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# Habitat protection planning for Indo-Pacific humpback dolphins (*Sousa chinensis*) in deteriorating environments: Knowledge gaps and recommendations for action

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## Abstract

1. In Chinese and South-east Asian waters, the coastal and estuarine environments are important habitats for the Indo-Pacific humpback dolphin (*Sousa chinensis*). Coastal and estuarine maritime engineering (CEME), including land reclamation, embankment or shoreline armouring, harbour construction and marine farming, permanently changes coastal environments and threatens the long-term persistence of marine biota and ecosystems. Such impacts on humpback dolphin viability, however, are rarely discussed.
2. Likely core habitat of the humpback dolphin was extrapolated based on present understanding of habitat characteristics, which is much narrower than present data describing the species' range. Some uninvestigated habitats near densely populated landscapes may be prone to intense CEME impacts.
3. CEME impacts compromise humpback dolphin survival through habitat loss, population fragmentation, alteration of ecological regimes and deterioration of ecosystem functionality. A 30% loss of core habitat can catastrophically reduce the population viability of this species. The best strategy to avoid CEME impacts on humpback dolphin viability is to adopt a conservative planning regime from the outset.
4. To inform habitat protection planning, current and past habitat configuration and habitat characteristics of the humpback dolphin can be clarified by systematically designed surveys, local ecological knowledge investigation, long-term satellite remote-sensing data and species distribution modelling exercises. Sound habitat protection planning includes mapping hierarchical marine protected area (MPA) networks using spatial planning algorithms and carefully examining CEME impacts from an ecosystem perspective.
5. To prevent inappropriate CEME planning, the inclusion of citizen science, local community participation, marine environmental education and effective information delivery is proposed. Questions relating to the proposed areas of habitat loss, the extent of environmental change and the status of population–

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habitat viability under the scenario of CEME impacts are proposed in order to examine and re-examine the environmental impacts of any CEME project.

KEYWORDS

baseline, ecosystem functionality, habitat loss, land reclamation, marine conservation planning, maritime engineering

## 1 | INTRODUCTION

Conservation of marine megafauna has attracted significant attention as a surrogate for an ecosystem-based solution to preserve biodiversity assemblages and ecosystem functionality (Hooker & Gerber, 2004; Weaver & Johnson, 2012; Pimiento et al., 2020; Wang et al., 2021). In coastal and estuarine waters, habitat protection of marine megafauna can be particularly challenging owing to anthropogenic activities from densely populated landscapes (Murray et al., 2019). Anthropogenic disturbances in coastal and estuarine waters can result from multiple mechanisms, but coastal and estuarine maritime engineering (CEME) associated with land reclamation, embankment (or shoreline armouring), harbour construction and marine farming are among the most influential (Figure 1). CEME directly destroys aquatic habitats, permanently turns natural coastal structures into artificial coastlines and changes regional ecological and oceanographic features that define ecosystem functionality (Vanhellemont & Ruddick, 2014; Jickells, Andrews & Parkes, 2016; Wisha et al., 2018; Gong et al., 2019). For marine megafauna, such as the Indo-Pacific humpback dolphin (*Sousa chinensis*), the impacts of

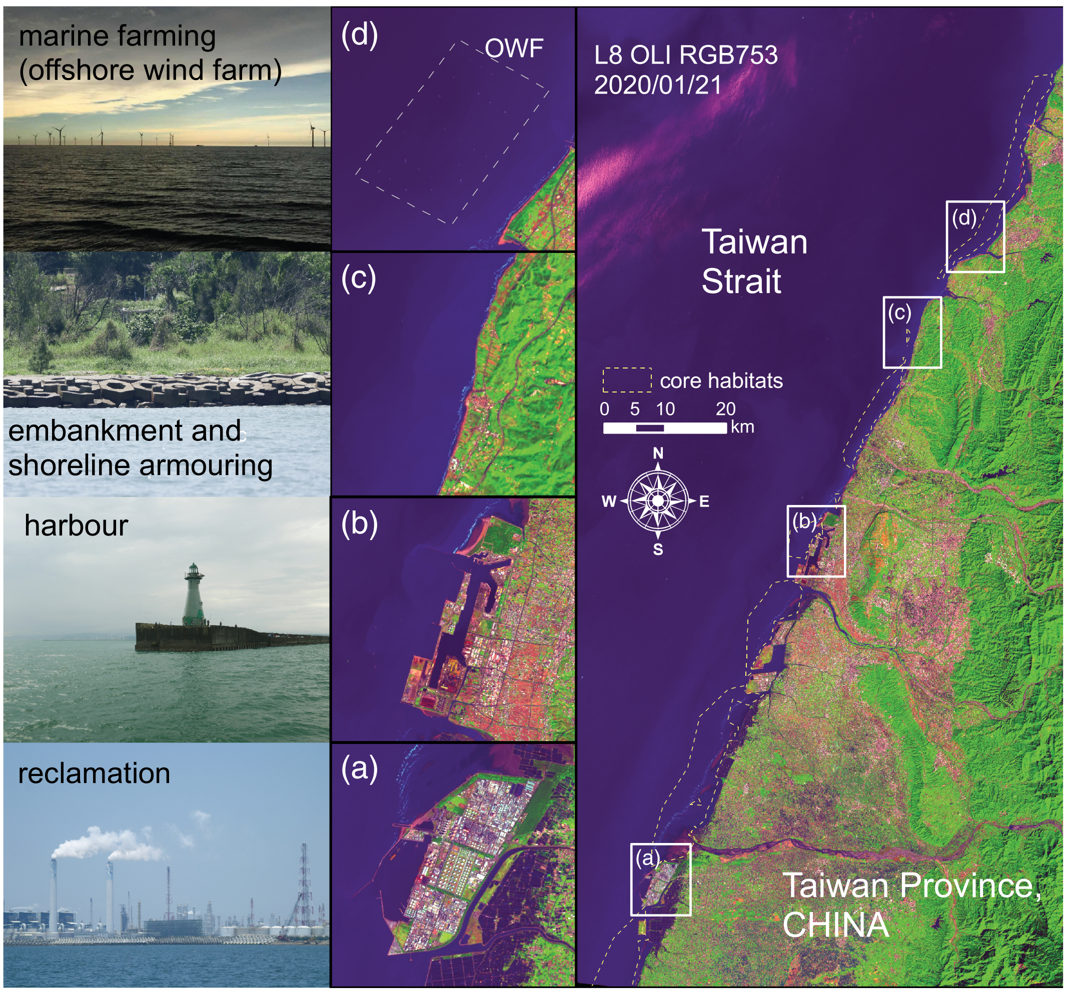


FIGURE 1 Coastal and estuarine maritime engineering (CEME) from reclamations (a), harbour construction (b), embankments and shoreline armouring (c) and marine farming (d) activities along the western coast of Taiwan. Core habitats of humpback dolphins (Huang, Wang & Yao, 2018) are outlined by dashed polygons

habitat loss and habitat-quality deterioration from CEME can overwhelm and mask the impacts from fishery disturbance on population survival (Huang, Chang & Karczmarski, 2014) even under the most favourable conditions (Karczmarski, Huang & Chan, 2017). Relevant discussions, however, are rare in habitat protection planning (Jefferson, Hung & Würsig, 2009; Jefferson, 2018; Huang et al., 2020).

In Chinese and South-east Asian waters, coastal and estuarine environments are important habitats for the Indo-Pacific humpback dolphin (Jefferson & Smith, 2016; Minton et al., 2016; Wang et al., 2016; Jutapruet et al., 2017; Wu et al., 2017; Kuit et al., 2019). Ecologically, coastal and estuarine environments are the transitional zones between freshwater and marine habitats (Attrill & Rundle, 2002) that provide ecological and biological functions (Savage et al., 2012; Jickells, Andrews & Parkes, 2016; Whitfield, 2020; Whitfield, 2021). Basing ecosystem-based marine biodiversity conservation on the protection of the humpback dolphin's habitat concurrently facilitates the protection of regional biodiversity assemblages and ecosystem functionality (Wu et al., 2017; Wang et al., 2021). Application of this strategy, however, relies heavily on whether the baseline of the humpback-dolphin's habitat configuration that describes the location, shape and size of habitat patches over a wide spatial range is accurate and complete (Ardron, Possingham & Klein, 2010; Huang et al., 2020; Wang et al., 2021). Throughout the species' range, baselines of habitat configurations of the humpback dolphin remain unsolved in most habitats, except in Chinese waters (Huang et al., 2020) and the Gulf of Thailand (Wang et al., 2021). Filling this gap can facilitate coastal and estuarine marine biodiversity conservation by informing habitat protection planning (Wang et al., 2021).

Across the species' range (Figure 2a), some major habitats have been substantially disturbed by large and extensive CEME activities (Murray et al., 2019), most notably in Chinese waters (Jefferson, Hung & Würsig, 2009; Karczmarski et al., 2017; Wang et al., 2017; Wu et al., 2017; Jefferson, 2018; Piwetz, Jefferson & Würsig, 2021). One of the difficulties in planning habitat protection action for humpback dolphins subject to CEME impacts comes from the fact that some present 'baselines' may have been altered by past CEME impacts (Huang et al., 2020). Basing habitat protection planning on those altered 'baselines' could result in habitats that are historically important but presently disturbed being omitted (as in Chou & Lee, 2010; Chou et al., 2011). Such a flawed habitat protection plan could interrupt individual movements, fragment the population's social composition (Wang et al., 2015; Wang et al., 2017) and ultimately compromise population viability by reducing effective population size (Huang, Chang & Karczmarski, 2014; Karczmarski, Huang & Chan, 2017). Information on the extent of habitat loss and habitat change associated with CEME activities is important to inform habitat protection planning to avoid this potential bias (Huang et al., 2020).

Huang et al. (2020) indicate the necessity to factor long-term changes in baseline conditions into habitat protection planning and propose an integrative research framework to facilitate data collection and analyses. These recommendations highlight the need to integrate the present understanding of humpback dolphin habitat characteristics and likely CEME impacts to inform sound habitat protection planning. In this study, baselines of humpback dolphin habitat characteristics and CEME impacts on the population and habitat were reviewed and summarized. Then, gaps in habitat protection planning, needed to address CEME impacts and recommendations to solve those gaps, were illustrated by an integrative framework. Finally, questions critical for examining/re-examining CEME impacts on humpback dolphin habitats were highlighted.

## 2 | HABITAT CONFIGURATION OF THE INDO-PACIFIC HUMPBACK DOLPHIN

Referring to earlier studies, coastal and estuarine waters shallower than 30 m deep were identified as general habitats of the humpback

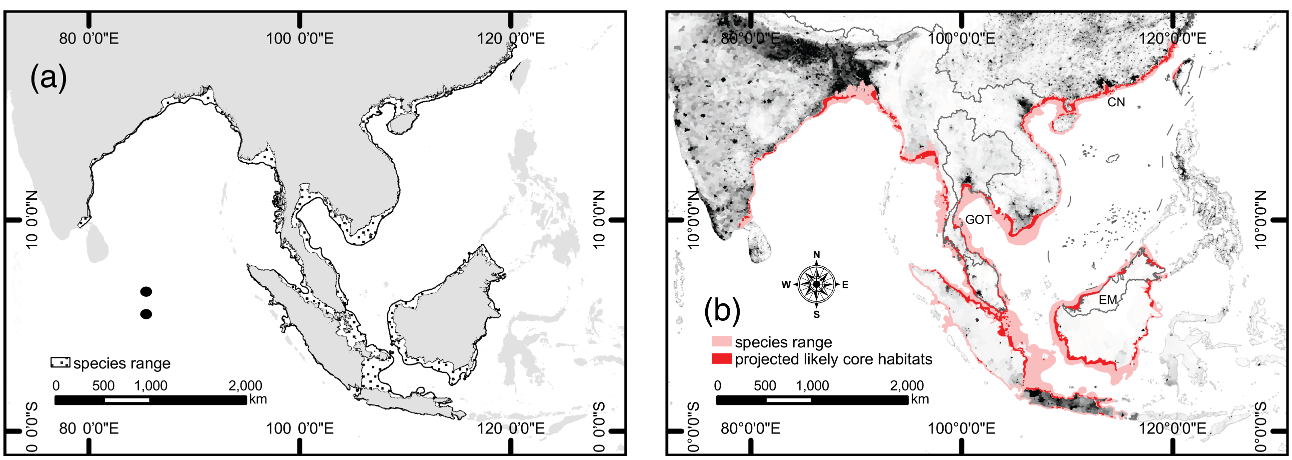


FIGURE 2 Species range (a), and projected likely core habitats (b) of Indo-Pacific humpback dolphins in association with presentation of human population density (bright–dark: low–high population density). Most of the likely core habitats have not been systematically investigated, except in Chinese waters (CN), the Gulf of Thailand (GOT) and eastern Malaysian (EM) waters. Data sources: species range of Indo-Pacific humpback dolphins (Jefferson et al., 2017), human population density (CIESIN, 2018)

dolphin (Jefferson, 2000; Jefferson & Smith, 2016; Jefferson et al., 2017). Environmental variables such as salinity, riverine runoff, suspended particles, primary production and nutrient loads influence the distribution and habitat use by humpback dolphins (Jefferson, 2000; Chen et al., 2010; Minton et al., 2016; Jutapruet et al., 2017; Wu et al., 2017). Recent studies based on species distribution modelling exercises highlight the importance of bathymetry and primary production (measured by chlorophyll-a concentration) in humpback dolphin distributions (Huang, Wang & Yao, 2018; Bao et al., 2019; Huang et al., 2019; Chen et al., 2020; Wang et al., 2021), which are summarized in Table 1.

Some studies have used 'distance to river mouth' to describe the distribution of humpback dolphins (Li et al., 2018; Chen et al., 2020) or other coastal delphinids that fill a similar niche to that of humpback dolphins (Jackson-Ricketts et al., 2020). These studies consistently indicate a brackish and turbid environment, i.e. the 'estuarine turbidity maximum' (ETM) areas in the river mouth as being particularly important (Wu et al., 2017; Asp et al., 2018). In the northern Beibu Gulf, China, the ETM area was proven to be a vital habitat of one humpback dolphin population (Wu et al., 2017; Peng et al., 2020) as early as the 1950s (Wu et al., 2017). Ecologically, the ETM area is a major nurturing site of fishes (Whitfield, 2020; Whitfield, 2021) and exports sediments to adjacent ecosystems (Asp et al., 2018). The ETM location is modulated by tidal dynamics and upstream river discharges (Asp et al., 2018; Abascal-Zorrilla et al., 2020). Seasonal changes in humpback dolphin distributions are associated with seasonal changes in riverine discharges (Jefferson, 2000; Chen et al., 2010; Lin, Akamatsu & Chou, 2015), which could result from the river–tide interaction in the ETM area (Asp et al., 2018; Abascal-Zorrilla et al., 2020). Reduction of river runoff (Karczmarski et al., 2017; Huang, Wang & Yao, 2018) and CEME construction can alter ETM dynamics (Yang et al., 2020; Jalón-Rojas et al., 2021) and therefore cause a change in the distribution and habitat configuration of humpback dolphins (Karczmarski et al., 2017; Huang, Wang & Yao, 2018).

Present understanding of humpback dolphin habitat characteristics (Table 1) may provide a proxy to approximate likely habitat configuration throughout the species' range. To solve this baseline, the following procedures were conducted:

1. Oceanographic data including bathymetry, chlorophyll-a concentration and net primary productivity in the range of the Indo-Pacific humpback dolphin (Jefferson et al., 2017) were extracted. The bathymetry data were derived from ETOPO1 1 Arc-Minute Global Relief Model (Amante & Eakins, 2009). The chlorophyll-a data from the Level 3 entire-mission composites of the Suomi National Polar-orbiting Partnership VIIRS (Visible Infrared Imaging Radiometer Suite) data were downloaded from the OceanColor website (https://oceancolor.gsfc.nasa.gov/). The net primary productivity data were prepared by downloading monthly composites of VIIRS-based Eppley-VGPM (Vertically Generalized Production Model) estimates from the Ocean Productivity database (http://www.science.oregonstate.edu/ocean.productivity/) and calculating the arithmetic average of monthly composites.
2. Grids of the bathymetry, chlorophyll-a concentration and net primary productivity raster falling within the range of the habitat characteristics in the core habitat (Table 1) were extracted and assigned as 'core-habitat grids'.
3. The polygons (in shapefile format) outlining core-habitat grids were converted from the raster layer.

Figure 2b shows the projected likely core habitat throughout the range of the Indo-Pacific humpback dolphin, which is much narrower than present data describing the species' range (Jefferson et al., 2017). This projection closely matches present knowledge on habitat configuration of humpback dolphins in Chinese waters (Huang et al., 2020), the Gulf of Thailand (Wang et al., 2021) and eastern Malaysia (Minton et al., 2016; Kuit et al., 2019) and implies that there are some uninvestigated habitats in waters prone to intense CEME

**TABLE 1** Habitat characteristics in the core habitats of Indo-Pacific humpback dolphins, measured by bathymetry and primary production (including chlorophyll-a concentration, chla, and net primary productivity, NPP)

| Habitats | Bathymetry (m) | Chla ($mg/m^3$) | NPP ($mg\ C/m^2/day$) | Sources |
|---|---|---|---|---|
| Western Taiwan | 10.4 (SD = 7.1) | 2.48 (SD = 0.50) | NA | Huang, Wang & Yao, 2018 |
| Pearl River Estuary | 6.9 (SD = 6.2) | 5.70 (SD = 1.79) | 4,330.7 (SD = 755.2) | Bao et al., 2019 |
| Shantou | 5.4 (SD = 4.9) | 5.54 (SD = 1.94) | 3,684.0 (SD = 560.6) | Bao et al., 2019 |
| Xiamen | 6.1 (SD = 8.9) | 4.10 (SD = 1.02) | 3,251.0 (SD = 460.4) | Bao et al., 2019 |
| Zhanjiang | 3.1 (SD = 2.82) | 5.03 (SD = 1.42) | 4,075.3 (SD = 780.9) | Bao et al., 2019 |
| Dafengjiang River Estuary | 3.52 (SD = 1.58) | 8.58 (SD = 0.23) | NA | Wu et al., 2017 |
| Northern Beibu Gulf[a] | 2.97 (SD = 1.82) | 6.34 (SD = 2.32) | 4,025.1 (SD = 1,955.5) | Huang et al., 2019 |
| Surat Thani, Thailand | 3.9 (SD = 0.46) | NA | NA | Jutapruet et al., 2017 |
| Gulf of Thailand | 4.73 (SD = 1.88) | 3.11 (SD = 2.47) | 3,655.4 (SD = 705.6) | Wang et al., 2021 |
| Borneo | 2–19.3* | NA | NA | Minton et al., 2016 |

[a]Recalculated from seasonal averages.
*Lower and upper bonds of reported ranges in four habitats.

histories by reference to the distribution of human density (CIESIN, 2018). In the absence of robust habitat configuration baselines, this habitat configuration (Figure 2b) can be adopted as a qualitative and precautionary proxy for marine conservation planning (as in Wang et al., 2021) and to measure the percentage of habitat loss for CEME environmental impact assessment.

## 3 | ECOLOGICAL AND ENVIRONMENTAL IMPACTS OF CEME ACTIVITIES

Coastal lands and river deltas are important residential areas for humans (Figure 2b), where large-scale CEME programmes are frequently planned as a 'low-cost–high-economic-return' solution to secure lands for urban growth and industrialization (Meng et al., 2017). For the Indo-Pacific humpback dolphin, CEME impacts compromise its long-term viability through population structure and ecosystem impacts (Table 2).

### 3.1 | CEME impacts on population structure

The most obvious CEME impact on the humpback dolphin is physical habitat loss. Along the western coast of Taiwan, Xiamen, the Pearl River Estuary and northern Beibu Gulf, CEME since the early 1970s has resulted in the loss of approximately 1,200 km$^2$ of coastal waters (Huang & Karczmarski, 2015). Decreases in habitat area directly reduce population viability by decreasing carrying capacity, which inhibits the potential to resist unpredictable extinction owing to stochastic fluctuation in reproduction and mortality rates (Huang, Chang & Karczmarski, 2014; Karczmarski, Huang & Chan, 2017). For a deteriorating population, a 30% loss of habitat area, particularly core habitat, can catastrophically compromise population viability (Huang, Chang & Karczmarski, 2014). Reduction of population viability, however, may not be immediately detectable, because current survey techniques for cetaceans are unable to detect early abundance declines (Huang et al., 2012). Worse yet, in some habitats, population abundance estimates were claimed to be 'rapidly increasing' in association with the CEME activity (Pan, 2013), which surely comes from inappropriate interpretation of survey results (Peng et al., 2020). For humpback dolphins, the risk to population viability from habitat loss owing to CEME construction should not be evaluated by the survey estimates alone, but should also refer to the percentage of habitat loss based on projected configuration of likely core habitats (Figure 2b).

CEME can reshape dolphin distribution across a wide spatial extent. Off the western coast of Taiwan, there were major CEME projects in the central region (Figure 3) during the 1990s (Karczmarski et al., 2017). Two 'hot zones' (north and south) of the humpback dolphin range separated by the central region were suggested in the baseline survey report (Chou & Lee, 2010), which was adopted for planning habitat protection programmes for the humpback dolphin (Chou et al., 2011). This 'two hot-zones' scenario, however, is associated with major CEME activities in the 1990s (Karczmarski et al., 2017). By factoring out the confounding CEME impacts on dolphin distribution, the differences in humpback dolphin distribution between northern, central and southern regions are not statistically significant (Karczmarski et al., 2017). Analyses based on species distribution modelling exercises further reinforce this conclusion by revealing a continuously distributed habitat configuration in the 1980s, before any major CEME construction (Huang, Wang & Yao, 2018). In Xiamen Bay, chronological records of sightings from

**TABLE 2** Summary of coastal and estuarine maritime engineering (CEME) impacts on humpback dolphin populations and habitat ecosystems

| | Impacts | Influences |
|---|---|---|
| Direct impacts | Habitat loss | • Increasing vulnerability and extinction risk |
| | Altering habitat preferences | • Changing distribution and habitat use patterns |
| | Interrupting social connectivity | • Fragmenting population structure<br>• Increasing vulnerability to stochastic extinction |
| Indirect impacts | Changing coastline texture and geometry | • Altering hydrodynamic systems<br>• Changing sediment-erosion processes<br>• Changing local ecological regime |
| | Increasing pollutant releases from nearby landscapes | • Depressing plankton activities and altering compositions<br>• Compromising ecosystem functionality<br>• Increasing risks to bioaccumulation of persistent pollutants |
| | Changing regional oceanographic characteristics | • Reduced primary production<br>• Extreme sea surface temperature increases<br>• Regime shift and ecosystem function deterioration |

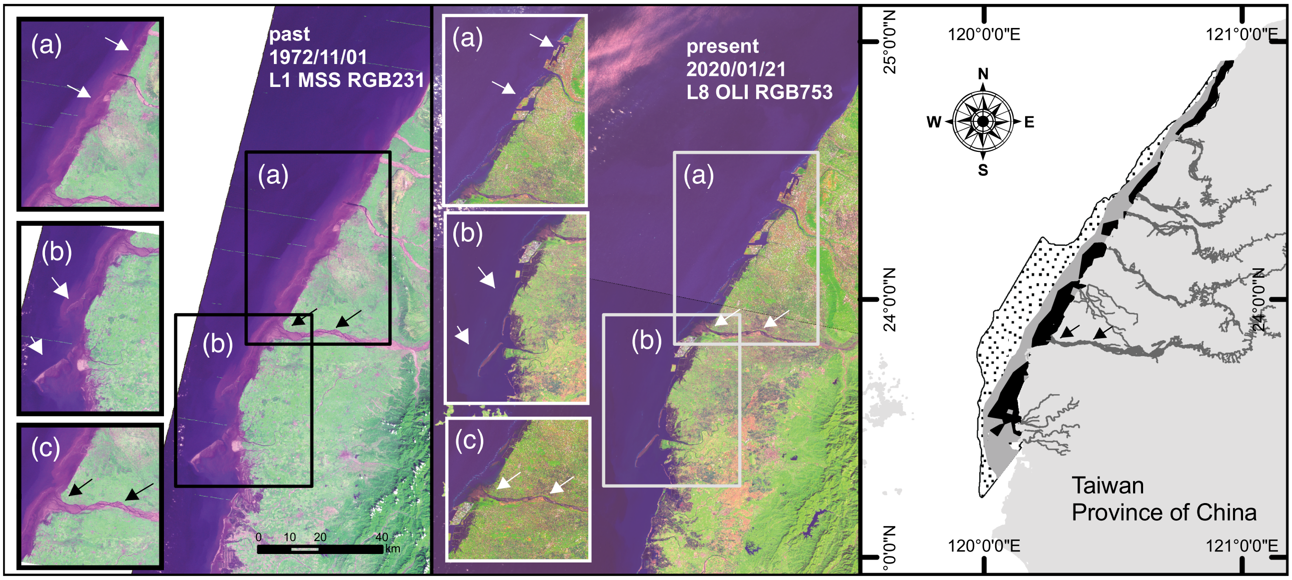


**FIGURE 3** Landsat images over western Taiwan, taken in 1972 (Landsat 1) and 2020 (Landsat 8), where intense reclamation (a), offshore sandbar deformation (b) and river-flow reduction (c) were observed

published literature indicate a displacement of a core distribution site from inshore to offshore waters and a significant preference for natural shorelines (Wang et al., 2017). In the Pearl River Estuary, humpback dolphin occurrences have decreased in habitats that are historically important but recently experienced intense CEME construction (Jefferson, 2018; Piwetz, Jefferson & Würsig, 2021). These reports show that habitat protection planning without taking into account those changes might neglect historically important habitats and be unable to maintain population integrity.

Intense CEME activities can impact population structure further. In a natural or lightly disturbed environment, habitat configuration of humpback dolphins comprises a series of core-habitat patches linked by movement corridors (Wu et al., 2017; Huang et al., 2019; Chen et al., 2020; Wang et al., 2021). Large-scale CEME can interrupt animal movements between habitat patches by outward-stretched embankment around harbours or reclamation sites (Wang et al., 2017; Wu et al., 2017) and compromise population viability (Huang, Chang & Karczmarski, 2014; Karczmarski, Huang, & Chan, 2017a). This impact can happen even when CEME is planned and implemented in 'less-important' waters between distribution 'hot-spots', such as the example in the western coastal region of Taiwan (Figure 3). In Xiamen Bay, the humpback dolphin population is socially divided into two distinct groups now, and younger individuals move between these social communities (Wang et al., 2015). Between the core distribution areas of these two social groups (Wang et al., 2017), dolphin occurrence and activities become sporadic (Wang et al., 2015). This association strongly implies a fragmented/fragmenting population structure. Similar fragmentations are happening to humpback dolphins along the western coast of Taiwan (Dungan et al., 2016), Hong Kong (Dungan et al., 2012) and perhaps the northern Beibu Gulf (Chen et al., 2016), which have all experienced large-scale CEME between core-distribution sites (Huang & Karczmarski, 2015; Karczmarski et al., 2017; Wu et al., 2017).

## 3.2 | CEME impacts on ecosystems

CEME can further compromise the viability of humpback dolphins by disrupting ecosystem pathways (Table 2). As previously described, CEME permanently changes coastline geometry and substrates. These changes, in turn, alter peripheral hydrodynamic systems and sediment-erosion dynamics (Min et al., 2008; Vanhellemont & Ruddick, 2014; Wisha et al., 2018; Yang et al., 2020) and hence lead to ecological changes compromising original habitat functionality (Jickells, Andrews & Parkes, 2016; Gong et al., 2019). Along the western coast of Taiwan, long-term Landsat data reveal successive changes in offshore sandbars near CEME sites (Figure 3), which may have changed local oceanographic dynamics and productivity (Karczmarski et al., 2017; Huang, Wang & Yao, 2018). Similar changes have been observed in the eastern Qinzhou Bay, northern Beibu Gulf, where intense CEME has substantially altered natural oceanographic conditions (Gong et al., 2019). These CEME-mediated changes in oceanographic dynamics are unlikely to be reversed in the future.

Many CEME sites constructed during the 1990s, when rapid urbanization and industrialization accompanied fast economic growth, did not consider mitigation and control measures against pollutant discharges. Coastal cetaceans living in this environment may suffer long-term health risks from bioaccumulation of persistent pollutants from birth (Wells et al., 2005; Jefferson, Hung & Lam, 2006). Severe contaminant levels have been reported in humpback dolphins and their habitats near CEME. In the Pearl River Estuary where the largest known humpback dolphin population in the world occurs, persistent organic pollutants and heavy metals in both humpback dolphin tissues and the environment have been recorded at harmful levels (Jefferson, Hung & Lam, 2006; Gui et al., 2017). Accumulative pollutants can further depress photosynthetic activity and the growth of plankton (Harriss, White & Macfarlane, 1970; Mosser et al., 1972) and alter marine plankton composition (Mosser, Fisher & Wurster, 1972), ultimately compromising habitat functionality (Gong et al., 2019).

CEME impacts can be amplified by alterations in nearby landscapes and adjacent catchments. Human interventions happening upstream can influence interactions between river discharges and tidal dynamics in the estuary (Yang et al., 2020), which further leads to changes in ETM area and location (Asp et al., 2018; Abascal-Zorrilla et al., 2020). Along the western coast of Taiwan, Landsat imagery has revealed reduced river flows in summer (Figure 3). Remotely sensed sea-surface temperature observations show warm spots in the river estuary during summer, as a result of rapid heating when reduced river water flows over uncovered river bed (Huang, Wang & Yao, 2018). Compared with sea-surface temperature profiles in the 1980s, estuarine sea-surface temperature has increased by over 5°C in the past three decades (Huang, Wang & Yao, 2018), an approximately three times greater rise than the coastal sea-surface temperature increase (Lima & Wethey, 2012), and seven times the global sea-surface temperature increase (Lima & Wethey, 2012). This extreme temperature increase, accompanied by reduced river runoff (Karczmarski et al., 2017) and declining marine primary production (Huang, Wang & Yao, 2018), can alter estuarine physical characteristics, ecosystem composition and thereby compromise dolphin habitat quality, such as in the example in the northern Beibu Gulf, China, which suffers hypoxia during summer in the estuary (Gong et al., 2019). Compromised habitat quality further reduces population viability, compounding the effects of unsustainable fishery activities (Slooten et al., 2013; Araújo et al., 2014).

## 4 | INFORMED HABITAT PROTECTION PLANNING FOR COASTAL CETACEANS IN/NEAR DISTURBED ENVIRONMENTS

To cope with the complexity of CEME impacts (Table 2), an integrative framework to inform habitat protection planning (Figure 4) was recommended that summarized five major components, STEPS (Huang et al., 2020), comprising: (i) surveys and studies to collect baseline data of humpback dolphins (S); (ii) threats of habitat loss and habitat changes from CEME construction (T); (iii) evaluation of spatial priority for maintenance of population and ecosystem persistence (E); (iv) prioritizing MPA networking and cautiously examining the practicability of 'mitigation measures' compensating for CEME impacts (P); and (v) stakeholder engagement campaigns that assist habitat protection practices (S). Knowledge and action gaps and surveys to resolve these gaps specific to each compartment are summarized below:

### 4.1 | Surveys and studies informing population baselines and habitat changes

Sound habitat protection planning starts from mapping important areas based on distribution data for biodiversity features (Ardron, Possingham & Klein, 2010; Passadore et al., 2018), which highlights the importance of conducting population surveys in a systematic or transect-designed manner (Passadore et al., 2018; Wang et al., 2021). Systematically designed surveys are also important to help understand unbiased vital statistics of the target population, including abundance (Wang et al., 2012; Jutapruet et al., 2015; Chen et al., 2016; Peng et al., 2020), survival rate (Wang et al., 2012; Chen et al., 2018; Peng et al., 2020), residency (Peng et al., 2020) and life history (Chang et al., 2016; Zeng, Wang & Zhu, 2021) through photographically based capture–mark–recapture analyses. Sometimes, population surveys are conducted in a focalized manner by targeting areas of animal aggregation to numerically 'increase' dolphin encounters, particularly where dolphin abundance could be numerically low (Pan, 2013; Wang et al., 2016). This manipulation, however, does not improve 'survey efficiency' nor model predictions (Guillera-Arroita et al., 2015), but, instead, can mislead habitat protection planning by narrowing the protection range and neglecting important habitats (Bao et al., 2019; Wang et al., 2021) and by focusing on local residents, but neglecting regular visitors and transients (Peng et al., 2020). In CEME-disturbed habitats, this omission bias is frequently associated with locations where dolphin occurrence is seemingly low (as in Chou & Lee, 2010; Chou et al., 2011). Population baseline survey for humpback dolphins, as well as other coastal cetaceans, should be designed and conducted in a systematic or transect manner that concurrently collects occurrence and photographically based capture–mark–recapture data (as in Chen et al., 2016; Wu et al., 2017; Jefferson, 2018; Peng et al., 2020). This is to unify the detectability of animals and minimize sampling bias throughout the survey space, as the basic goal is to estimate unbiased habitat configuration and population vital statistics (Guillera-Arroita et al., 2015; Passadore et al., 2018; Peng et al., 2020; Wang et al., 2021). This recommendation is particularly important for humpback dolphins in habitats near sparsely populated landscapes (Figure 2b) to build an undisturbed or lightly disturbed baseline.

Ideally, baseline data on dolphin distribution and abundance should be collected as early as possible before any CEME project begins. In practice, however, baseline surveys are seldom funded until the time when concern that a CEME project might impact charismatic marine megafauna survival becomes apparent. This situation frequently occurs in waters near densely populated landscapes where industrialization and urbanization are escalating, as in western Taiwan (Karczmarski et al., 2017), Xiamen (Wang et al., 2017), Pearl River Estuary (Jefferson, 2000; Huang & Karczmarski, 2015) and northern Beibu Gulf (Chen et al., 2016; Wu et al., 2017; Peng et al., 2020) in China. The present IUCN status assessment of the Indo-Pacific humpback dolphin (Jefferson et al., 2017) does not factor in CEME impacts on population survival, at either the species or the regional level, and therefore could understate potential risks of local

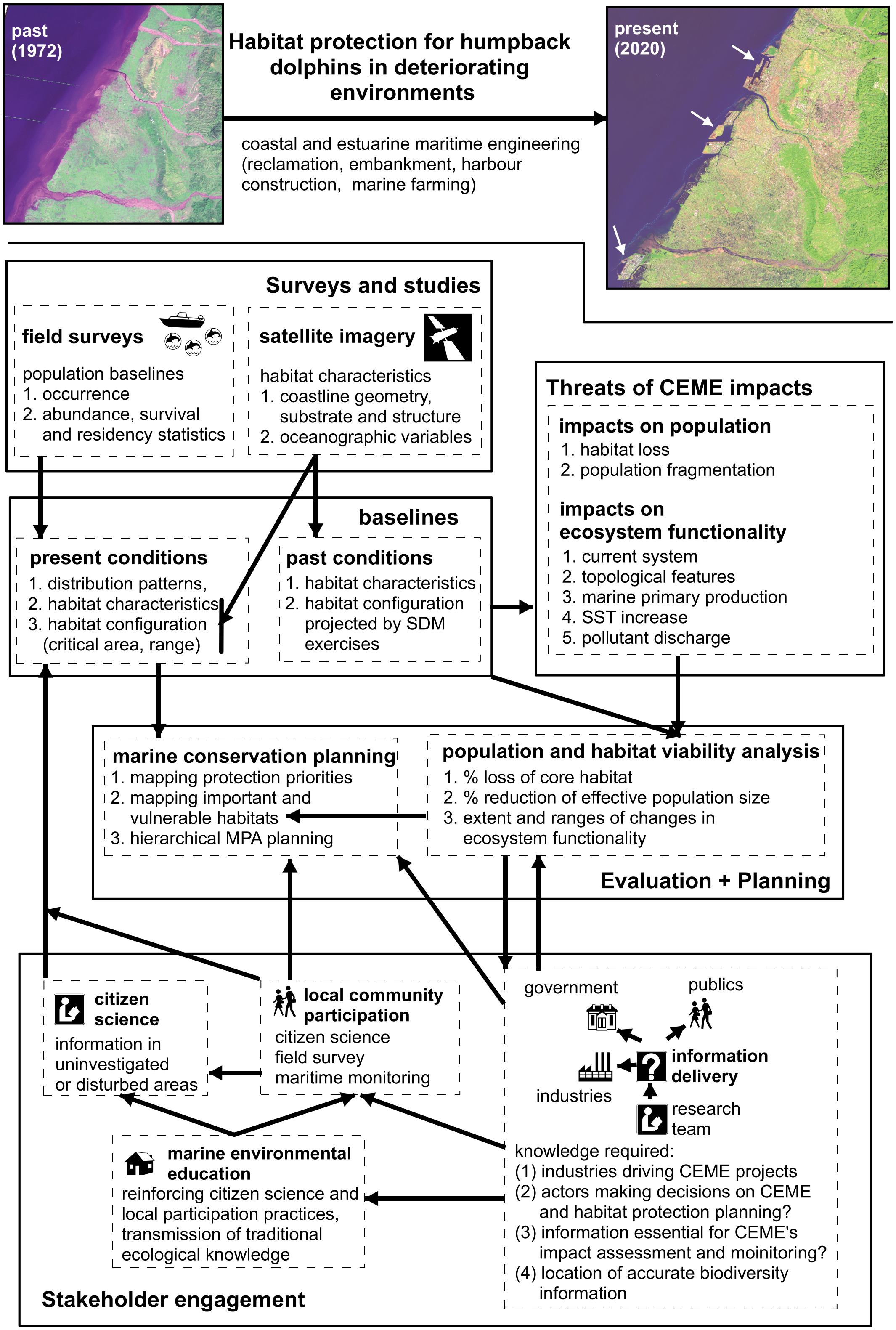


**FIGURE 4** The integrative framework of habitat protection planning that summarizes five major components (STEPS) to cope with the complexity of CEME impacts

extinction. To solve this gap, long-term changes in the distribution and habitat configuration can be explored through comparison of satellite remote-sensing data over several decades (Karczmarski et al., 2017; Wang et al., 2017; Wu et al., 2017), investigation of local ecological knowledge (Wu et al., 2014; Wu et al., 2017) and extrapolating habitat configuration by species distribution modelling exercises before (Huang, Wang & Yao, 2018) and after CEME construction by introducing hydraulic-dynamic models (Q. Li, personal communication). For satellite remote-sensing data, Landsat archives (https://glovis.usgs.gov/) can be used to map coastline changes and habitat loss since as early as the 1970s with fine spatial resolution. Level 3 ocean-colour data (https://oceancolor.gsfc.nasa.gov/l3/), on the other hand, can be used to measure macroscopic oceanographic characteristics and understand long-term oceanographic changes (Huang, Wang & Yao, 2018). These approaches are particularly important in potential *S. chinensis* habitats near densely populated landscapes (Figure 2b).

## 4.2 | Mapping habitat protection priorities through marine conservation planning

Sound habitat protection planning for marine megafauna considers the holistic protection of entire ecosystems (Ardron, Possingham & Klein, 2010; Weaver & Johnson, 2012; Wang et al., 2021). In Chinese waters, habitat protection planning for humpback dolphins needs to increase MPA coverage first (Huang et al., 2020), but also needs to consider ensuring population connectivity between habitat patches and maintaining intact ecosystem functionality (Bao et al., 2019). Bao et al. (2019) proposed a strategy of adopting MPAs as connecting nodes in the MPA network to ensure population and ecosystem connectivity at a population scale. The success of this strategy, however, could be ensured only if effective management and maintenance are implemented in the corridors between MPAs (Prof. J. M. Baxter, personal communication). A strategy alternative to the 'nodal' MPA network design (Bao et al., 2019) comes from the hierarchical design that delineates areas with differential protection priorities by a variety of tools for spatial protection (Ardron, Possingham & Klein, 2010; Weaver & Johnson, 2012; Day et al., 2019). Zonation algorithms like MARXAN provide a statistically sound approach for mapping habitat protection priorities at an eco-regional or national scale (Ardron, Possingham & Klein, 2010; Wang et al., 2021). In the Gulf of Thailand, Wang et al. (2021) mapped five critical habitats for the protection of major ecosystems based on MARXAN exercises, which improved the present conservation gaps substantially. Similar approaches can be applied to the configuration of core habitats in Chinese waters, species range and indicators of marine biodiversity abundance (OBIS, 2021), and marine primary productivity (http://sites.science.oregonstate.edu/ocean.productivity/index.php), which helps solve habitat protection priorities and identify areas that are important for maintaining humpback dolphin populations, biodiversity assemblages and ecosystem functionality on the national and species levels (S.L. Huang, unpublished results).

Sometimes, the designation of 'protected areas', or more precisely 'compensation areas', is proposed to compensate for habitat loss owing to CEME construction (as in Airport Authority Hong Kong, 2014). Decisions on such 'compensation' or 'mitigation' plans, however, should be cautiously examined in terms of whether the 'compensation area' proposal could really create a new environment that is suitable for humpback dolphins and whether the survival of those humpback dolphins formerly inhabiting the lost habitat could be assured in the 'compensation' areas (Elliott et al., 2007). To the extent that humpback dolphins require a wide range of habitats to accommodate a viable population (Karczmarski, Huang & Chan, 2017) and humpback dolphins' core habitats are often associated with regional biodiversity and ecosystem function centres (Wu et al., 2017; Wang et al., 2021), the goal of 'creating' a new environment suitable for humpback dolphins can be difficult to achieve. The best strategy is to minimize and avoid CEME impacts on the viability of humpback dolphins and ecosystem functionality in the first place. This requires careful planning that takes unbiased and holistic biodiversity baselines (as in Figure 2b) and ecological impacts (Table 2) into account, which can be facilitated through stakeholder engagement practices.

## 4.3 | Stakeholder engagement: practices, objectives and present gaps

Sound marine biodiversity conservation includes not only top-down management through policy and MPA designation, but also bottom-up practices through stakeholder engagement campaigns (Gaymer et al., 2014; Boon & Baxter, 2020; Noble & Fulton, 2020). Throughout the humpback dolphins' range, public engagement is practised in some habitats, such as the Pearl River Estuary (http://hkdcs.org/) and central west Gulf of Thailand (Dr Suwat Jutapruet, personal communication). Public engagement is essential for humpback dolphin conservation against improper CEME planning through citizen-science practices informing biodiversity baselines (Chandler et al., 2017; Harvey et al., 2018), the participation of local communities (Agrawal & Redford, 2006; Gaymer et al., 2014), marine environmental education (Lucrezi et al., 2019; Sakurai & Uehara, 2020) and efficient information delivery between stakeholders from the science, conservation, resource-extraction and development sectors (Boon & Baxter, 2020; Huang et al., 2020). For humpback dolphins in CEME-disturbed habitats, habitat protection planning needs to address current gaps that hinder the above stakeholder engagement campaigns (Table 3).

Citizen-science practices have been proven to be effective to inform marine biodiversity distribution (Chandler et al., 2017; Harvey et al., 2018). For humpback dolphins, opportunistic observations in uninvestigated areas are critical to evaluate CEME impacts on population connectivity and avoid 'omission bias'. Tourists on marine ecotourism ventures are potential candidates to engage in citizen-science practices (Harvey et al., 2018; Wu et al., 2020). Local fishing communities, as well, can accommodate citizen-science practices (Chandler et al., 2017; Quintana et al., 2020), because most marine ecotourism operations are operated by local fishers (Mustika et al., 2012; Wu et al., 2020). *Ad hoc* training programmes for boat captains and tour managers (Wu et al., 2020) and a platform with user-friendly smartphone interfaces for both captains and tourists to upload their records are recommended to distribute observation records (Table 3).

**TABLE 3** Practices, target audiences, objectives and gaps in public engagements that work towards habitat protection for humpback dolphins in disturbed habitats (TEK, traditional ecological knowledge)

| Practices | Target audiences | Objectives | Information/action gaps |
|---|---|---|---|
| Citizen science | Fishers, tourists, tourism managers | Informing on dolphin occurrences in uninvestigated habitats | The platform to register, verify and distribute observation records |
| Participation of local communities | Fishers, particularly artisanal fishers | 1. Accommodating citizen science<br>2. Assisting baseline surveys<br>3. Conducting voluntary maritime monitoring | 1. The network organizing and coordinating local community, research and management sectors<br>2. How to motivate willingness of local people |
| Marine environmental education | Tourists of marine ecotourism; kin of local communities, | 1. Reinforcing citizen science practices and local participation<br>2. Facilitating TEK transmission, particularly in disturbed habitats where humpback dolphins are no longer sighted | 1. Audiences' knowledge background<br>2. Curriculum and lecture design<br>3. Periodic and reinforced education programme<br>4. Evaluation of marine environmental education outcomes |
| Effective information delivery | Research teams, government sectors, actors driving CEME projects | Ensuring data used in conservation planning and CEME impact assessment to be the latest and robust | The platform to share survey results, CEME project and conservation planning between stakeholders |

Local communities, particularly fishing villages, can provide proactive functions for humpback dolphin conservation against CEME impacts, in addition to just accommodating citizen-science practices. In Chinese waters, collaboration between fishers and research teams supports population surveys (Wu et al., 2017; Huang, Wang & Yao, 2018; Peng et al., 2020) and informs the historical distribution of humpback dolphins (Wu et al., 2014; Wu et al., 2017). Fishers are excellent observers of marine biodiversity distribution and for monitoring illegal and unsustainable fishing, sand mining and marine pollution in the course of doing their jobs. Involving local people in habitat protection actions for humpback dolphins can substantially reduce monitoring costs and at the same time raise local conservation awareness and personal growth through reputational benefits (Quintana et al., 2020). A network coordinating local communities and various stakeholder sectors is essential for local participation practices (Granek et al., 2008), which can be facilitated by conservation non-governmental organizations (Table 3). Such an arrangement, the Marine Mammal Conservation Working Group, was established by the Hong Kong government more than 25 years ago, and has been an important tool in humpback dolphin conservation in Hong Kong (see Jefferson, Hung & Würsig, 2009).

Both citizen-science and local participation practices can benefit from marine environmental education programmes (Damerell, Howe & Milner-Gulland, 2013; Sakurai & Uehara, 2020). Marine environmental education dedicated to humpback dolphin conservation has been locally conducted (such as https://hkdcs.org/public-awareness/seminar-education-programme/), although its conservation efficacy has not been statistically evaluated yet. To achieve conservation of humpback dolphins in disturbed habitats, it is important to eliminate gaps in public knowledge of conservation targets, and increase understanding of conservation objectives and willingness/capability to adopt specific behaviours to achieve conservation objectives throughout much of the species' range (Table 3). Addressing these gaps requires audience-specific programming in reference to CEME impacts on local environments, biodiversity status, livelihoods and local/traditional ecological knowledge regimes supported by citizen science and local participation practices.

Ideally, both habitat protection planning and CEME zoning should refer to the latest and most robust information on dolphin distribution to avoid irreversible impacts on humpback-dolphin population viability. In practice, however, CEME planning and environmental impact assessments frequently use incomplete or flawed data, such as the sand-mining project at the Dafengjiang River Estuary (https://www.thepaper.cn/newsDetail_forward_3335090, in Chinese) in the northern Beibu Gulf and habitat protection planning for humpback dolphins (Chou et al., 2011, in Chinese) and environmental impact assessment in the offshore wind-farm development project (https://eiadoc.epa.gov.tw/eiaweb/11.aspx?hcode=1050020A&srctype=0, in Chinese) off the western coast of Taiwan. These flaws indicate a long-term lack of information delivery between stakeholders of the scientific, conservation and development sectors (Huang et al., 2020). To bridge this gap, answers to the following questions are essential for effective information delivery:

1. What are the industries that drive CEME projects?
2. Who are the actors that make decisions on CEME and habitat protection planning?
3. What information is required to evaluate and monitor environmental impacts of CEME?
4. Where can accurate and relevant information on biodiversity distribution be acquired for all stakeholder sectors?

Sharing published survey results with conservationists, developers and public groups, particularly in the local language (such as http://8.134.14.177:8080/dolphindb/portal/index.action, in Chinese), can be one practicable solution, which can be integrated with previously discussed citizen science and local participation practices. To take dolphin viability into account for CEME zoning and the resulting environmental impact assessment, teams conducting surveys on population status of humpback dolphins and local-community representatives need to be involved to ensure the latest and most robust data are considered.

## 5 | CONCLUSIONS

Throughout the species' range, many humpback dolphin habitats have not been systematically investigated, except in Chinese waters, the Gulf of Thailand and eastern Malaysian waters. Extrapolation of likely core habitats based on present understanding of habitat characteristics of humpback dolphins provides a precautionary baseline to evaluate CEME impacts on population viability and conduct ecosystem-based conservation planning at the species range. CEME impacts compromise humpback dolphin viability by reducing habitat area, partitioning population structures, altering ecological regimes and deteriorating ecosystem functionality. A 30% loss of core habitat owing to CEME construction can cause catastrophic impacts directly on population viability of this species. As ecosystem damage from CEME construction can be difficult to repair, the best strategy is to minimize and avoid CEME impacts through cautious planning that takes representative biodiversity baselines and potential impacts on ecosystem functionality into account at the beginning of the process.

Four major gaps hindering sound habitat conservation planning against inappropriate CEME planning comprise: (1) how to build a complete and unbiased baseline informing present population status; (2) how to figure the changes in baseline conditions to avoid the omission of historically important but presently disturbed habitats; (3) how to highlight important habitats critical for regional biodiversity assemblages and ecosystem functionality; and (4) how to ensure that the latest and spatially representative baselines are adopted in habitat conservation and CEME planning. Knowledge gaps associated with how to build representative baselines and how to measure spatial protection priorities can be addressed by:

1. conducting systematically designed (transect) surveys to collect unbiased occurrence and vital statistics data;
2. investigating local ecological knowledge and comparing long-term satellite remote-sensing data across the population range to explore the regional distribution gradients, extent of habitat loss and environmental changes;
3. extrapolating habitat configuration in the past, present and, if there is a need, the future by species distribution modelling exercises; and
4. mapping habitat protection priorities through spatial planning algorithms (such as MARXAN) based on core habitat configuration and indicators of biodiversity abundance and marine ecosystem functionality to highlight important areas and inform hierarchical MPA networking.

Action gaps associated with smoothing information delivery and raising public awareness combating inappropriate CEME projects, on the other hand, merit further social-science surveys and studies to illustrate practicable guidelines of action planning. This paper proposes citizen-science, local community participation and marine environment education campaigns.

Based on above discussions, answers to the following questions must be provided in CEME planning and environmental impact assessments to minimize and avoid the irreversible CEME impacts on humpback dolphins:

1. Are baselines of humpback dolphin distribution and habitat characteristics complete and unbiased throughout the population range to determine if the CEME project would destroy core habitats and interrupt population connectivity? What will be the habitat area occupied by the CEME project?
2. What will be the spatial extent of oceanographic changes upon CEME construction? What will be the likely range of changes in the local ecological regime, such as sea surface temperature, primary production and oceanographic current systems, once the CEME is constructed?
3. Are the above changes/impacts factored into CEME environmental impact assessment, particularly through the exercise of population and habitat viability analysis taking into account the scenarios of population fragmentation and habitat deterioration? Does the CEME environmental impact assessment explicitly illustrate and address these risks, including the cumulative impacts from multiple projects?
4. What is the survival threshold of the humpback dolphin population? What will be the survival likelihood of humpback dolphins, either above or below the threshold, once the CEME is constructed? What mitigation and compensation measures will be used to reduce the risk to humpback dolphin survival when numbers drop below the survival threshold? What is the practicability of those mitigation and compensation 'measures'?

Both ongoing and planned CEME projects should be re-examined in terms of the above four questions, and their ecological impacts re-evaluated. In this context, conservation non-governmental organizations play a proactive role helping to coordinate science and local community sectors, and help to conduct practices of citizen-science, maritime monitoring, marine environmental education and information sharing that will prevent improper CEME planning.

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## CONFLICT OF INTEREST

All authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

Data available on request from the first author.

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