

Using local ecological knowledge to inform regional conservation prioritization for threatened marine megafauna

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Abstract: Due to high costs and time constraints, it can be difficult for traditional field-based methods to acquire sufficient data to identify priority species or areas in marine conservation planning. Local ecological knowledge (LEK) is increasingly used as an important source of information for evidence-based management strategies, but its usefulness for informing conservation prioritization for threatened marine species has rarely been assessed. Here, we conducted the first range-wide systematic survey of five marine megafauna (Indo-Pacific humpback dolphin, Indo-Pacific finless porpoise, dugong, whale shark, sea turtles) using interviews with fishers in the northern South China Sea (SCS), one of the richest marine biodiversity hotspots in the world, to assess the ability of LEK to highlight priority species and areas for conservation. Our results reveal that the dugong has become functionally extinct in China, while the Indo-Pacific finless porpoise, whale shark, and sea turtles have all experienced more severe declines compared to the Indo-Pacific humpback dolphin. Based on the sighting histories of these threatened species, regional conservation priorities and management activities should therefore focus on reducing disturbance pressure in the Beibu Gulf and eastern Guangdong for the Indo-Pacific finless porpoise and in eastern/southern Hainan Island for the whale shark and sea turtles. These findings challenge current conservation strategies that prioritize the Indo-Pacific humpback dolphin in the SCS, suggesting that coastal dolphins might not be good indicators of the population trends of sympatric marine megafauna. While LEK cannot provide precise abundance and habitat data for highly threatened marine species, we demonstrate that it offers comparable long-term population trend and wide-scale distribution data to inform the prioritization of conservation actions.

Keywords: indicator species; dugong; sea turtle; Indo-Pacific humpback dolphin; conservation prioritization; South China Sea

1. Introduction

Biodiversity conservation is constantly faced with the challenges posed by limited resources, commonly referred to as the “conservation resource allocation problem” (Wilson et al., 2006). Therefore, a crucial facet of effective conservation decision-making involves the identification of priority species and areas requiring focused management efforts (Mace et al., 2006). Strategic allocation of conservation efforts serves to optimize the investment of time and financial resources. This can be achieved by minimizing the number of species that require monitoring, or by determining the optimal pattern of allocating conservation resources across regions, which requires investigating species distribution patterns (Mace et al., 2006). Both species-based and region-based prioritization approaches require evidence-based conservation decision-making that is dependent upon extensive datasets. Unfortunately, obtaining comprehensive data for threatened species to inform conservation prioritization is often a substantial challenge. These efforts can be logistically and technically difficult, and can be perceived as irrelevant by resource managers and local communities (Arponen et al., 2008; Danielsen et al., 2005; Mazor et al., 2016).

Most of the data that are used for prioritizing conservation planning are derived from field surveys conducted by trained scientists (Danielsen et al., 2005; Turvey et al., 2015). However, this approach for monitoring biodiversity and resource use requires substantial investment of time, effort and funding, making it difficult to sustain, particularly in countries with limited financial resources (Aragones et al., 1997; Danielsen et al., 2005; Teixeira et al., 2013). An alternative potential approach is provided by citizen science, whereby valuable information about target species and ecosystems can be obtained from people who are not trained in scientific methods but who utilize the same environments (Tengö et al., 2021). Citizen science research methods often aim to access local ecological knowledge (LEK), representing the understanding and insights about locally-occurring biodiversity that resource users derive from their lived interactions with the environment (Inglis, 1993). LEK has been increasingly acknowledged as a valuable source of data for wildlife conservation, and surveys that employ social science methods offer a cost-effective approach to gather comparative data on species that are typically challenging to investigate through traditional field-based strategies (Buchholtz et al., 2020; Early-Capistrán et al., 2022; Mclean et al., 2013; Nuez et al., 2023; Turvey et al., 2014; Turvey et al., 2016). Interview-based sighting histories can be used to determine the distribution and status of threatened species across different landscapes, facilitating area-based conservation prioritization (Archer et al., 2020; Cheng et al., 2021; Nash et al., 2016; Noble et al., 2020). However, although LEK can be employed to inform regional conservation prioritization for highly threatened species in terrestrial systems (Magalhães et al., 2022; Turvey et al., 2015), it remains underutilized for determining priority species within multispecies systems. Since the effectiveness of similar conservation approaches may vary across different aquatic and terrestrial landscapes, which can differ fundamentally in their physical, biological and sociopolitical characteristics (Lourie and Vincent,

2004), the use of LEK to inform conservation prioritization for marine species should be further assessed.

The South China Sea (SCS) is a marginal sea of the western Pacific Ocean with an area of over 3.5 million km², which extends from the Strait of Malacca in the southwest to the Strait of Taiwan in the northeast. The SCS is home to a diverse range of marine megafauna, including five of the world's seven sea turtle species (Wang, 1993; Wei, 2016) and over 30 of the world's 90 cetacean species (Jefferson et al., 2015; Lin et al., 2019; Wang, 2012). It is thus recognized as one of the richest marine biodiversity hotspots (Carpenter and Springer, 2005; Tittensor et al., 2010). Many of its species are directly or indirectly threatened by anthropogenic pressures, which are escalating due to rapid human population growth and economic development in the countries that border the SCS (Chan et al., 2007; Li et al., 2020; Wei, 2016). This concern highlights the urgent need for regional conservation programmes for the SCS's marine megafauna. Many countries surrounding the SCS have chosen the Indo-Pacific humpback dolphin (*Sousa chinensis*, hereafter humpback dolphin) as a surrogate species to assess the extent of anthropogenic disturbance, safeguard the conservation of coastal waters, and serve as a symbol for conservation awareness and fundraising (Huang et al., 2021; Liu et al., 2023; Minton et al., 2016). The choice of the humpback dolphin as a priority species is predominantly based on the availability of monitoring data from long-term field surveys, rather than from comparative assessment within a comprehensive multi-species conservation framework. However, existing knowledge of most other marine megafaunal species in the SCS is mainly based upon stranding records, with limited field investigations or satellite tracking (Lin et al., 2020; Liu et al., 2022; Wang et al., 2012; Yeh et al., 2020), making it difficult to assess their status or population trends. It is therefore extremely important to investigate the population status of marine megafauna in this key region, to allow assessment of their status and to inform regional conservation prioritization for these at-risk species.

The purpose of this study was to use the SCS as a case study system to explore the usefulness of LEK to help identify priority species and areas for conservation action. In particular, we investigated three key questions: (1) Does investigation of LEK represent a cost-efficient method for informing species prioritization in multispecies systems through comparison of population trends? (2) Can interview-based sighting histories across different locations be used to determine priority areas for conservation? (3) Is the current strategy of selecting the humpback dolphin as a priority species in the SCS effective for wider biodiversity conservation?

2. Materials and methods

2.1. Survey species and location

Five representative SCS marine megafaunal taxa were selected for investigation: humpback dolphin, Indo-Pacific finless porpoise (*Neophocaena phocaenoides*, hereafter finless porpoise), dugong (*Dugong dugon*), whale shark (*Rhincodon typus*), and sea turtles. Although 90% of sea turtles in the region are green turtles (*Chelonia mydas*), five species occur locally (Wang, 1993), which may be challenging for

untrained observers to distinguish, and so the general category of “sea turtle” was used in interviews. These taxa were chosen for several reasons. Firstly, they represent diverse taxonomic groups: humpback dolphins and finless porpoises are cetaceans, dugongs are the sole sirenian species in China, whale sharks are elasmobranchs and the largest fish species, and sea turtles are reptiles adapted to marine environments. Secondly, they are all sensitive to human activities due to their coastal distribution and k-selected life history strategy. Thirdly, they are all flagship species in China, attracting significant attention from both the government and the public regarding their status and population trends. Finally, they are well recognized in local culture due to their distinctive morphology and body coloration, which reduces the likelihood of misidentification by fishers.

Community-based surveys were conducted in four Chinese maritime provinces (Hainan, Guangxi, Guangdong, Fujian) along the northern SCS between 18°15'N-109°30'E and 26°02'N-119°19'E (Fig. 1). A total of 66 fishing communities belonging to 22 municipalities were chosen as interview locations. The selection criteria for survey locations considered factors such as regional length of coastlines, distance to nearby cities, and numbers of registered fishing families (Table S1). Our survey area covers the entire known range of dugongs, humpback dolphins and finless porpoises in mainland Chinese waters (Jefferson et al., 2017; Marsh and Sobotzick, 2019; Wang and Reeves, 2017). Whale sharks and sea turtles have a wider marine distribution, and we interpret the data collected from Fuzhou (the northernmost surveyed city in Fujian) as partly reflecting their distribution in the East China Sea as well as the SCS.

2.2. Interview design and survey

To ensure that we collected a representative sample of LEK from fishing communities in the northern SCS, we employed a proportional sampling approach based on data about fishing communities available from the Chinese Ministry of Agriculture (2020) and local ocean fishery bureaus (Table S1). Respondents were selected if they were professional fishers, primarily engaged in fishing as their main livelihood, and had lived in the selected survey location for a significant portion of their lives. To identify respondents, we randomly selected fishers while walking through each community. Additionally, local community heads sometimes referred us to respondents known for their extensive LEK through targeted “snowball sampling” (Newing, 2011). To avoid bias, sex and ethnicity were not used as selection criteria, but interviews were not conducted with respondents below the age of 18. To ensure independence of responses, only one respondent was interviewed per household/boat.

LEK data were collected using a standardized methodological protocol previously applied in research on marine mammals in the SCS (Lin et al., 2019; Lin et al., 2023). Interviews were conducted using a standard questionnaire that included a combination of multiple-choice, short free-response and multi-part questions, taking approximately 45 minutes to complete (Supplementary questionnaire). The questionnaire first covered background information about the respondent, including their age, education, fishing experience, and perceptions of the present status of the SCS ecosystem and its fisheries. Subsequent sections focused on respondent experiences, interactions and attitudes

associated with the five target megafaunal taxa, which were discussed in the same order in all interviews. Respondents were shown colour photographs of each taxon from different angles to establish recognition. If they could not recognize them from the photographs, standard Mandarin names were used to prompt recall. After identifying each taxon, further questions were asked to gather ecological and morphological details to confirm accurate recognition. For taxa that they recognized, respondents were asked whether they had ever seen them in the wild, along with information on the timing and location of sightings.

Interviews were conducted between 15 July and 13 August 2019 by a team consisting of one senior researcher, three graduate students, and 21 well-trained volunteers recruited mainly from local universities. Most volunteers were fluent in local languages/dialects and were studying marine biology or ecology. Prior to conducting interviews, volunteers received training in species identification and interview methods. Interviews were mainly conducted in Mandarin, with occasional use of Cantonese, Hokkien or Hainanese, on a one-to-one basis in relaxed and informal settings. Participation of respondents was voluntary, and interviews were conducted only following free prior informed verbal consent. Respondents were provided with a statement explaining the purpose of the survey and were assured that their data would be kept anonymous. They were informed that they could stop the interviews at any time or choose not to answer any question. Further details about survey design are provided in Lin et al. (2022b) and Lin et al. (2023).

2.3.Data analysis

When analyzing historical population trends of marine animals using LEK surveys, several methods are commonly employed. The simplest analytical approach involves asking directly about population trends during fishers' experiences (Nuez, 2023) or comparing their catch across age groups in different periods (Hallwass et al., 2013). For species targeted by fisheries, utilizing information on best catches and the largest individuals ever caught can be employed to reconstruct time series as indicators of population trends and age structure changes (Bravo-Calderon et al., 2021; Sáenz-Arroyo et al., 2005, 2016). For non-fishery target species, it is possible to reconstruct time series based on the temporal distribution of last-sighting dates to use as indices of population trends. Species that maintain substantial and regularly-encountered populations will have respondent last-sighting dates that cluster in the recent past, resulting in steep sighting-history slopes in regression analysis. Conversely, species that have experienced severe declines typically exhibit last sightings further back in the past, leading to shallower and possibly negative slopes in regression models. This pattern has been well documented for several threatened aquatic species (Turvey et al., 2010; Turvey et al., 2012) and terrestrial species (Turvey et al., 2015). We therefore calculated mean last-sighting dates and slopes to compare population trends between different taxa and regions.

To analyze spatial sighting history patterns, we categorized all 22 surveyed communities into 10 city groupings based on their geographic location and sample size, arranged from north to south: Fuzhou, Xiamen, Shantou, Zhuhai (including Jiangmen

and Zhongshan), Yangjiang, Zhanjiang, Qinzhou (Beihai and Fangchenggang), northern Hainan (Changjiang, Chengmai, Danzhou, and Lingao), eastern Hainan (Lingshui, Qionghai, Wanning, and Wenchang), and southwest Hainan (Dongfang, Ledong, and Sanya). We assessed whether there were significant differences in respondents' fishing effort (reported fishing experience in years) and vessel length (mean $\pm$ standard deviation, SD). As both fishing effort and vessel length did not meet the assumption of a normal distribution (Shapiro-Wilk test, $p < 0.001$), we used the nonparametric Kruskal-Wallis test to examine if there were significant differences between city groupings.

For analysis, we considered only the most recent sighting event reported by each respondent when asked when they had last seen each taxon at sea. To determine encounter rates, we calculated the proportion of respondents reporting sighting events relative to the total number of interviews conducted in each city grouping. Frequency of last-sighting dates per city per year was expressed as a proportion of the total number of observations for the sighting history dataset in each city grouping, and differences in last-sighting histories between cities during 1990-2019 were explored using generalized linear models (GLMs) following Turvey et al. (2015, 2016). Following Turvey et al. (2015), sightings from before 1990 were excluded from analysis, as a small number of old records can create a long "tail" that greatly extends the time series. For instance, 92.47% of humpback dolphin last-sighting records dated from after 1990, with only 7.53% ($n = 36$) occurring before this date, but these older records dated from as far back as 1959, thus substantially expanding the species' time series. The inclusion of such markedly older records can flatten the overall sighting-history slope and lead to wider confidence intervals for commonly seen species. We considered last-sighting history trajectories between species to be significantly different if confidence intervals of regression slopes did not overlap for each species. For comparative purposes, 83% confidence intervals were used, which provide an approximate $\alpha = 0.05$ test; comparisons using two sets of 95% confidence intervals are too conservative (Payton et al., 2003). Lower sighting-history slopes indicate fewer sightings have occurred near the present. Such comparisons were conducted between different taxa across the overall dataset, and between the same taxa across different locations.

We used multiple regression to investigate whether variation in respondent sightings of marine megafauna was determined by variation in respondent fishing activities or interview locality. Respondent experience of marine megafauna was used as the response variable (experience of having seen each taxon: 0/1), and boat length, number of fishing years and city grouping were selected as explanatory variables (fixed effects in models). We constructed full additive multivariate GLMs with logit link and binomial error structure. During model construction, Fuzhou was used as the randomly selected reference city to test for significant variation in respondent sightings across other cities.

All models were built in R 4.1.1 (R Development Core Team, 2021), with the significance level set as $p < 0.05$.

3. Results

A total of 788 respondents were interviewed across Fujian ($n = 157$), Guangdong ($n = 259$), Guangxi ($n = 98$), and Hainan ($n = 274$). Respondents had a mean age of 51 years (range = 19–105, $SD = 13$). Most respondents were men (96%) and had received education to junior middle school level (88%). Respondents had extensive fishing experience, with a mean of 25.25 ± 13.68 years in the fishing industry. They spent approximately half of each year at sea (185 ± 67 days), thus making them highly knowledgeable about the biological resources of the SCS. The majority of fishing vessels used by respondents (78%) were less than 30 m in length (19.65 ± 13.29 m) and were primarily utilized for fishing within 100 km of the shore (66 ± 355 km), indicating higher fishing efforts in coastal waters. There were significant differences in respondent boat length between surveyed cities, with Fuzhou and Yangjiang having significantly longer fishing boats compared to other cities (Kruskal-Wallis test, $p < 0.001$). However, there were no significant differences in fishing effort between surveyed cities (Kruskal-Wallis test, $p = 0.548$).

Based on last-sighting data reported by respondents, dugongs have exhibited the most severe decline in the northern SCS, followed by whale sharks, finless porpoises, sea turtles and humpback dolphins (Table 1). The majority of respondents reported encounter histories of humpback dolphins (68.65%) and sea turtles (69.29%), with fewer reporting sightings of finless porpoises (39.34%) and whale sharks (41.75%), and only a small number (4.70%) reporting dugong sighting. Humpback dolphins had the highest sighting rate in the past decade (47.72%), followed by sea turtles (35.53%), finless porpoises (22.59%), whale sharks (17.64%) and dugongs (1.02%). Similar trends were shown in analysis of mean last-sighting dates: humpback dolphins showed the most recent reported sighting year (2013 ± 11 year), followed by sea turtles (2010 ± 12), finless porpoises (2009 ± 13), whale sharks (2007 ± 13) and dugongs (1996 ± 16). Last-sighting regressions showed that all species had significantly lower sighting-history slopes compared to humpback dolphin (2.15 ± 0.98). In addition, a significantly lower slope was shown by dugong (0.02 ± 0.02) compared to all other species, and by whale shark (0.58 ± 0.16) compared to humpback dolphin and sea turtles (1.37 ± 0.48) (Fig. 2).

Comparative analysis was possible for most megafaunal taxa, although dugongs were excluded from this analysis due to insufficient sighting reports for all four surveyed provinces. Respondents reported more recent last-sighting dates and higher associated sighting-history slopes for humpback dolphins and finless porpoises in Guangdong compared to the other three provinces (Fig. 3). In contrast, more recent last-sighting dates and higher sighting-history slopes were reported in Hainan for sea turtles and whale sharks. Further analysis of sighting histories across the 10 surveyed city groupings revealed further spatial distribution patterns (Fig. 4). The highest proportions of humpback dolphin sightings were reported from Xiamen (96.88% of respondents) and Zhuhai (96.15%) and the lowest proportions were reported from eastern Hainan (29.52%) and northern Hainan (46.91%), and the highest sighting-history slopes were shown in Zhuhai (0.34), Qinzhou (0.33), and Xiamen (0.30) whereas significantly lower slopes were shown in eastern Hainan (0.09) and northern Hainan (0.06). For finless porpoises, the highest proportions of sightings were reported from Fuzhou

(59.14%), northern Hainan (55.56%) and Zhanjiang (54.79%), and the highest sighting-history slopes were shown in Fuzhou and Zhanjiang (both 0.16) whereas the lowest slopes were shown in Zhuhai and Xiamen (both 0.03). For whale sharks, the highest proportions of sightings were reported from eastern Hainan (68.57%), Yangjiang (68.29%) and southwest Hainan (53.41%), and a significantly higher sighting-history slope was shown in eastern Hainan (0.25), which was more than two times higher than the second-highest slope (Fuzhou, 0.10). For sea turtles, the highest proportions of sightings were reported from Yangjiang and all three locations in Hainan (all approximately 80%), and the highest sighting-history slopes were shown in eastern Hainan (0.32) and southwest Hainan (0.25), with all other cities having slopes lower than 0.20.

Multivariate GLM analysis showed that respondent sighting experiences of megafaunal taxa were statistically correlated with fishing effort, boat length and survey location (Table 2). In all cases, fishers with longer fishing experience were statistically more likely to have seen megafauna compared to those with less experience ($p < 0.05$ in all models). There was a significant positive relationship between boat length and sighting likelihood for all taxa except finless porpoise ($p = 0.06$), indicating that the likelihood of encountering humpback dolphins, sea turtles and whale sharks increases as boat length increases. Compared to Fuzhou, respondents were less likely to have seen humpback dolphins in eastern Hainan ($p < 0.001$), but were more likely to have seen them in Xiamen, Shantou, Zhuhai, Yangjiang, Zhanjiang and Qinzhou (all $p < 0.01$). For finless porpoises, Yangjiang, Zhanjiang and northern Hainan showed similar sighting likelihoods compared to Fuzhou, while the other six cities showed lower sighting likelihoods. For whale sharks, Yangjiang, southwest Hainan and eastern Hainan showed higher sighting likelihoods compared to Fuzhou ($p < 0.01$). For sea turtles, southwest Hainan showed a higher sighting likelihood compared to Fuzhou ($p = 0.005$), while Xiamen and Zhuhai showed lower sighting likelihoods ($p < 0.05$).

4. Discussion

Some potential errors and uncertainties must be taken into consideration before interpreting the findings of this study. Firstly, there is a possibility of species misidentification responses by respondents. To minimize the risk of misidentification, we carefully selected morphologically distinctive megafauna as target taxa for investigation. After initial identification of animals from photographs, we also asked respondents to provide species names and to describe how they can be differentiated morphologically from other taxa, to confirm correct identification. Secondly, memory decay and biased of informers can introduce noise into the interview data (Fowler, 2009; Gomm, 2004). We thus only analyzed data of the last-sighting year reported by respondents, as using years as the unit can help minimize errors in memory compared to month and week. We also provided clear instructions and visual aids such as maps to help trigger accurate recall and reduce memory decay and biases in respondents (Nash et al., 2016; Turvey et al., 2016). Lastly, the varying ecological habits and behaviours of different taxa could lead to differing detection rates independent of their population

status. For instance, humpback dolphin encounter rates might be over-reported because of the species' preference for inshore habitats and its distinctive pink/white body color, making it easier to be observed and recognized by fishers. However, the other megafaunal taxa included in our study are also morphologically distinctive and have a near-shore distribution for at least part of their life history, suggesting that they should also be detectable and identifiable by fishers if they are locally present.

In spite of these uncertainties, LEK surveys can provide useful long-term population trend and wide-scale distribution data to inform the prioritization of marine conservation actions. Many of the world's most vulnerable and rapidly changing ecosystems are also among the most data-poor for conservation management, leading to an increased interest in developing new methods for long-term environmental change monitoring and conservation planning (Azzurro et al., 2011; Beaudreau and Levin, 2014). Ecological data collection using citizen science approaches has experienced rapid development in recent years (McClure et al., 2020), which has enabled untrained members of the public to participate widely in the data collection process, and has provided significant support for understanding the abundance, distribution and population trends of many species. Compared to traditional field survey methods, citizen science is characterized by lower costs, effort and time investment, making it particularly suitable for conservation programmes in many biodiversity-rich but resource-poor regions. LEK is one of the most commonly used citizen science data types, and can enable the population status and trends of target species to be assessed using past encounters reported by untrained observers. Although such interview-based sighting histories do not provide absolute abundance data to evaluate temporal population changes, they allow comparative assessment of relative population dynamics between different species or sites, and can identify conservation-priority species that have experienced more severe population declines. Our study supports the previous conclusion that interview-based informant data can be applied to construct multi-taxon decline curves in freshwater environments (Turvey et al., 2010; Turvey et al., 2012), and we confirm the applicability of this data type in monitoring marine biodiversity change and prioritizing conservation actions. Our findings also indicate that LEK can identify potential hotspots of conservation-priority species distributions across large geographic regions, thus providing a valuable baseline for identifying critical habitats and focusing further field investigations for target species. Since there is an urgent need to develop low-cost and rapid methods for assessing and monitoring the status and threats of marine species at a global scale, our findings highlight the potential of large-scale systematic interview-based approaches to make a significant contribution towards this goal.

Although all of the taxa in our study are protected by the Chinese government (National Forestry and Grassland Administration, 2021), they have received varying levels of practical attention and protection. Humpback dolphins, referred to as the “giant panda of the sea”, are the most extensively studied and protected marine species in China, with all known populations being the focus of systematic field surveys and occurring in designated or proposed marine protected areas (Huang et al., 2021; Lin et al., 2022a; Liu et al., 2023). In contrast, other marine megafaunal species have received

much less regional attention, with basic ecological information (e.g. population size and geographic range) for sea turtles, whale sharks and finless porpoises remain largely unknown. Only one marine protected area has been established in Huidong (Guangdong Province) for sea turtles, and none have been designated or proposed for whale sharks or finless porpoises. Although the decline of humpback dolphins in China has been well confirmed (Huang et al., 2021; Li et al., 2020; Liu et al., 2023), our study highlights the fact that other marine megafaunas are experiencing even more severe regional population declines. For instance, less than 5% of the 788 respondents reported past sightings of dugongs, and only eight respondents reported sightings within the past 10 years. This alarming trend leads to the conclusion that dugongs have suffered a rapid population collapse in recent decades and are now functionally extinct in China (Lin et al., 2022b; Lin et al., 2022c). Furthermore, whale sharks, finless porpoises and sea turtles also have fewer recent respondent sightings, older mean last-encounter dates and lower combined sighting-history slopes, indicating more concerning population trends compared to humpback dolphins (Table 1, Fig. 3). These findings challenge current marine conservation strategies that prioritize humpback dolphins in China, and we suggest that an increased investment in research and conservation efforts for other highly threatened marine megafauna is urgently needed.

Although the concept of an ‘indicator species’ has various meanings, serving as a proxy to understand changes in populations of other species (population indicators) is one of its important functions (Caro and O’Doherty, 2001). However, traditional field-based methods make it challenging to monitor multiple sympatric species simultaneously over extended periods. This limitation has led to a lack of quantitative evidence to support the effective use of cetaceans as population indicator species (Turvey et al., 2012), despite their widespread focus for marine conservation efforts (Katona and Whitehead, 1988; MacLeod, 2009; Lin et al., 2022a; Parsons et al., 2015). Our findings suggest that although humpback dolphins do indeed share comparable population decline trends with other sympatric marine megafauna, significant differences in rates of decline were observed between co-occurring taxa, with both whale sharks and dugongs exhibiting significantly lower combined sighting-history slopes (Fig. 2). This conclusion differs from a previous investigation, which found that the decline of the baiji (*Lipotes vexillifer*) showed a statistically similar population trend to several members of its co-occurring aquatic fauna, and thus acted as a population trend indicator in an extremely degraded freshwater system (Turvey et al., 2012). The reason for this difference may be due to the fact that entire geographically constrained river ecosystems can be susceptible to collapse in response to intense, spatially focused but diverse human activities, resulting in similar population trends across species occurring within the same drainage basin (Duncan and Lockwood, 2001). In contrast, diverse habitats and spatial variation in human pressures across larger expanses of marine environment might instead lead to differing population trends among species with varying life history strategies and distribution patterns. Irrespective of possible reason, our analysis of population trends across five sympatric megafaunal taxa indicates that the humpback dolphin might not be the most appropriate indicator species for other near-shore marine megafauna, and conservation strategies based around single

coastal dolphin species might therefore inadvertently neglect other taxa that are experiencing more serious population declines.

Although fishing communities around the northern SCS were surveyed at random, and hence important distribution areas for marine megafaunal taxa may not have been captured evenly, our results seem robust, as the sighting histories of humpback dolphins reported by respondents in different locations (Table 2, Fig. 4) are highly correlative with previous field studies. For example, Zhuhai, Qinzhou and Xiamen have confirmed resident humpback dolphin populations (Jefferson et al., 2017; Liu et al., 2023) and have high respondent sighting proportions and sighting-history slopes, whereas eastern and northern Hainan have no resident humpback dolphins and have correspondingly lower respondent encounter indices. Although only limited independent stranding records or field investigation data are currently available for other species (Lin et al., 2020; Liu et al., 2022b; Wang et al., 2012; Yeh et al., 2020), we therefore interpret our LEK data for finless porpoises, whale sharks and sea turtles as likely to be correspondingly accurate, and propose that they can be used to inform spatial conservation prioritization. Based on regional encounter rates and sighting regression slopes, we thus identify eastern Guangdong and the Beibu Gulf as hotspots for finless porpoises, while coastal waters from the Taiwan Strait to Yangjiang are areas with lower encounter probability for this species. For whale sharks and sea turtles, the waters around Hainan, especially eastern and southern Hainan, are instead interpreted as the most crucial habitats. These regional findings provide an essential baseline for identifying potential locations for in-depth field surveys and prioritizing different areas for conservation action in the future.

Our data also provide new insights into megafaunal population status and their conservation implications at locations of special concern. High overall sighting frequencies, coupled with low recent sighting proportions and sighting-history slopes, suggest that Yangjiang and northern Hainan may be experiencing substantial recent humpback dolphin population declines (Fig. 4). The low sighting proportion and sighting-history slope for the coastal waters of eastern Hainan indicates that no resident humpback dolphin population inhabits this area, despite it being considered as part of the species' current range according to the IUCN Red List (Jefferson et al., 2017). Conversely, Yangjiang exhibits a very high encounter rate of whale sharks and sea turtles compared to nearby city groupings; this pattern may reflect the significantly larger fishing boats used in this region, which could be associated with increased detections of these more offshore-distributed taxa. In addition, although estuaries represent productive ecosystems that constitute favoured habitats for many coastal marine animals, Zhuhai shows surprisingly low encounter rates and regression slopes for finless porpoises, whale sharks and sea turtles (Table 2 and Fig. 4). This pattern is likely to reflect the intense human activities in the Pearl River estuary, which are likely to have reduced local abundances of these marine megafauna.

Based on our results, we propose three specific conservation suggestions. Firstly, our findings largely support the current distribution of marine protected areas for humpback dolphins in Chinese waters. The Chinese government has established marine protected areas for this coastal dolphin species in Xiamen, Shantou, Zhuhai, Jiangmen

and Zhanjiang (Liu et al., 2023). Additional marine protected areas are under consideration in Qinzhou and southwestern Hainan (Lin et al., 2022a). These locations show higher humpback dolphin sighting frequencies and recent encounter reports, indicating that the current habitat-based conservation strategy for this species seems to be appropriate. However, special attention and protection actions are warranted for Yangjiang, where the abundance of humpback dolphins in the Moyang River Estuary is estimated to be 528 individuals (Li et al., 2019), but where our data suggest that the species has experienced substantial recent population decline. Secondly, to date, only one marine reserve has been established to protect the nesting grounds of sea turtles, in Huizhou (east of the Pearl River Estuary). As our data indicate that the waters around Hainan have the highest numbers of sea turtle sightings (Fig. 4), and the Xisha Archipelago is also identified as a primary nesting ground (Mazor et al., 2016; Wei, 2016; Yeh et al., 2020), we recommend that these areas be considered as top-priority protected areas for sea turtles. Finally, given the absence of protected areas for whale sharks and finless porpoises in the northern SCS, we suggest designating the waters around eastern and southern Hainan as priority areas for whale shark conservation, and the Beibu Gulf and eastern Guangdong as priority areas for finless porpoise conservation. By establishing marine protected areas in these regions, we can enhance conservation efforts for these seriously declining species and contribute to the overall protection of marine megafauna in the SCS.

5. Conclusion

Our results show that the dugong has become functionally extinct in China, and that finless porpoises, whale sharks and sea turtles all show more severe declines compared to humpback dolphins. These findings challenge current conservation strategies that prioritize the humpback dolphin in this region, suggesting that conservation actions designed around coastal dolphins may not always align with actions needed to protect other threatened marine taxa. In addition, our study also provides up-to-date insights into the population status, trends and priority areas for target species in this region, suggesting that regional conservation priorities and management activities should focus on reducing disturbance pressure in the Beibu Gulf and eastern Guangdong for finless porpoises, and in eastern and southern Hainan for whale sharks and sea turtles. Since these conclusions are based only on LEK surveys, their accuracy needs to be confirmed by field surveys. Future research should involve a prompt initiation of field surveys for finless porpoises, whale sharks and sea turtles in the SCS to establish precise assessments of population abundance and decline rates, and to identify species hotspots based on the approximate distribution areas indicated by interview-based sighting histories. Our study was only able to focus on five representative marine megafaunal taxa, and we recommend that future research should also investigate a wider range of threatened animals in the SCS (e.g., baleen whales, tuna), to provide new baselines on their population status and historical trends.

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CRediT authorship contribution statement

Mingli Lin: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **Mingming Liu:** Methodology, Formal analysis, Writing – original draft. **Heidi Ma:** Formal analysis, Writing – review & editing. **Samuel T. Turvey:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Songhai Li:** Conceptualization, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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Data Availability Statement

Data will be made available on request.

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Table 1. Summary of respondent sightings and last-sighting histories for five marine megafaunal taxa in the northern South China Sea. Abbreviations: SCH: *Sousa chinensis*, NPH: *Neophocaena phocaenoides*, DUG: *Dugong dugon*, RTY: *Rhincodon typus*, STU: sea turtles.

	SCH	STU	NPH	RTY	DUG
Informer number	788	788	788	788	788
Sighting records	541	546	310	329	37
Sighting rate (%)	68.65	69.29	39.34	41.75	4.70
Sightings in past decade	376	280	178	139	8
Sighting rate in past decade (%)	47.72	35.53	22.59	17.64	1.02
Mean last-sighting date	2013±11	2010±12	2009±13	2007±13	1996±16
Slope	2.15	1.37	0.88	0.58	0.02
Lower bound of slope (8.5%)	1.17	0.89	0.57	0.42	0.00
Upper bound of slope (91.5%)	3.13	1.85	1.18	0.74	0.039

Table 2. Final multivariate generalized linear models (GLMs) investigating respondent sightings of four marine megafaunal taxa around 10 city groupings in the northern South China Sea. Fuzhou represents the randomly selected reference city.

Predictor	Estimate	SE	z-value	P-value
1. <i>Sousa chinensis</i>				
Intercept	0.416	0.062	6.730	<0.001
Boat length	0.003	0.001	2.252	0.025
Fishing year	0.003	0.001	2.637	0.008
Xiamen	0.431	0.069	6.257	<0.001
Shantou	0.280	0.068	4.132	<0.001
Zhuhai	0.439	0.067	6.593	<0.001
Yangjiang	0.195	0.077	2.522	0.012
Zhanjiang	0.260	0.067	3.867	<0.001
Qinzhou	0.295	0.061	4.830	<0.001
Northern Hainan	-0.063	0.065	-0.979	0.328
Southwest Hainan	0.122	0.064	1.893	0.059
Eastern Hainan	-0.240	0.061	-3.946	<0.001
2. <i>Neophocaena phocaenoides</i>				
Intercept	0.397	0.071	5.615	<0.001
Boat length	0.003	0.001	1.898	0.058
Fishing year	0.005	0.001	4.018	<0.001
Xiamen	-0.255	0.079	-3.233	0.001
Shantou	-0.178	0.078	-2.293	0.022
Zhuhai	-0.359	0.076	-4.707	<0.001
Yangjiang	-0.157	0.088	-1.776	0.076
Zhanjiang	0.002	0.077	0.026	0.979
Qinzhou	-0.245	0.070	-3.495	<0.001
Northern Hainan	-0.013	0.074	-0.172	0.864
Southwest Hainan	-0.261	0.074	-3.542	<0.001
Eastern Hainan	-0.270	0.070	-3.883	<0.001
Eastern Hainan	0.011	0.031	0.342	0.732
3. <i>Rhincodon typus</i>				
Intercept	0.132	0.069	1.908	0.057
Boat length	0.008	0.001	5.759	<0.001
Fishing year	0.003	0.001	2.555	0.011
Xiamen	-0.067	0.077	-0.865	0.388
Shantou	-0.099	0.076	-1.299	0.194
Zhuhai	-0.082	0.075	-1.092	0.275
Yangjiang	0.264	0.087	3.046	0.002
Zhanjiang	-0.049	0.076	-0.644	0.519
Qinzhou	-0.032	0.069	-0.469	0.640
Northern Hainan	0.063	0.073	0.864	0.388
Southwest Hainan	0.196	0.072	2.716	0.007
Eastern Hainan	0.345	0.068	5.051	<0.001

4. Sea turtles				
Intercept	0.506	0.066	7.647	<0.001
Boat length	0.003	0.001	2.673	0.008
Fishing year	0.004	0.001	3.851	<0.001
Xiamen	-0.159	0.074	-2.155	0.032
Shantou	0.029	0.073	0.402	0.688
Zhuhai	-0.200	0.071	-2.797	0.005
Yangjiang	0.116	0.083	1.405	0.160
Zhanjiang	-0.107	0.072	-1.479	0.140
Qinzhou	-0.046	0.065	-0.700	0.484
Northern Hainan	0.128	0.069	1.846	0.065
Southwest Hainan	0.195	0.069	2.833	0.005
Eastern Hainan	0.108	0.065	1.660	0.097

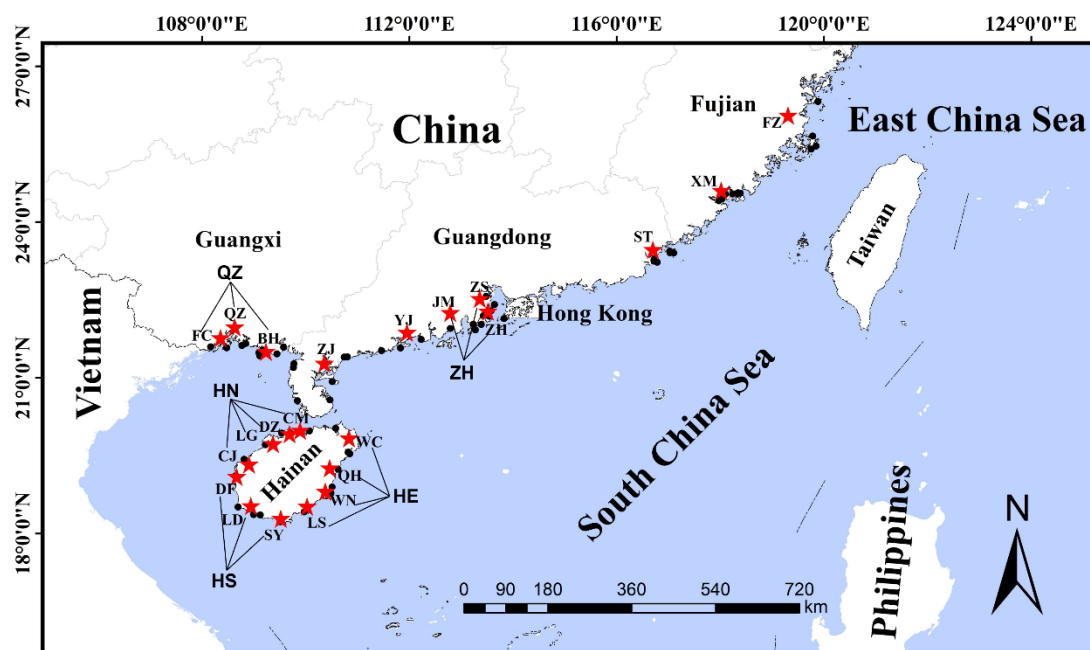


Figure 1. Locations of 66 fishery towns (black circles) in 22 cities (red stars) surveyed across four Chinese provinces along the northern South China Sea. In order to better present the results, some neighbouring cities are combined as single points. Abbreviations: FZ: Fuzhou, XM: Xiamen, ST: Shantou, ZH: Zhuhai (also including ZS: Zhongshan, JM: Jiangmen), YJ: Yangjiang, ZJ: Zhanjiang, QZ: Qinzhou (also including BH: Beihai, FC: Fangchenggang), HE: eastern Hainan (including WC: Wenchang, QH: Qionghai, LS: Lingshui, WN: Wanning), HN: northern Hainan (including CM: Chengmai, LG: Lingao, DZ: Danzhou, CJ: Changjiang), HS: southwest Hainan (including SY: Sanya, DF: Dongfang, LD: Ledong).

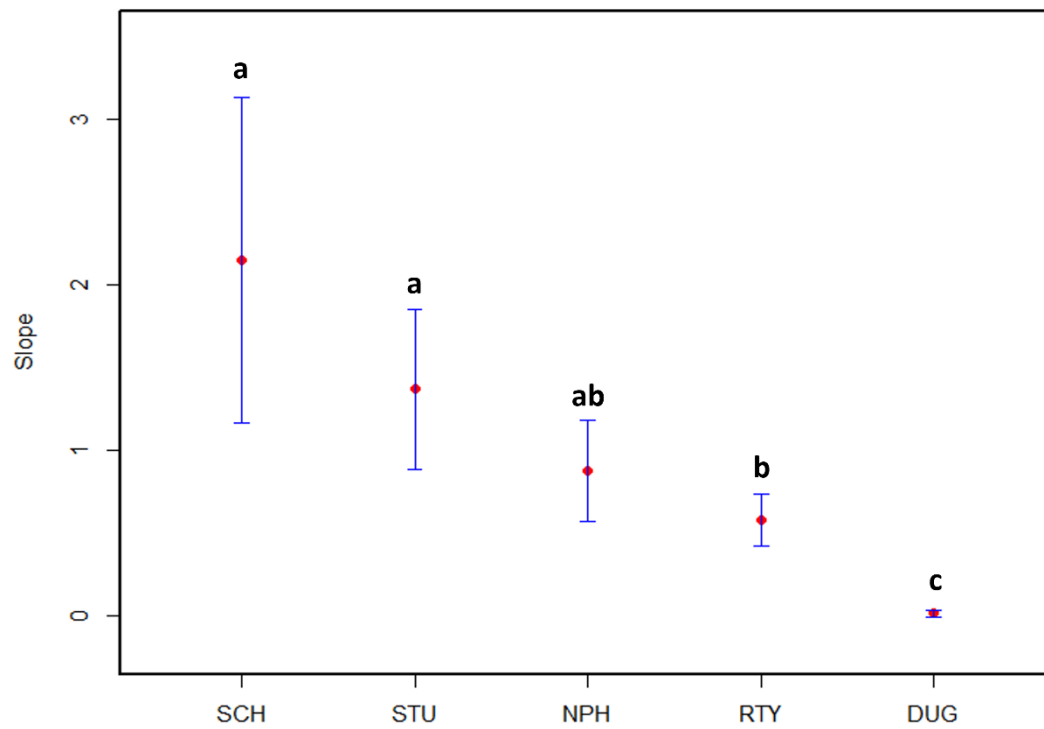


Figure 2. Slopes and 83% confidence intervals of last-sighting history regressions for five marine megafaunal taxa. Abbreviations: SCH: *Sousa chinensis*, NPH: *Neophocaena phocaenoides*, DUG: *Dugong dugon*, RTY: *Rhincodon typus*, STU: sea turtles. Different letters indicate significant differences.

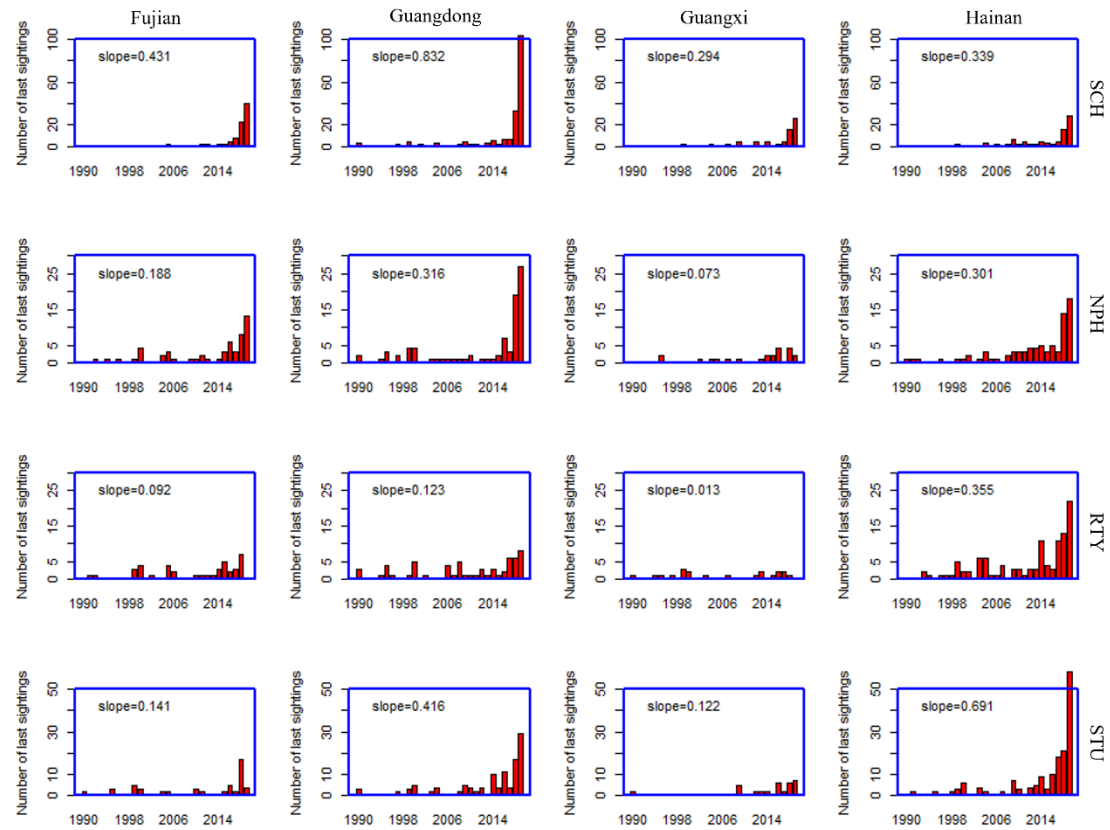


Figure 3. Frequency distributions of last-sighting year data across four provinces for four marine megafaunal taxa during the period 1990–2019. Abbreviations: SCH: *Sousa chinensis*, NPH: *Neophocaena phocaenoides*, RTY: *Rhincodon typus*, STU: sea turtles. Dugong was excluded due to limited encounter data.

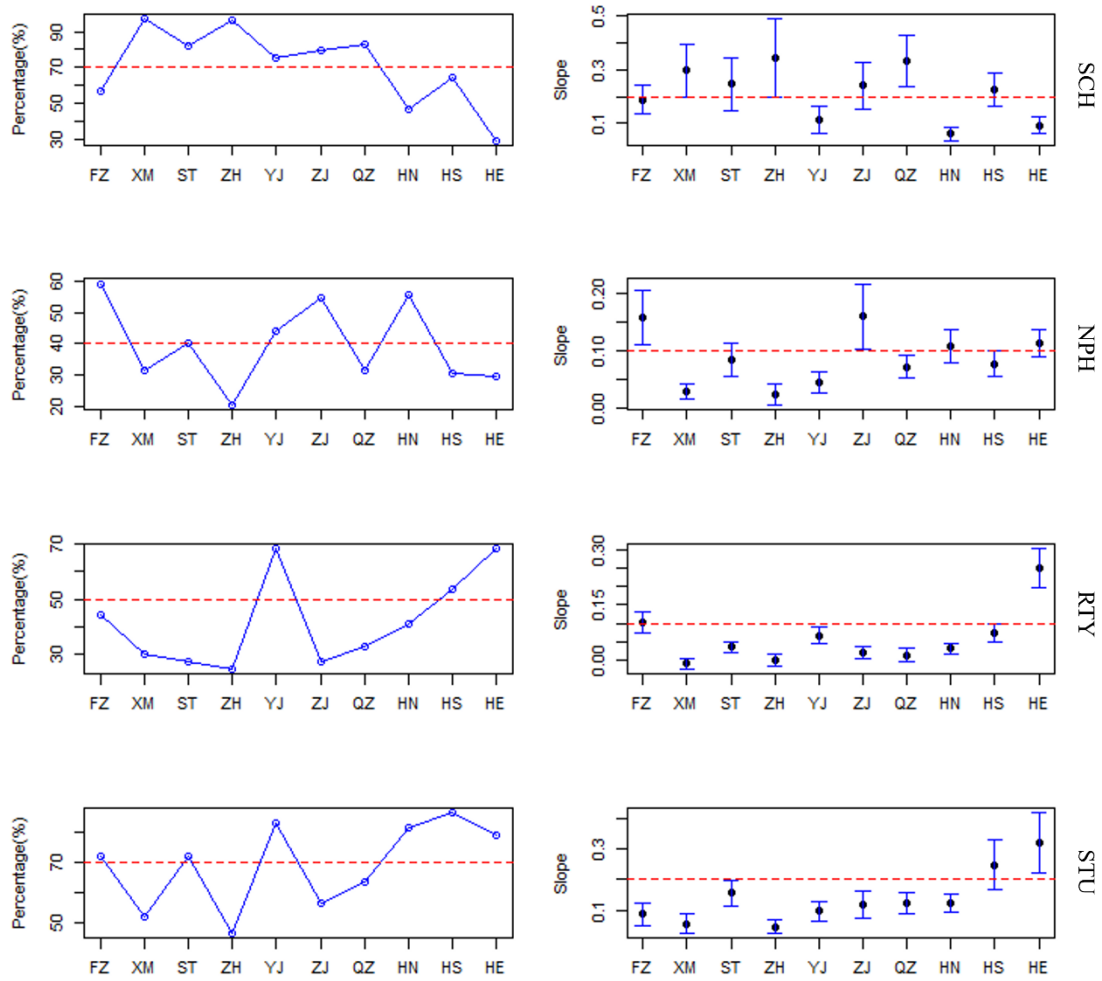


Figure 4. Sighting percentages and regression slopes with 83% confidence intervals of combined last-sighting history data for four marine megafaunal taxa in 10 surveyed city groupings. See Figure 1 for city grouping abbreviations. Abbreviations: SCH: *Sousa chinensis*, NPH: *Neophocaena phocaenoides*, RTY: *Rhincodon typus*, STU: sea turtles. Dugong was excluded due to limited encounter data.