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Conservation planning for threatened marine megafauna: Moving forward with a better approach

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Abstract

1. For threatened marine megafauna, such as the Indo-Pacific humpback dolphin (*Sousa chinensis*), sound conservation planning should aim to ensure demographic and ecological persistence of populations. One method to address this challenge is through ecosystem-based conservation planning (ECP) based on threatened marine megafauna distribution, biodiversity richness, and ecosystem functionality.
2. ECP exercises for the Indo-Pacific humpback dolphin in Chinese and adjacent northern Vietnamese waters were conducted based on the Indo-Pacific humpback dolphin distribution, Hill-2 biodiversity index, and marine net primary productivity. Habitat protection priorities were scored using the program MARXAN and were used to identify special areas for conservation (SACs) for the Indo-Pacific humpback dolphin.
3. To ensure the minimal risk of local extinction, the SACs enclosed a total of 26,858 km^2 of waters, accounting for 49.9% of core habitats of the Indo-Pacific humpback dolphin and 24.3% of the IUCN Red List species in the study region. To enclose 30% of biodiversity richness and ecosystem functionality, a total of 40,179 km^2 SACs was required.
4. In the context of threatened marine megafauna conservation, megafauna distribution can be used to highlight focal areas, while information on biodiversity richness and ecosystem functionality should be factored in. Using surrogates with different ecological niches would be a better tactic to ensure sufficient protection coverage by minimizing the omission bias.
5. The conservation of threatened marine megafauna in coastal and estuarine waters shares similar objectives with global marine biodiversity conservation. The challenges to conduct ECP exercises come from data scarcity and poor data quality in representing distributions of biodiversity features. A certified open-access database that shares survey effort, occurrence, population density, and habitat mapping at national and local scales is recommended. Such a result requires national planning, investment, and policing.

Shiang-Lin Huang and Haiping Wu contributed equally to this article.

KEYWORDS
biodiversity richness, ecosystem functionality, ecosystem-based conservation planning, Indo-Pacific humpback dolphin, MARXAN, surrogate

1 | INTRODUCTION

Challenges in conservation planning for threatened marine megafauna in coastal and estuarine waters come not only from the intensification of coastal development and engineering activities (Huang et al., 2022), but also from the complexity of conservation planning and implementation. Marine megafauna generally have broad distribution ranges spanning national, ecoregional, or even continental regions (Sequeira et al., 2019; Morrick et al., 2021), and these are often difficult to survey completely (Hammond et al., 2021) and protect (Wang et al., 2021; Huang et al., 2022). For threatened marine megafauna, such as the Indo-Pacific humpback dolphin (*Sousa chinensis*), sound conservation planning needs to ensure the identification of special areas for conservation (SACs) that can provide sufficient space to accommodate a viable population (Karczmarski, Huang & Chan, 2017b). Throughout the range of the Indo-Pacific humpback dolphin (Huang et al., 2022), many existing marine protected areas (MPAs) do not meet this requirement (Hu et al., 2020). Many marine megafauna species are top predators in the marine ecosystem and are highly sensitive to changes in marine environments (Hazen et al., 2019). Conservation planning for top predators of marine megafauna further needs to consider the maintenance of ecosystem functionality, which provides nutrient–energy provision and offspring nursery functions (Hooker, Whitehead & Gowans, 2002; Srivastava & Vellend, 2005) and in this way ensure the SACs can ecologically accommodate a persistent population (Hooker, Whitehead & Gowans, 2002; Hazen et al., 2019). Biodiversity richness has been reported as one of the major determinants of ecosystem functionality (Tilman, Isbell & Cowles, 2014), and MPAs can effectively restore critical ecosystem functionality as well as biodiversity richness (Cheng et al., 2019). The conservation of threatened marine megafauna in coastal and estuarine waters shares similar objectives with global marine biodiversity conservation.

Conventional conservation planning for threatened marine megafauna concentrates on occurrence 'hotspots' of the target species, but omits areas connecting 'hotspots' (Chou et al., 2011; Colléony et al., 2017; Huang, Wang & Yao, 2018; Wang et al., 2021) and seldom takes account of the importance of biodiversity richness and ecosystem functionality to ensure a persistent environment for the target species (Hooker, Whitehead & Gowans, 2002). Such shortfalls become obvious when dealing with the protection of charismatic, but threatened or endangered, flagship species, such as whales and dolphins. The debate over habitat protection planning for the Critically Endangered Indo-Pacific humpback dolphin in the eastern Taiwan Strait in the early 2010s (Chou & Lee, 2010; Ross et al., 2010; Chou et al., 2011) provides a classic example. In that habitat protection planning, conservation attention was focused on two separate 'hotspots' for the Indo-Pacific humpback dolphins and overlooked the 'connective waters' where dolphin sightings are seemingly sporadic (Chou & Lee, 2010). The areas of the two 'hotspots' are much smaller than the threshold to spatially maintain a viable population (Karczmarski, Huang & Chan, 2017b). During the past five decades, habitats of the Indo-Pacific humpback dolphin in the eastern Taiwan Strait have been impacted by intense coastal maritime engineering (Karczmarski et al., 2017a; Huang et al., 2022), rising sea-surface temperatures, and declining marine primary production (Huang, Wang & Yao, 2018). This 'hotspots-based' conservation planning, once implemented, would confine dozens of remaining dolphins into small but functionally deteriorated 'hotspots' with impeded individual movements (Yeh, 2011), thus substantially increasing the probability of local extinctions (Huang, Chang & Karczmarski, 2014; Karczmarski, Huang & Chan, 2017b).

Ecosystem-based conservation planning (ECP) aims to achieve biodiversity richness and ecosystem functionality (Weaver & Johnson, 2012; IUCN, 2016a; da Luz Fernandes, Quintela & Alves, 2018) through the use of zoning tools offering species and biodiversity layers, such as marine Ecologically or Biologically Significant Areas (marine EBSAs) (Weaver & Johnson, 2012; Bax et al., 2015; Dunstan et al., 2016), Key Biodiversity Areas (KBAs) (IUCN, 2016b; Hoyt, 2018), and Important Marine Mammal Areas (IMMAs) (IUCN-MMPATF, 2020). Marine megafauna are often recommended as surrogates to protect marine biodiversity richness in ECP exercises (Zacharias & Roff, 2001; Hooker & Gerber, 2004; Sergio et al., 2008; Hazen et al., 2019; Wang et al., 2021), with the advantage that this attracts public attention and funding (Zacharias & Roff, 2001; Sergio et al., 2008). In practice, the difficulties of using ECP exercises as a spatial tool for marine megafauna conservation come from the lack of explicit connection between biodiversity/ecosystem features and megafauna distribution, the mismatch of distributions between selected biodiversity–ecosystem targets and megafauna, and data scarcity/poor data-quality representing distributions of marine megafauna, marine biodiversity, and ecosystem at an ecoregional or national scale (Agardy et al., 2003; Sergio et al., 2008; Spalding et al., 2016; Wang et al., 2021). ECP exercises that do not address these gaps can report over-optimistic protection coverage (Weaver & Johnson, 2012; Smallhorn-West & Govan, 2018) but omit habitats critical for maintaining biodiversity richness and ecosystem functionality, as well as population connectivity (Rodrigues & Brooks, 2007; Sergio et al., 2008; Colléony et al., 2017; Wang et al., 2021).

In southern China and South-east Asia, conservation of the Indo-Pacific humpback dolphin has been accompanied by heated discussion in association with marine biodiversity and ecosystem conservation in coastal and estuarine waters (Jefferson et al., 2017; Huang et al., 2022). Existing MPAs in the range of the Indo-Pacific humpback dolphins do not provide sufficient spatial protection (Jefferson, 2018; Hu et al., 2020; UNEP-WCMC & IUCN, 2020; Wang et al., 2021). This insufficiency may be particularly acute in Chinese waters, as humpback dolphin viability has been critically low in some habitats due to intense anthropogenic activities (Jefferson et al., 2017), including dolphin–fishery interactions (Wu et al., 2022), coastal maritime engineering (Huang et al., 2022), unsustainable dolphin-watching tourism (Wu et al., 2020), and harmful persistent pollutants (Jefferson et al., 2017). Many discussions emphasize the significance of protecting core habitats, or more precisely 'hotspots' of animal sightings for the Indo-Pacific humpback dolphin (Chou & Lee, 2010; Chou et al., 2011; Wu et al., 2017; Li et al., 2019; Fang et al., 2021). Those discussions, however, focus on local distributions and seldom deal with questions previously described: the examination of plan targeting, surrogate selection, and SAC scoping. Bao et al. (2019) and Huang et al. (2019), however, proposed some perspectives to protect population integrity and ecosystem functionality in the conservation planning for the Indo-Pacific humpback dolphin.

In the context of conservation planning for threatened marine megafauna, either by regarding ECP as a spatial tool to delineate SACs for threatened marine megafauna or assigning marine megafauna species as surrogates to facilitate marine biodiversity and ecosystem conservation, shortfalls of biodiversity targeting and plan scoping (Leslie, 2005) can be minimized by examining whether the following issue are addressed:

1. For planning, whether the SAC highlights the regional biodiversity richness and/or megafauna distribution.
2. For threatened marine megafauna, whether the SAC encloses a sufficient space to accommodate a demographically viable population.
3. Whether the SAC mapping encloses sufficient biodiversity richness to accommodate an ecologically persistent population.

The current study conducted ECP exercises to score the habitat protection priority for the Indo-Pacific humpback dolphin using a combination of surrogates. Areas important to ensure long-term persistence of humpback dolphin populations and maintain regional biodiversity richness and ecosystem functionality are highlighted. Finally, actions to address information important for ECP for threatened marine megafauna are summarized.

2 | MATERIALS AND METHODS

2.1 | Data preparation

The assessment region was defined by the species range of Indo-Pacific humpback dolphins (Jefferson et al., 2017) in Chinese and adjacent northern Vietnamese waters (Figure 1). Three biodiversity datasets were prepared and used as surrogates for the following ECP exercises (Table 1), including the habitat configuration of the Indo-Pacific humpback dolphin in Chinese and northern Vietnamese waters (Bao et al., 2019; Huang, Wang & Yao, 2018; Huang et al., 2019, merged by Huang et al., 2020), indicators of biodiversity richness and marine net primary productivity (NPP). Data on marine NPP were used to represent ecosystem functionality (Tittensor et al., 2010; Vallina et al., 2014) and adopted the numerical average of monthly composites that were downloaded from the Ocean Productivity website (http://sites.science.oregonstate.edu/ocean.productivity/index.php), using the ocean colour data derived from Visible and Infrared Imager/Radiometer Suite (VIIRS) on board the Suomi National Polar-orbiting Partnership (SNPP). Hill-2 biodiversity index (Hill2) and the number of IUCN Red List species N_{IUCN} were downloaded from Ocean Biogeographic Information System (OBIS; https://obis.org) and were used to represent regional biodiversity richness. The calculation of Hill-2 number discounts rare species, unlike the Hill-1 number that is sensitive to sampling-effort heterogeneity (OBIS: https://obis.org/indicators/documentation/). Locations of mangroves (Bunting et al., 2018), coral reefs (UNEP-WCMC & WorldFish Centre, 2018), and seagrass (Green & Short, 2003; UNEP-WCMC & Short, 2018) ecosystems (Figure 1a) were downloaded from the Ocean Data Viewer at the UN Environment Programme World Conservation Monitoring Centre (https://data.unep-wcmc.org/datasets) and used as baselines to test the performance of SACs in protecting focal marine ecosystems (Wang et al., 2021).

The assessment range (Figure 1a) was divided into *ca*. 100-km^2 protection-unit (pu) grids and removed the terrestrial areas (Figure 1b). For grid i, the presence of humpback dolphins $p_{\mathrm{hd},i}$ was defined as either 1, 0.35, or 0.05 (Wang et al., 2021), depending on whether grid i is in the range of likely core habitat (1.0), likely habitat maxima (0.35), or species range (0.05). To standardize biodiversity richness and ecosystem functionality throughout the study region, zonal means of Hill2, N_{IUCN}, and net primary productivity (NPP) of grid i were extracted and rescaled to values between 0 and 1 ($r_{\mathrm{Hill2},i}$, $r_{N_{\mathrm{IUCN}},i}$ and $r_{\mathrm{NPP},i}$ respectively). B_i, the biodiversity richness of grid i, was then determined by

$$B_i = \sqrt{\exp\left(r_{\mathrm{Hill2},i} + r_{N_{\mathrm{IUCN}},i}\right)} \tag{1}$$

The ecosystem functionality of grid i (E_i), was represented by

$$E_i = \sqrt{a_i \times r_{\mathrm{NPP},i}} \tag{2}$$

where a_i is the area (in km^2) of grid i.

2.2 | ECP exercises: Scoring the habitat protection priority

MARXAN software (Ardron, Possingham & Klein, 2010) was used to measure the habitat protection priority (HPP) under a variety of ECP scenarios (Table 2). In this study, HPP was defined by the probability that the grid was selected in MARXAN exercises (Ardron, Possingham & Klein, 2010; Wang et al., 2021). Three ECP scenarios targeting water area (S0), the habitat of the Indo-Pacific humpback dolphin (S1), and the combination of ecosystem functionality and biodiversity richness (S2) were defined (Table 2). Scenario S0 was used to explore the importance of biodiversity surrogates in ECP exercises. Scenarios S1 and S2 were used to test the influence of surrogate selection and targeting on ECP outputs.

Three feature files (pu.dat, puvspr2.dat, and spec.dat) were prepared for running MARXAN (Ardron, Possingham & Klein, 2010) by the following processes:

1. In the pu.dat file, the costs of pu grids were assumed to be positively correlated with grid area (Ardron, Possingham & Klein, 2010) and inversely related to grid importance (I) in representing local biodiversity and ecosystem functionality values (Wang et al., 2021): the larger the area and the lower the importance of the grid, the higher the cost of the grid will be. For grid i, the importance under the scenario s, $I_{s,i}$ was defined as either 1 for scenario S0 (no biodiversity targeting), $\exp(p_{\mathrm{hd},i})$ for scenario S1 (targeting humpback dolphins' core habitats), or $B_i \exp(r_{\mathrm{NPP},i})$ for scenario S2 (targeting regional biodiversity richness and ecosystem functionality) (Table 2). By rescaling the ratio $a_i/I_{s,i}$ to values between 0 and 1 ($r_{a/I}$), the cost of grid i for scenario s ($c_{s,i}$) was calculated using

$$c_{s,i} = 1 + \exp(r_{a/I}) \tag{3}$$

which ranges between 2 (when $r_{a/I} = 0$) and 3.7183 (when $r_{a/I} = 1$).

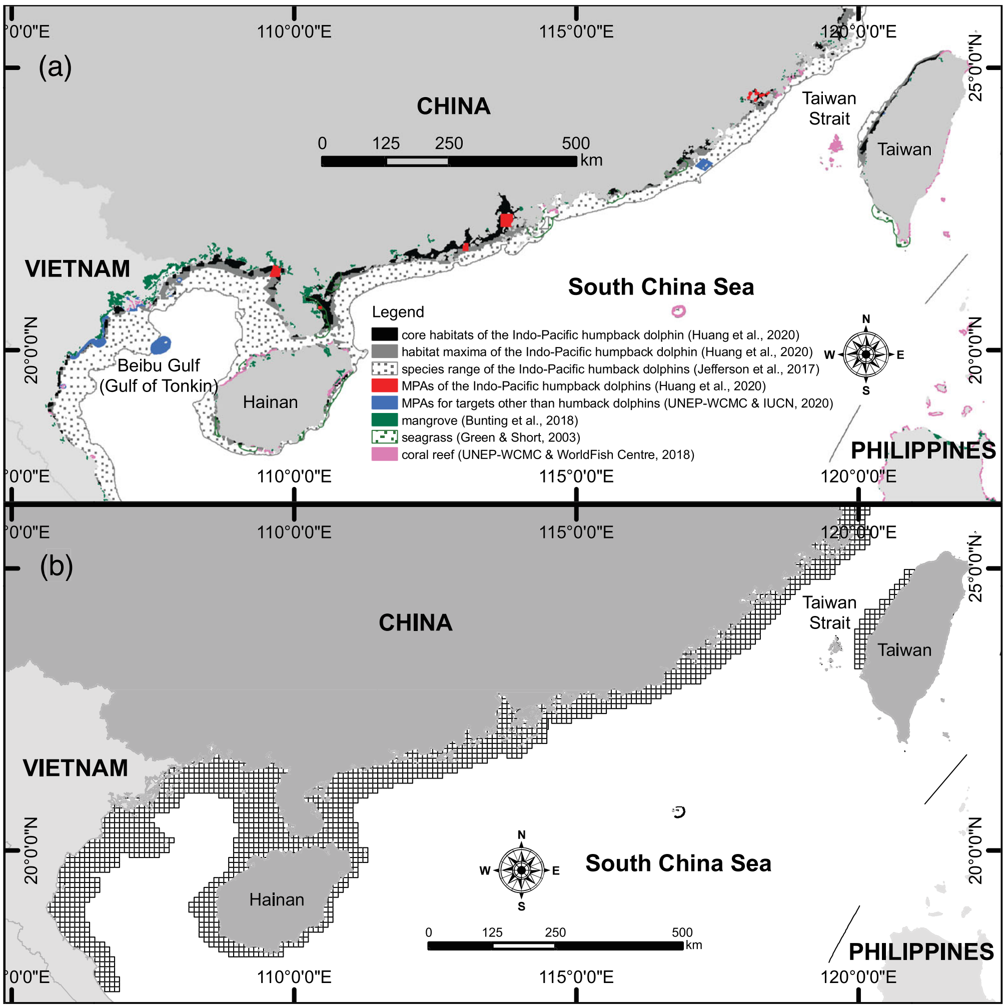

FIGURE 1 Habitat configuration: (a) the Indo-Pacific humpback dolphin in Chinese and northern Vietnamese waters, including the species range in this region (Jefferson et al., 2017), likely habitat maxima and likely core habitats (according to Huang, Wang & Yao, 2018; Bao et al., 2019; Huang et al., 2019 as merged by Huang et al., 2020). Marine protected areas (MPAs) (Huang et al., 2020; UNEP-WCMC & IUCN, 2020) and focal ecosystems including mangroves (Bunting et al., 2018), coral reefs (UNEP-WCMC & WorldFish Centre, 2018), and seagrass beds (Green & Short, 2003; UNEP-WCMC & Short, 2018) in/near the assessment range are outlined; (b) the species range (Jefferson et al., 2017) in Chinese and adjacent northern Vietnamese waters was divided into *ca*. 100 km^2 grids of protection units used for running MARXAN exercises.

2. In the puvspr2.dat file, the 'amount' of conservation features in grid i ($m_{s,i}$) was defined as a_i, $a_i \times p_{hd}$, and $B_i \times E_i$ for scenarios S0, S1, and S2 respectively (Table 2).
3. In the spec.dat file, the 'target' of MARXAN exercises under scenario s was defined as 30% of the sum of amounts in the 'puvspr2.dat' file (Ardron, Possingham & Klein, 2010; Wang et al., 2021). Preliminary tests by manually calibrating from 1 to 20 set the species penalty factor (spf) as 17.25 for all scenarios to reach the protection target (Table 2).

MARXAN scenarios were tested by 5,000 repeats, and each repeat ran 10,000,000 iterations. For each scenario s, the frequency that grid i was selected in the 5,000 repeats was defined as the HPP of grid i of scenario s ($HPP_{s,i}$). The maximal number of $HPP_{s,i}$ between scenarios S1 and S2 was assigned as the ecosystem-based HPP of grid i ($HPPe_i$).

TABLE 1 Features of marine biodiversity used in this study

Type	Features (sources)
Marine biodiversity and ecosystems	Habitat configuration of the Indo-Pacific humpback dolphin in Chinese waters (according to Huang, Wang & Yao, 2018; Bao et al., 2019; Huang et al., 2019; merged by Huang et al., 2020)
	Species range of the Indo-Pacific humpback dolphin humpback dolphin (Jefferson et al., 2017) https://www.iucnredlist.org/species/82031425/123794774
	Global Mangrove Watch 2016 (Bunting et al., 2018) https://data.unep-wcmc.org/datasets/45
	Seagrass (Green & Short, 2003; UNEP-WCMC & Short, 2018) https://data.unep-wcmc.org/datasets/7
	Global distribution of coral reefs (UNEP-WCMC & WorldFish Centre, 2018) https://data.unep-wcmc.org/datasets/1
	Hill2 index (https://obis.org/indicators/)
	Numbers of IUCN's Red List species (https://obis.org/indicators/)
Marine protected area (MPA)	MPA with the Indo-Pacific humpback dolphin (Huang et al., 2020)
	MPA with other conservation targets (UNEP-WCMC & IUCN, 2020) http://www.protectedplanet.net/
Oceanography	Net primary production (Ocean Productivity) http://sites.science.oregonstate.edu/ocean.productivity/

2.3 | SAC scoping

$HPPe_i$ was not literally incorporated into the necessity to designate MPAs, although one of the original functions of the algorithm MARXAN is helping to designate MPA networks (Ardron, Possingham & Klein, 2010). Instead, it was used for delineating SACs for the Indo-Pacific humpback dolphin in the study region. Based on present knowledge of the distribution range of the Indo-Pacific humpback dolphin (Jefferson et al., 2017), eight regional 'populations' were assigned for *pu* grids in the eastern Taiwan Strait, Xiamen, Shantou, Pearl River Estuary, eastern Leizhou Peninsula, northern Beibu Gulf, Hainan, and the northern Vietnamese waters (Figure 1). In the current study, the term 'population' was defined as the animals that share the same habitats (IUCN, 2021; cited by Hammond et al., 2021); this is not necessarily the same as a biological population that has distinctive boundaries (Hammond et al., 2021). The waters between Shantou and the Pearl River Estuary habitats and the waters north of Xiamen habitat were further assigned as 'connecting corridors' based on suitable-habitat mapping and local ecological knowledge surveys on the baseline of historical distribution (Wu et al., 2014; Chen et al., 2020), even although humpback dolphin occurrence in those areas might be sporadic or in some cases not yet investigated.

For the eight habitats of the Indo-Pacific humpback dolphin, the SAC scoping considered two minimum areas: first, the minimum area needed to ensure a minimal risk of local extinction under the lowest disturbance (i.e. the demographic persistence of a population; Karczmarski, Huang & Chan, 2017b); and second, the minimum area needed to achieve 30% protection of biodiversity richness and ecosystem functionality (Ardron, Possingham & Klein, 2010; Huang, Chang & Karczmarski, 2014). For the Indo-Pacific humpback dolphin, the minimum area needed to ensure a minimal risk of local extinction is at least 3,000 km^2 for core habitats (Karczmarski, Huang & Chan, 2017b). For each habitat, pu grids were chosen by $HPPe_i$, from high to low, until the sum of areas of the chosen grids was larger than the minimum optimal area to ensure a minimal risk of local extinction (3,000 km^2), which was designated as SAC1. B_i and E_i in SAC1 were summed (B_{SAC1} and E_{SAC1} respectively) and compared with the sum of

TABLE 2 Scenarios used for running MARXAN software in assisting ecosystem-based conservation planning in the study region

Scenario	Biodiversity surrogate	Target in 'pu.dat' file (percentage of total amount)	Grid's biodiversity and ecosystem importance $I_{s,i}$	Amount (in 'puvspr2.dat' file)
S0	Water areas (null)	30%[a]	1	a_i
S1	Indo-Pacific humpback dolphin distribution	30%[a]	$\exp(p_{hd,i})$	$a_i \times p_{hd,i}$ $p_{hd,i} = 1, 0.35, 0.05$
S2	B_i and NPP (E_i)	30%[a]	$B_i \times \exp(r_{NPP,i})$	$B_i \times E_i$

[a]Ardron, Possingham & Klein (2010), Huang, Chang & Karczmarski (2014), Wang et al. (2021).
Abbreviations: a_i: area in grid i; B_i: biodiversity abundance in grid i; E_i: ecosystem function indicator in grid i; $p_{hd:i}$: presence of the Indo-Pacific humpback dolphin in grid i; NPP: net primary productivity.

all B_i and all E_i across the study region. For habitats in which either B_{SAC1} or E_{SAC1} did not reach 30% of the sums of all B_i or all E_i, grids were further chosen until the second threshold was reached, i.e. 30% of the sum of all B_i and that of all E_i, which was designated SAC2 for the maintenance of biodiversity richness and ecosystem functionality. For ‘connecting corridors’, grids in which $HPPe_i$ is higher than 0.30 were also assigned to SAC2. For all pu grids, grids in which $HPPe_i$ is higher than 0.1 were highlighted as the range to maintain population and ecosystem connectivity (SACc). Areas of SAC1, SAC2, and SACc were calculated, and the percentages of spatial coverage between conservation planning (existing MPAs and SAC designations) and biodiversity features (marine areas, habitats of Indo-Pacific humpback dolphins, number of IUCN Red List species, and locations of seagrass, coral-reef, and mangrove ecosystems) were summarized.

3 | RESULTS

The HPPs from scenarios S0, S1, and S2 are shown in Figure 2a–c respectively. When the biodiversity and ecosystem surrogate were not factored in, MARXAN exercises based on scenario S0 reported an ‘undifferentiated’ habitat protection priority (Figure 2a) that poorly highlighted focal areas. When habitat configuration of the Indo-Pacific humpback dolphin was factored in, low to intermediate HPPs were estimated (Figure 2b). When the indicators of biodiversity abundance and ecosystem functionality were factored in, the MARXAN exercises showed high HPPs in the core habitats of presently known Indo-Pacific humpback dolphin populations and intermediate HPPs in connecting waters (Figure 2c). The distribution of $HPPe_i$ (Figure 2d) indicates the southern sector of western Taiwanese waters, Xiamen Bay, the coastal waters off Shantou, the Pearl River Estuary, Zhangjiang, the northern Beibu Gulf, and south west of Hainan Island in Chinese waters, as well as the Red River Estuary in northern Vietnamese waters and connective waters north of Xiamen Bay and between Shantou and Pearl River Estuary habitats were important for conservation of the Indo-Pacific humpback dolphin and also for regional biodiversity richness and ecosystem functionality.

To ensure the minimal risk of local extinction under the lowest disturbance, the HPP value to delineate SAC1 was regional specific (Figure 3): 0.10 for the eastern Taiwan Strait, 0.25 for the Shantou and Hainan habitats, 0.40 for the Xiamen Bay, 0.55 for the northern Vietnamese waters, 0.60 for Leizhou Bay (or Zhanjiang), 0.65 for the northern Beibu Gulf, and 0.90 for the Pearl River Estuary. To protect at least 30% of biodiversity richness and ecosystem functionality, additional areas would be required in the Pearl River Estuary (HPP > 0.80), Zhanjiang (HPP > 0.43), the northern Beibu Gulf (HPP > 0.44), northern Vietnamese waters (HPP > 0.44), and Hainan habitats (HPP > 0.20) for SAC2 designation (Figure 3). SAC1, SAC2, and SACc enclosed 26,858 km^2, 40,179 km^2, and 78,797 km^2 waters respectively, accounting for 49.9%, 65.6%, and 86.7% respectively of the core habitats of the Indo-Pacific humpback dolphin (Table 3).

Except for the protection of the mangrove ecosystem, SAC designations provided higher spatial coverage of protection for seagrass (from 29.8% to 54.5% of distributions) and coral-reef (from 11.0% to 20.8% of distributions) ecosystems than those by existing MPAs (Table 3). For the distribution of mangrove ecosystems, the SAC designation provided 0.6% (by SAC1) to 2.9% (by SACc) of spatial coverage, but existing MPAs alone protect 15% of the mangrove ecosystems (Table 3). For the number of IUCN Red List species, the SAC designations provided protection for 24.3% (SAC1), 30.7% (SAC2), and 59.1% (SACc) of the species, which are much higher than the percentages provided by existing MPAs (Table 3).

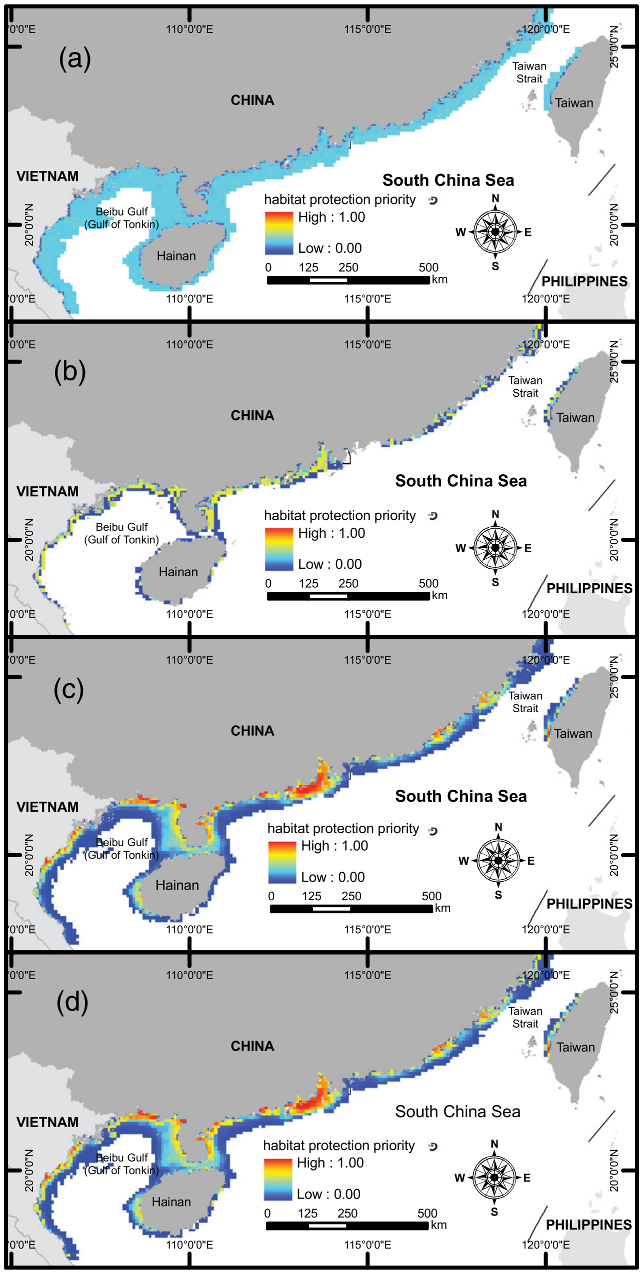

FIGURE 2 Priorities (values between 0 and 1) of habitat protection (HPP_i) scored by MARXAN exercises from scenarios (a) S0, (b) S1, and (c) S2. (d) Taking the larger HPP_i between scenarios S1 and S2, the ecosystem-based $HPPe_i$ highlighted areas important for Indo-Pacific humpback dolphin survival and maintenance of biodiversity richness and ecosystem functionality.

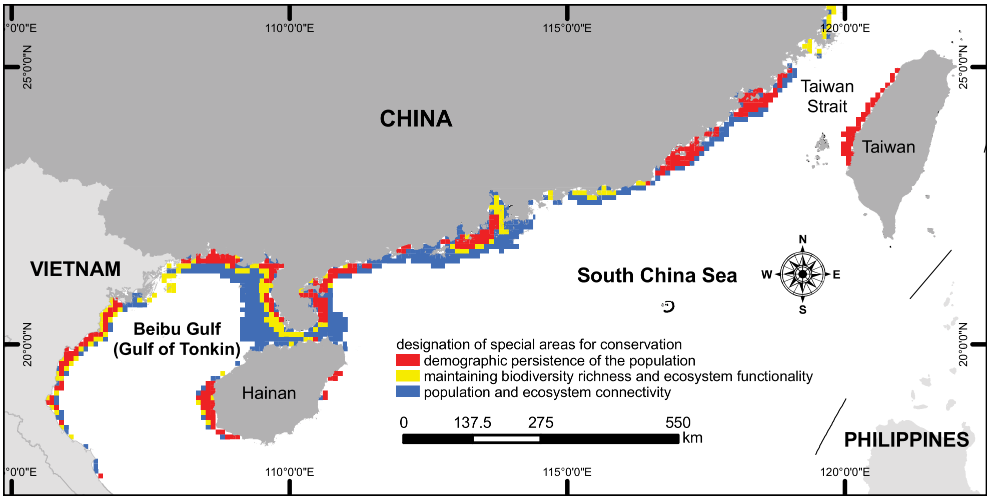

FIGURE 3 Special area of conservation (SAC) designations for the Indo-Pacific humpback dolphin to accommodate demographically persistent populations (SAC1: red sectors), biodiversity richness and ecosystem functionality (SAC2: yellow + red sectors), and connectivity of populations and ecosystems (SACc: blue + yellow + red sectors) in Chinese and adjacent northern Vietnamese waters.

TABLE 3 Percentages of spatial coverage on biodiversity and ecosystem features provided by different protection zonations

	Spatial coverage (%)				
Biodiversity targets	MPA_{HD} (1,241 km^2)	MPAs (8,256 km^2)	SAC1 (26,858 km^2)	SAC2 (40,179 km^2)	SACc (78,797 km^2)
Water areas in the study region	0.8	5.3	17.2	25.8	50.5
Core habitats of the Indo- Pacific humpback dolphin	5.6	7.8	49.9	65.6	86.7
IUCN Red List species	5.0	9.0	24.3	30.7	59.1
Ecosystem functionality	2.7	8.8	23.0	34.0	61.2
Seagrass[a]	0.2	0.2	29.8	38.0	54.5
Coral reef[a]	0.0	3.6	11.0	13.2	20.8
Mangrove[a]	0.0	15.0	0.6	2.5	2.9

[a]Distributions of the seagrass, coral-reef, and mangrove ecosystems were not factored in the ecosystem-based conservation planning exercises of this study.
Abbreviations: MPA_{HD}: marine protected area dedicated for the Indo-Pacific humpback dolphin in the study region; SAC1, SAC2, and SACc: special areas for conservation for ensuring population viability (SAC1), maintaining biodiversity richness/ecosystem functionality (SAC2, with inclusion of SAC1), and maintaining population/ecosystem connectivity (SACc, with inclusion of SAC1 and SAC2) in the study region.

4 | DISCUSSION

4.1 | Objective targeting, surrogate selection, and SAC scoping in conservation planning for threatened marine megafauna

The ECP exercises can be generally divided into three processes, including objective targeting, surrogate selection, and SAC scoping. The objective targeting is usually plan or scenario specific (Agardy et al., 2003), which, in turn, defines the use of biodiversity surrogates and determines the range of SAC scoping. The objective of ECP exercises can target the percentage of marine areas or territory waters (as in scenario S0), areas of animal aggregations (such as in scenario S1), and regional biodiversity richness and ecosystem functionality patterns (such as in scenario S2). In national conservation planning, the percentage of marine areas being protected is frequently regarded as an achievement of protection efficacy (Smallhorn-West & Govan, 2018). The results for scenario S0 showed that aiming to have this indicator as the planning target does not provide sound and explicit SAC designation for either the Indo-Pacific humpback dolphin or regional biodiversity conservation. If the percentage of protected marine areas is set as the objective of conservation planning, it often results in a bias towards ease of implementation than necessity of protection (Devillers et al., 2015) and overstates the protection achievement (Smallhorn-West & Govan, 2018).

When ECP exercises target biodiversity objectives, the use of suitable biodiversity and ecosystem surrogates becomes necessary (Olds et al., 2014; Ward et al., 2020). The surrogate selection in ECP exercises has to address two questions: which surrogates should be chosen and whether the chosen surrogate can represent regional biodiversity and ecosystem functionality patterns (Zacharias & Roff, 2001; Barton et al., 2020). In the current study, HPPs from MARXAN exercises highlighted similar locations of focal areas for the

Indo-Pacific humpback dolphin (S1) and regional biodiversity richness and ecosystem functionality (S2). HPPs of scenario S1, however, reported generally lower HPPs than those of scenario S2. Directly translating HPPs of scenario S1 into the SAC designation may be prone to underestimating the necessity of protection and a narrower range of protection, which highlights the shortfall of 'hotspot-based' conservation planning. Though MARXAN exercises of scenarios S1 and S2 reported different HPPs, both scenarios outlined similar locations of focal areas. Recent studies indicate a significant association between distribution of the Indo-Pacific humpback dolphin and marine chlorophyll *a* concentration (Wu et al., 2017; Huang, Wang & Yao, 2018; Huang et al., 2019; Chen et al., 2020; Wang et al., 2021). Marine chlorophyll *a* concentration is the major variable determining NPP (Behrenfeld & Falkowski, 1997) that is used as an indicator of regional ecosystem functionality in the current study (scenario S2). Data on marine NPP are globally available (Ocean Productivity), but data on the distribution of humpback dolphins (*Sousa* spp.) are not, except for the Indo-Pacific humpback dolphin (Huang et al., 2022). For coastal and estuarine waters where humpback dolphin distribution is not yet known, NPP and indicators of marine biodiversity richness may be feasible surrogates to inform precautionary SAC designation.

None of the SAC designations in the current study provide sufficient coverage of mangrove and coral-reef ecosystems. The 'shortage' of protection coverage may arise from mismatches of distributions between biodiversity surrogates and focal ecosystems. Spatially, mangroves and marine megafauna occupy different distribution spaces: mangroves on river deltas, and dolphins in marine waters. Though some humpback dolphin populations utilize the creek systems in river deltas, such as the Indian Ocean humpback dolphin (*Sousa plumbea*) in the Indus Delta Creek System (Kiani & van Waerebeek, 2015), similar habitat-use patterns are not observed in the study region. Ecologically, the Indo-Pacific humpback dolphin prefers brackish and turbid waters in estuaries (Wu et al., 2017), which are a mismatch with the coral-reef environments (Yentsch et al., 2002). In contrast, the moderate overlap between seagrass and Indo-Pacific humpback dolphin distributions (UNEP-WCMC & Short, 2018; Huang et al., 2022) is consistent with moderate protection coverage by the designated SACs (29.8–54.5% of seagrass distribution). The shortage of protection coverage of SAC designations on mangrove and coral-reef ecosystems in the current study highlights the association between objective targeting and surrogate selection in conservation planning. A critique may conclude that threatened marine megafauna were not a 'good' surrogate to capture major ecosystems in ECP exercises. Such a critique, however, highlights the importance of examining fundamental questions at the beginning of ECP exercises, such as: "What are the ECP objectives targeting?" and "Does the biodiversity surrogate choosen match the ECP targets?" Such a critique, indeed, may further trigger a debate on whether marine biodiversity conservation exclusively targeting 'focal ecosystems', such as mangroves, seagrass, and coral reefs, provides sufficient protection on biota and ecosystem functionality in coastal and estuarine environments. Shortfalls of SAC designation in mangroves and coral reefs imply a negative conclusion from the aforementioned debate.

Scoring the protection priority is the major step in marine conservation planning. The SAC scoping then can be defined by scored protection priorities, namely HPPs in the current study. Usually, SAC scoping is performed by classifying HPPs by a threshold value (Ardron, Possingham & Klein, 2010; Wang et al., 2021). This study, however, indicated that such a 'one-value-for-all' tactic may narrow SAC scoping and could be unable to meet conservation planning objectives. This study showed that HPP thresholds for SAC scoping are regionally specific. For populations with narrow distribution ranges, such as those in the eastern Taiwan Strait, Xiamen Bay, Shantou, and south west of Hainan, SAC scoping requires lower HPP thresholds in order to enclose sufficient areas to demographically and ecologically satisfy long-term persistence of threatened marine megafauna. Furthermore, the difference in HPP thresholds between SAC1 and SAC2 indicated the threshold for SAC scoping is objective specific. The scope to protect ecosystem functionality of habitats is wider than the scope to ensure demographic persistence for threatened marine megafauna.

4.2 | Implications for planning of habitat protection actions: MPA designation and national planning

This study indicates lower HPP thresholds of SAC scoping for the Indo-Pacific humpback dolphin in the eastern Taiwan Strait, Shantou, and Hainan habitats, which emphasizes the urgency and necessity to implement habitat protection actions. The eastern Taiwan Strait and Shantou habitats, where small numbers of dolphins inhabit poorly protected environments (Wang et al., 2016a; Wang et al., 2016b), urgently require the designation of MPAs such as marine national parks and strict enforcement and management of MPAs to minimize impacts of local anthropogenic activities. Recent unpublished abundance estimates of the Indo-Pacific humpback dolphin in the eastern Taiwan Strait reveal an alarming decline, from approximately 100 dolphins in 2006 (Wang et al., 2007) to around 50 dolphins (Dr C.-Y. Yao, personal communication), a far faster rate of decline than predicted by Huang, Chang & Karczmarski (2014). Unlike other humpback dolphin habitats, the eastern Taiwan Strait and Shantou habitats are either geographically or anthropogenically isolated from neighbouring habitats (Wang et al., 2016c; Bao et al., 2019), and hence are unlikely to acquire demographic supplements from nearby populations. Both Shantou and the eastern Taiwan Strait habitats have deteriorated due to intense pollution (Zhuang et al., 2019), large-scale maritime engineering development (Huang et al., 2022), and a decrease in marine primary production (Huang, Wang & Yao, 2018). Indo-Pacific humpback dolphins in these two habitats have significantly lower viability than those in other habitats. Recently, an ambitious wind farm construction project has been announced to occur in the eastern Taiwan Strait habitat (Thousand Wind Turbines Project: https://www.twtpo.org.tw/offshore_show.aspx?id=963, in

Chinese). This project would undoubtedly impact humpback dolphin survival by altering natural environment and ecosystem structure (Vanhellemont & Ruddick, 2014; Shiang-Lin Huang, unpublished results); however, relevant discussions are still uncommon and not considered in either environmental impact assessments or mitigation measures (Environmental Impact Assessment Inquiry System: https://eiadoc.epa.gov.tw/eiaweb/11.aspx?hcode=1050020A&srctype=0, in Chinese). Re-examining the ecosystem impacts of offshore wind farm construction and operation on the Indo-Pacific humpback dolphin habitat, and adjusting offshore wind farm planning and mitigation measures accordingly, is essential (Huang et al., 2022). For the Indo-Pacific humpback dolphin in the south west of Hainan, the habitat protection planning is subject to data deficiency in the abundance, survival and reproductive rates, residency, and distribution estimations, even though this 'population' has been investigated since 2014 (Li et al., 2016). Before the aforementioned information is published, the designation of an SAC based on the current study would provide a precautionary baseline for MPA designation.

The scope of conservation planning discussed herein is far beyond regional administrative borders, as is the SAC designation (Figure 3). Putting SAC designation into act conservation practice requires national planning and policing (McCook et al., 2019; Hu et al., 2020). More than 100 MPAs have been announced and more MPAs will be announced in the future (McCook et al., 2019) throughout the coast of southern China. Ideally, those MPAs can provide sufficient protection to ensure, at least, demographic persistence of populations of the Indo-Pacific humpback dolphin. In practice, the present gap between MPA designation and conservation efficacy may not come from questions of 'where', but from questions of 'how' (McCook et al., 2019; Hu et al., 2020). The major challenge in MPA designation and management comes not only from ineffective MPA practices (Hu et al., 2020), but also from the lack of explicit biodiversity and ecosystem targeting during scoping phases, even though the protection of marine ecosystems has been explicitly enlisted as a prioritized national policy (McCook et al., 2019). Most of the MPAs announced are still small (Hu et al., 2020) and mainly aim at local hotspots of focal biodiversity features (such as the Indo-Pacific humpback dolphin). MPA coverage over the SAC2 range is still low.

Among spatial tools such as marine EBSAs, KBAs, and IMMAs, the IMMA is a tool specifically aimed at cetacean habitats (IUCN-MMPATF, 2020) and has been identified in southern Vietnam waters, but not yet in Chinese coastal waters as the regional workshop to identify such areas has not extended yet to East Asia. Though HPP scoring and subsequent SAC designation is not necessary for identification of IMMAs (IUCN-MMPATF, 2020), this process provides an adaptive and objective regional-specific prioritization to assist IMMA delineation and avoid the formation of protection gaps. As the habitat configuration of the Indo-Pacific humpback dolphin in Chinese waters is better understood (Huang et al., 2020; Huang et al., 2022) and waters important for demographic persistence of the Indo-Pacific humpback dolphin are highlighted in the current study, we urge recognition for the SAC designation, at least the SAC1 as IMMAs through the following procedures: (1) inviting experts to submit proposed Areas of Interest; (2) assessing proposed Areas of Interest against the IMMA criteria based on satisfying one or more of eight criteria in the categories of (a) Red List status, (b) abundance and distribution, (c) feeding, reproductive, or migration areas, and (d) distinctiveness and marine mammal diversity; and (3) submitting candidate IMMA proposals for review by an external panel of reviewers (IUCN-MMPATF, 2020).

4.3 | Uncertainties and solutions to improve ECP gaps

Uncertainties in the ECP exercise primarily arise from three major sources: data comprehensiveness (factoring in biodiversity features as thoroughly as possible), data completeness (data as spatially complete as possible), and data quality (qualitative or quantitative). Sound ECP exercises should address these uncertainties to avoid protection gaps that cause omission biases.

ECP exercises frequently include as many biodiversity features as possible—as in Magris et al. (2018)—to ensure the comprehensive coverage of biodiversity features and ecosystems. At a national or ecoregional scale, however, not all biodiversity and ecosystem distribution data are available and not all available biodiversity distribution data are complete and without gaps (Figure 1). Adopting biodiversity surrogates in ECP exercises is necessary (Leslie, 2005), which determines ECP results as discussed herein. In the current study, MARXAN results of scenarios S1 and S2 highlight similar areas. SAC2 enclosed a wider region than SAC1 did. This 'inconsistency' does not represent inadequate or insufficient surrogacy of marine megafauna in ECP exercises, but rather emphasizes that habitat protection planning for threatened marine megafauna requires an ecosystem perspective. The scope of habitat protection for threatened marine megafauna should not, and cannot, be restricted to areas of animal aggregations, as in conventional 'hotspot-based' conservation planning, but should consider both habitat configuration of surrogates and ecosystem functionality.

The second uncertainty influencing ECP results comes from whether the information on biodiversity distributions is complete without gaps due to lack of data, lack of investigations, or non-random surveys prone to sampling bias (Rosel et al., 2011; Guillera-Arroita et al., 2015). Basing habitat protection planning on suitable-habitat mapping from species distribution modelling exercises has been frequently recommended as a primary approach (Rodrigues & Brooks, 2007; Ardron, Possingham & Klein, 2010; Passadore et al., 2018; Wang et al., 2021). One argument favouring the use of directly observed biodiversity distributions in ECP exercises comes from the fact that habitat mapping exercises can overestimate the range of distributions and include some areas where animals never or seldom occur (Guillera-Arroita et al., 2015). This 'false-positive' bias happens when basing habitat mapping exercises on a small sample size, particularly when the survey was conducted in a non-random design (Guillera-Arroita et al., 2015; Bao et al., 2019; Wang et al., 2021), such as those in Liu et al. (2019) or Wang et al. (2016b).

In this situation, a 'false-negative' bias also happens in habitats distant from the sample area (Bao et al., 2019; Wang et al., 2021), besides overestimating habitat ranges in areas near/adjacent to the sampling area (Bao et al., 2019). For marine megafauna, the range of direct observations is prone to bias from habitats where distributions are never or rarely surveyed (e.g. Chou & Lee, 2010; Chou et al., 2011) or where the 'observed' distributions are subject to anthropogenic disturbance (Karczmarski et al., 2017a; Huang et al., 2022). The cost of committing a false-positive bias may be simply 'wasting' conservation resources (not necessarily catastrophic), but the cost of committing a false-negative bias will leave important biodiversity features unprotected (as in Chou et al., 2011). The importance of collecting direct observation data in habitat protection planning can never be overemphasized. The use of directly observed distribution data, however, should consider whether the surveys are designed and conducted in a spatially representative manner that covers all/most distributions (Passadore et al., 2018; Bao et al., 2019; Hammond et al., 2021; Wang et al., 2021). If not, suitable-habitat mapping by species distribution modelling exercises based on directly observed distribution in ECP exercises can minimize the risk of omission bias.

The third uncertainty that influences ECP results comes from the information on biodiversity distributions being often qualitative rather than quantitative, such as the habitat configuration of the Indo-Pacific humpback dolphin used in this study. Quantitative data on biodiversity distribution, particularly measures of population density, are important to define the 'amount' profile in the file 'puvspr2.dat' in MARXAN exercises. Regression-based density-surface modelling (Mannocci et al., 2015; Roberts et al., 2016) can help to provide quantitative data. This approach, nonetheless, requires a well-planned design to ensure representative spatial coverage, to calibrate 'true-absence' data (Passadore et al., 2018). Before this calibration is prepared, we argued for treating the ECP result as a precautionary solution based on currently available information for the conservation of the Indo-Pacific humpback dolphin. Open-access data on biodiversity indicators (such as OBIS/SeaMap) and marine ecological variables, such as the Ocean Productivity and Ocean Color websites, provide quantitative indicators of biodiversity richness and marine ecosystem functionality. These data, however, are prone to coarse spatial resolution, which may not be suitable for ECP exercises at a regional scale. Ecosystem-based conservation planning at national or provincial scales requires grid-based biodiversity and ecosystem functionality data at fine spatial resolution, which in turn requires substantial effort to coordinate research teams and devise strategies for combining and using data collected from different seasons and years and using different methodologies.

5 | CONCLUSION

The conservation of threatened marine megafauna in coastal and estuarine waters shares similar objectives with global marine biodiversity conservation. In the context of marine biodiversity conservation, designating SACs through ECP exercises is a major step to highlight areas that are important for threatened marine megafauna conservation. In this approach, three questions should be addressed, including objective targeting, surrogate selection, and SAC scoping. The objective targeting directly determines surrogate selection and further defines SAC scoping. For the conservation of threatened marine megafauna, the ECP objectives should target the minimum areas needed for a viable population and maintenance of biodiversity richness and ecosystem functionality. The megafauna distribution can be used to highlight focal areas, and the indicators or surrogates of biodiversity richness and ecosystem functionality should be factored in concurrently. Using surrogates with different ecological niches would be a better tactic in ECP exercises for marine biodiversity conservation.

The challenges to conducting ECP exercises for threatened marine megafauna come from data scarcity and poor data quality in representing distributions of biodiversity features. Quantitative modelling exercises projecting distribution and density gradients of targeted megafauna, particularly regression-based density-surface modelling, are recommended for informing the amount and importance of protection units in ECP exercises. This approach, however, relies heavily on systematic and grid-based line-transect survey designs to collect representative distribution data. Databases such as OBIS/SeaMap, Ocean Color, Ocean Productivity, Ocean Data Viewer of the UN Environment Programme World Conservation Monitoring Centre, and IUCN's spatial data on distribution of Red List species provide free distribution data on animals, biodiversity richness, and ecosystems at a global scale. A certified open-access database that shares survey effort, occurrence data, and habitat mapping results in formats for use in geographic information system layers is recommended to facilitate ECP exercises at national and local scales. This approach requires national planning, investment, and policing.

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CONFLICTS OF INTEREST

All authors declare no conflict of competing interest.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

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