Shelf Bioregion, while other documents relating to the same MPA planning process (e.g., [Lieberknecht et al., 2016](#)) were not captured and may capture a broader range of design guidelines. Finally, while we briefly discussed the lack of governance MPA objectives and design guidelines, further studies should investigate whether this lack is due to a gap in best practices, a gap in implementation, or regional differences in design. More specifically, it is important to explore the different systems of governance and governments, as many do not include community participation, influencing the integration of governance in MPA objectives and design guidelines.

In our synthesis, we limited our scope to the frequency of usage of different design guidelines, suggesting the integration of less frequently used guidelines with those more frequently used. Given the growing recognition that MPAs need to be ecologically effective and equitably reinforced, future work should focus on the comprehensiveness of MPA objectives and design guidelines for individual MPAs and the research on implementation challenges or successes.

5. Conclusions

Despite the recognition of the need for an integrated MPA design approach, many MPAs have been, and continue to be, designed without adequate consideration of social systems. While there is increasing availability of the best ecological knowledge, socioeconomic and governance information are still limited/insufficient. As a result, MPA design has mostly been guided by ecological guidelines to achieve conservation objectives ([Hopkins et al., 2020](#)), with little attention on how they affect social systems. This imbalance increases the risk that MPA success is causing unintended negative social impacts to adjacent communities (e.g., conflicts and dislocation of local communities) ([Christie, 2004](#)). These negative impacts are often associated with poorly designed MPAs that failed to consider local needs ([Bennett et al., 2021](#)), excluded local communities from the decision-making processes, and limited their access to sites important for their livelihoods and survival ([Agrawal and Redford, 2009](#); [Brockington and Igoe, 2006](#)), thereby causing social inequities. Therefore, MPA success should be assessed through a combination of ecological (e.g., connectivity, size, and shape; [Agardy et al., 2011](#); [Mascia et al., 2010](#)) and social (i.e., socioeconomic and governance, such as effective enforcement within MPA boundaries; [The Ecology Centre, The University of Queensland, 2009](#)) criteria even though the main objective of the MPA is only conservation or fisheries (or other objectives like tourism). The broad sets of guidelines reported here for various MPA objectives can be used as a starting point for designing more successful and equitable MPAs, but should be flexible enough to incorporate local contexts and idiosyncrasies. Furthermore, such ecological and social criteria should be integrated in the planning stages of the MPA by applying design guidelines that promote the achievement of MPA objectives while minimising negative impacts on adjacent ecosystems and communities. Without this integrated approach, poor MPA planning and implementation can generate significant costs without achieving any of the intended MPA objectives.

A notable gap remains in the integration of ecological, socioeconomic, and governance considerations, essential for the effectiveness of MPAs ([Meehan et al., 2023](#)). Although numerous design guidelines are scattered across the literature, they principally focus on ecological criteria ([Giakoumi et al., 2018](#); [Burns et al., 2023](#); [Gill et al., 2017](#)), with less attention on criteria that quantify socioeconomic and governance needs ([Jones et al., 2017](#)). MPA design should ideally integrate the local environmental, socioeconomic, and governance context ([Agardy et al., 2011](#)). MPA design should also consider both negative and positive socioeconomic impacts on the adjacent communities ([Mascia et al., 2010](#))

to ensure that MPAs are responsive to social factors. Additionally, the design process should involve local stakeholders in the early planning stages ([Salm et al., 2006](#)) as well as ensuring equitable enforcement to enhance MPA effectiveness ([Jones and Long, 2021](#)). Therefore, new approaches place emphasis on both the ecological effectiveness of MPAs and their ability to provide socioeconomic benefits to local communities (e.g., [Ban et al., 2011](#)). Similarly, governance operates across governments, communities, and economic systems, and can generate complex dynamics when local actors are not involved and when equity and justice are not adequately addressed ([Battaglia et al., 2025](#)). While even in cases where there is a strong will for the protection of marine resources, conflicts can arise between involved actors ([Jones et al., 2019](#)). Recently established MPAs that have incorporated governance guidance early in the design process have set clear governance guidelines to hold involved actors accountable for their actions (e.g., [Précoma-de La Mora et al., 2021](#); [Lundquist et al., 2015](#); [Dickinson et al., 2010](#)). This trend shows a growing recognition that MPAs need to be ecologically effective, equitably reinforced, and socially just to ensure long-term success ([Gaines et al., 2010](#)). While the integration of ecological, socioeconomic, and governance guidelines is suggested to ensure this long-term success, such an integrated approach has not been consistently applied in MPA planning and is often under-represented in the literature.

This literature review highlights use patterns in the application of design guidelines for MPAs. We find that ecological guidelines are prominent in MPA design guidelines, as characteristics such as size, shape, replication, ecological importance, and connectivity play an important role in siting MPAs. While socioeconomic guidelines were considerably less used than ecological guidelines, they were still addressed in several documents. In contrast, MPA governance guidelines and objectives are considerably under-represented in the literature, thereby underlining the need to integrate governance context in the design stages of MPAs to ensure fairness and equity. These findings suggest that a comprehensive approach to MPA design (i.e., through the integration of ecological, socioeconomic, and governance guidelines) can better capture the complex nature of MPAs. Further studies should focus on testing ecological, socioeconomic, and governance guidelines to see whether the use of each guideline can produce co-benefits or tradeoffs across different MPA objectives. By integrating ecological, socioeconomic, and governance guidelines in the design process, MPA design can be improved, thus ensuring that MPAs are equitable, just, and meet their objectives.

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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

Data are provided in Supplementary material 2. Additional datasets and scripts used for the analysis are available on GitHub at the following repository: <https://github.com/alessiacosta/MPA-guidelines-analysis.git>.

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