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Utilizing interview-based data to measure interactions of artisanal fishing communities and cetacean populations in Kuching Bay, Sarawak, East Malaysia

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ABSTRACT

Kuching Bay is a significant area for artisanal fishing activities as well as an Important Marine Mammal Area (IMMA) for coastal cetaceans. A total of 286 fishers from eight fishing communities were interviewed between 2011 and 2019 to determine the nature and extent of cetacean-fishery interactions in the area. The main types of fishing gears recorded were gillnets, trammel nets, trawl nets, longlines, handlines and crab traps, with the use of gears varying by season and target species. Depredation, net damage, and entanglements in fishing gear were the most frequently reported negative interactions with cetaceans. Thirty-six percent of fishers reported having experienced a cetacean entanglement in their fishing gear at least once. More than half (58.1%) of the respondents who experienced bycatch were able to disentangle and release the animals alive. The more conservative calculated bycatch rate of 0.36 cetaceans per fisher over a fishing career indicates that a minimum estimated average of 19 cetaceans are involved in bycatch annually in Kuching Bay, with as many as nine of these incidents likely resulting in mortality. However, a less conservative method yields a bycatch rate of 0.57 per fisher, and estimated an average of 30 bycaught cetaceans per year. Irrawaddy dolphins (*Orcaella brevirostris*) were reported to be at the highest risk (72.9% of reported incidents), with an estimated minimum of seven individuals caught and killed per year. Despite the negative interactions, 77.2% of respondents reported a generally positive attitude toward cetaceans based on their value for tourism and as indicators of fish presence and a healthy ecosystem. Mutualistic relationships between fishers and cetaceans were documented, with 53% of respondents reporting that they feed discarded fish to cetaceans. The results of this study can be used to guide effective mitigation measures, which should focus on training fishers in safe handling and release of entangled cetaceans, and, more importantly, methods to prevent interactions with gillnets.

1. Introduction

In areas where fisheries activities overlap with cetacean distribution, interactions can typically occur in many forms. Positive interactions include cooperative fishing between cetaceans and fishers (e.g. Smith et al., 2009), while negative interactions range from depredation (catch or bait consumption from the fishing gear) (Bearzi et al., 2011; Santana-Garcon et al., 2018; Pardalou and Tsikliras, 2020), to damage to fishing gear (Pardalou et al., 2022), depletion of cetaceans' prey (Bearzi et al., 2006), perceived reduction in quality of fishers' target catch (Bearzi, 2002), or entanglement in gear (bycatch) (Smith and Jefferson, 2002; Reeves et al., 2008, 2013; Jaaman et al., 2009; Gray and Kennelly, 2018). Bycatch in fisheries is known to be the leading cause of human-induced mortality to cetaceans worldwide (Read, 2008) and is one of the most significant challenges for cetacean conservation (Northridge et al., 2017). Small coastal cetaceans such as Irrawaddy dolphins (*Orcaella brevirostris*), Indo-Pacific finless porpoises (*Neophocaena phocaenoides*), Indo-Pacific humpback dolphins (*Sousa chinensis*) and Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) are particularly vulnerable to bycatch in artisanal fishing gears especially

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gillnets (e.g., Brownell et al., 2019).

Cetacean bycatch is also a concern in Malaysia, where the fisheries sector makes an important contribution to the economy by providing employment, food security and exports (Teh et al., 2015; Peter et al., 2016a; FAO, 2023). Boat-based surveys conducted in Sarawak's Kuching Bay (Fig. 1) documented the distribution, abundance, and habitat preferences of finless porpoises, as well as Irrawaddy, Indo-Pacific humpback, and Indo-Pacific bottlenose dolphins (Minton et al., 2011, 2013; Zulkifli Poh, 2013; Peter et al., 2016b). These studies led to the designation of the Kuching Bay as an Important Marine Mammal Area (IMMA) (IUCN-MMPATF, 2020).

The IUCN Red List of Threatened Species has assessed Irrawaddy dolphins as Endangered (Minton et al., 2017), while Indo-Pacific humpback dolphins and finless porpoises are Vulnerable (Jefferson et al., 2017; Wang and Reeves, 2017), and Indo-Pacific bottlenose dolphins are considered Near-Threatened (Braulik et al., 2019). Estimates of the abundance of Irrawaddy dolphins in the Kuching Bay were 233 individuals (mark-recapture CV = 22.5%, 95% confidence interval 151–360); finless porpoises, 135 individuals (line transect CV = 31%, 95% confidence interval 74–246); and humpback dolphins, 84 individuals (mark-recapture CV = 16.4%, 95% confidence interval 61–116) (Minton et al., 2013; Zulkifli Poh et al., 2016). The confidence intervals of the abundance estimates for Irrawaddy dolphins that were generated through line-transect methods (149 individuals, CV = 28%, 95% confidence interval 87–255) overlapped with those generated from mark-recapture models. Photo-identification studies revealed that Irrawaddy dolphins demonstrated a high rate of site fidelity within the study area, and are likely a resident population with limited immigration or emigration (Minton et al., 2013).

By documenting active fishing effort encountered during line transect surveys between 2011 and 2013, Peter et al. (2016a) reported a high degree of overlap between fisheries effort and cetacean distribution in the Kuching Bay. Observed fishing effort was predominated by open-decked wooden or fiberglass fishing boats under 10 m in length deploying gillnets. About 70% of the active gillnets observed were attended, with fishers waiting in their boats at a distance within 100 m and with a clear visual line to the net (Peter et al., 2016a) (Fig. 2).

A subsequent analysis of Irrawaddy dolphin distribution and fishing effort using the Bycatch Risk Assessment (ByRA) toolkit (Verutes et al., 2020) revealed that the most suitable Irrawaddy dolphin habitat overlapped significantly with fishing effort using gillnets, thus creating a high bycatch risk year-round, particularly in river mouths during the pre-monsoon and monsoon seasons, and slightly further offshore in the post-monsoon season (Hines et al., 2020). Effective mitigation of this bycatch risk requires a better understanding of the precise nature and scale of interactions between fisheries activities and cetaceans.

Estimating mortality from bycatch is an essential component of understanding a cetacean population's conservation status, and determining how urgent and far-reaching mitigation measures need to be in order to prevent irreversible population decline (e.g., Moore et al., 2021; Wade et al., 2021). Bycatch monitoring on large commercial fleets is traditionally conducted by on-board observers, employed by government or fisheries management bodies, and placed on a representative proportion of the fishing fleet, to monitor bycatch and other aspects of the fishery. These observers can collect detailed information on fishing effort (e.g., number of sets or hauls of nets, or trawling hours for trawls), which, in combination with observed bycatch, can be used to calculate "bycatch per unit of effort" (BPU) statistics that can be extrapolated to the wider fishery to calculate overall annual mortality (e.g., Moore et al., 2021). However, in small scale fisheries, like those occurring in the Kuching Bay, it is impossible to place on-board observers on vessels that only accommodate a maximum of two to four crew members. Furthermore, in Sarawak there are no formal systems in place to monitor cetacean interactions or bycatch through logbooks or any other form of self-reporting or inspection (Jaaman et al., 2009).

In such difficult-to-monitor fisheries, interview surveys have commonly been employed as a means to describe and assess fishing effort and bycatch risk (e.g., Moore et al., 2010; Moore et al., 2021).

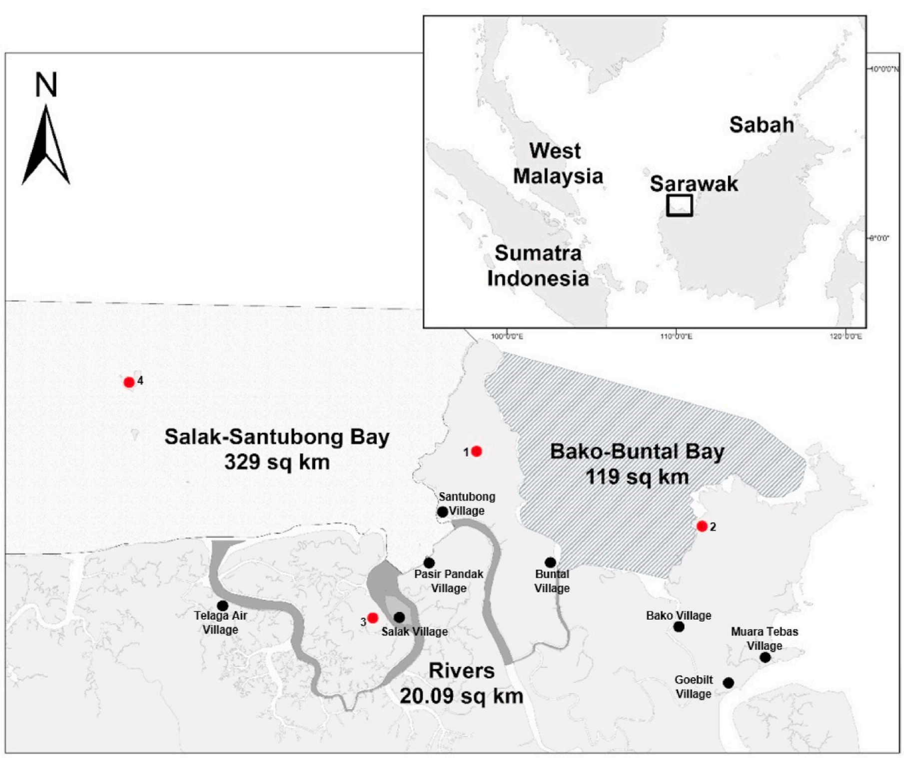

Fig. 1. The Kuching Bay study area (defined by the box in the inset) showing the location of the eight coastal villages targeted for interviews in this study (black circles); and the four main protected areas in the study area (red circles): 1. Mount Santubong National Park; 2. Bako National Park; 3. Kuching Wetlands National Park; 4. Satang Besar Island (Source: Minton et al., 2013).

Fig. 2. Typical artisanal fishing operation in Kuching Bay: gillnets which are set for a few hours at a time while fishers wait nearby. Irrawaddy dolphins often surface near fishing boats as fishers haul their catch and some fishers discard low value "trash" fish and feed them to the dolphins.

Interview surveys also offer wealth of insights especially of fishers' knowledge and perceptions, in addition to physiology of aquatic animals and the environment's ecosystem values (Nunes et al., 2021; Seary et al., 2021; Debrot et al., 2022). This study utilized interview-based data to determine the nature and extent of interactions between fishing communities and the cetacean populations in Kuching Bay. The interviews provide insight into the exact nature of fishing practices, and highlight some of the difficulties with quantifying fishing effort in small scale artisanal fisheries. The interview results are also used to calculate a crude annual bycatch mortality rate, and to identify the areas and gears associated with mortality. The resulting insight into the scope, and scale of bycatch and the gears and practices involved, coupled with existing information on geographical and temporal mapping of bycatch risk (Hines et al., 2020) are used to recommend future studies and effective conservation strategies that can reduce the potential negative impacts of these interactions on both fishers and cetaceans.

2. Materials and methods

2.1. Survey area

The study was conducted in the coastal area defined as "Kuching Bay" (Minton et al., 2013), situated approximately 37 km north of Kuching City, the capital city of Sarawak, Malaysia. The study area comprises a total of roughly 470 km^2, divided between three components, including the Salak-Santubong Bay (329 km^2), the Bako-Buntal Bay (119 km^2), and interconnecting portions of the Telaga Air and Salak River, as well as the Santubong and Buntal Rivers (with a combined area of 20.09 km^2) (see Fig. 1). The area also includes the protected areas of the Kuching Wetlands National Park (a RAMSAR site), and the Talang-Satang National Park, Sarawak's first marine national park. The bay is also bordered by two terrestrial parks, the Santubong National Park and Bako National Park. These national parks attract both local and international tourists for land- and water-based tourism activities. Fishers based in villages along the coast conduct regular and widespread artisanal fisheries activities throughout Kuching Bay's rivers and coastal areas (Department of Fisheries Malaysia, 2014). Fishers from eight selected villages along the coast (Fig. 1) were chosen as the targets for the fisheries interviews conducted in this study. These villages were chosen because they host the majority of fishing effort in the region and have the most active artisanal fishing communities in Kuching Bay. Six other villages bordering the study area were excluded from the study as they do not use the study site as primary fishing grounds and were unlikely to contribute fishing effort to the areas used by the cetaceans in this study.

2.2. Data collection

Semi-structured interviews were carried out between June 2011 and October 2019 in eight coastal villages. Interviewers based themselves in central meeting places for fishers, such as jetties, boathouses, coffee shops and fish markets, and selected participants based on their availability and willingness to participate in a 15–20-min-long questionnaire. A snowball sampling technique was used, with each respondent suggesting other potential participants in their village. Although sampling bias may occur for this technique, other studies have considered that this method yields a sample that is broadly representative, in terms of fisher's knowledge and experience (e.g., Ayala et al., 2019; Dewhurst-Richman et al., 2020; Nunes et al., 2021). The research team conducted interview sessions informally on a one-to-one basis using local languages. Informed consent for participation in this study was obtained from all respondents. Although the University where the researchers were based at did not require ethics approval for interview surveys at the time when the interviews took place, all interviewees were informed about the purpose of the study, and assured that the data collected were confidential, and their anonymity would be protected.

The questionnaire, adapted from the CMS-UNEP Dugong Questionnaire Survey (Pilcher and Kwan, 2012) (see Supplementary Material) included a total of 61 questions (17 open-ended and 44 closed). These assessed fishermen's level of experience, types of fishing gears used, frequency, locations and timing of fishing effort and practices, target species, cetacean sightings, cetacean-fishery interactions, and fishers' perceptions of cetaceans and legal protections. Interviewers were instructed in interview techniques and the importance of asking questions in an open-ended manner that would not "lead" respondents to believe that a certain answer was expected. This was particularly important for the questions related to fishers' perceptions and interactions with cetaceans, which were all open-ended and were

Table 1
List of variables used for analysis with their description and categories.

	Variables	Description and categories
Demographic data	Village	Name of village of where interviews were conducted (coded 1–8 for each different village)
	Age	Respondents' age in years
Cetacean-fishery interaction	Positive interaction	Feeding of discards to cetaceans; use of cetaceans to locate fishing grounds; perception of cetaceans as 'entertainment' at sea
	Negative interaction	Depredation; net damage due to cetaceans; boat/propeller strike; and fishing operation disrupted due to the presence of cetaceans
Bycatch	Cetacean bycatch	Fisherman reported finding a cetacean in fishing net at some point in his career
Local perceptions	Cetacean population	Perceived trend in cetacean population over the years (increase; decrease; no change)
	Bycatch utilisation (live caught)	Release; sell or eat
	Bycatch utilisation (dead caught)	Discard or bury; sell or eat; report to authorities

categorised post-hoc after the interviews were conducted, rather than having categories presented as options for responses. A labelled laminated map of Kuching Bay and cetacean illustrations were used to help respondents provide more accurate data on fishing areas, cetacean sightings, and the cetacean species involved.

Interviews were carried out in two study periods, with the first set of interviews conducted between 2011 and 2014 and the second set of interviews from 2016 to 2019. During the first study period (2011–2014) fishers were asked whether they had accidently caught dolphins, but they were not asked whether entangled animals were found dead or alive. This question was refined in the 2016 to 2019 period to allow an accurate assessment of entanglement outcomes.

An effort was made to interview at least 10% of fishers from each village, in order to achieve a representative sample. Determining what number comprised 10% required a detailed breakdown of the number of registered fishers in villages situated near the Santubong River. Statistics reported and published for the wider Santubong region from year 2014 were used, supplemented by a more detailed village-by-village breakdown (Department of Fisheries Malaysia, 2014).

2.3. Data processing and analysis

All responses were recorded on paper forms during interviews and later encoded, compiled and anonymised in a single standardized Excel spreadsheet. Because some respondents did not answer every question, the total number of responses varied per question, and calculated results were based on the actual number of responses rather than the full 286 interviews conducted. Descriptive statistics were calculated in Microsoft Excel, and data involving coordinates and approximation of sighting locations were plotted in Google Earth Pro to obtain coordinates to allow mapping of reported cetacean sighting locations in ESRI® ArcMap™ 10.2.

Generalized Linear Models (GLM) were used to determine whether there were any significant correlations between fishers' age, or location and the categories of cetacean interactions. Binary responses (yes/no) were analysed using binomial logistic regression with the logit link function. Response variables with more than two categories (difference in cetacean population, positive and negative interactions and dead bycatch utilisation) were analysed using ordinal logistic regression. Where responses included more than two categories, dummy variables were created for covariates to investigate which covariates were significantly different from each other. GLMs were run with all relevant covariates, using a backward selection procedure. At each step, non-significant variables were dropped (F-test), and the model was re-run until all remaining covariates were significant. All variables included in the analysis are listed in Table 1. The final model of remaining covariates was reported in Table 2. Statistical analysis was performed using IBM SPSS Statistics 20.

2.4. Bycatch estimates

In order to obtain a representative sample of fishers, a minimum of 10% of the registered fishers in every village were interviewed. (e.g., Pilcher and Kwan, 2012; Pilcher et al., 2017). Following Moore et al. (2010) we used the results of interview surveys to estimate bycatch rates. However, rather than calculating the bycatch rate as the number of (cetacean) individuals caught per boat per year, we calculated an estimate for the number of cetaceans caught per fisher, and used this to extrapolate annual bycatch rates. Although the questionnaire was originally designed to assess a fisher's experience of bycatch in the past year, interviewers noted that fishers had difficulty putting time frames on their responses and invariably provided information on their bycatch experiences over their entire careers. The minimum annual bycatch rate per village was calculated by assuming that each fisher who reported experiencing bycatch at some point in his career had entangled a minimum of one cetacean. An average individual fisher's bycatch rate (BR) was estimated for each village by dividing the number of respondents reporting a catch (DC) by the total number of interviewees in that village (FI). In short:

Table 2
Generalized Linear Model results used to determine the effect of age and village location on the response variables. Results are displayed as follows: nominal explanatory variables included in final model, the significance based on chi-square tests (x^2), with p-value (the significant categories of each explanatory variable are explained in the results of cetacean-fishery interaction, cetacean bycatch, and local perceptions) and degrees of freedom (d.f). Significant values are highlighted in bold ($p < 0.05$).

Response variables	Explanatory variables	x^2	p-value	d.f
Cetacean bycatch	Age	4.927	0.177	3
	Village	15.794	**0.027**	7
Perceived changes in cetacean population	Age	3.652	0.302	3
	Village	11.063	0.136	7
Catch utilisation (live caught)	Age	6.441	0.092	3
	Village	22.276	**0.002**	7
Catch utilisation (dead caught)	Age	3.917	0.271	3
	Village	13.852	0.054	7
Law awareness	Age	5.066	0.167	3
	Village	18.556	**0.010**	7
Negative interactions:				
Net damage	Age	2.010	0.570	3
	Village	19.268	**0.007**	7
Depredation	Age	0.362	0.948	3
	Village	38.172	**<0.0001**	7
Boat/propeller strike	Age	2.191	0.534	3
	Village	14.111	**0.049**	7
Disrupt fishing operation	Age	1.292	0.731	3
	Village	5.785	0.565	7
Positive interactions:				
Feeding cetaceans	Age	5.575	0.134	3
	Village	36.501	**<0.0001**	7
Indicate fish availability	Age	6.654	0.084	3
	Village	27.790	**0.0002**	7
Entertainment at sea	Age	2.269	0.519	3
	Village	12.754	0.078	7

$BR = DC/FI$

A second, less conservative bycatch rate per fisher was estimated by assigning each respondent a value of one, three or five entangled cetaceans based on the number of reported incidents over his career. The individual fisher bycatch rate was then calculated by totalling the number of cetaceans reported to be caught in each village over the respondents' careers, and dividing this number by the number of interviewees in the village. For both the conservative, and less conservative approaches, each village bycatch rate was multiplied by the total number of fishers registered in the village (F) (Department of Fisheries Malaysia, 2014) to estimate the total reported cetacean bycatch:

Total reported cetacean bycatch $= BR*F$

Published statistics from Department of Fisheries Malaysia (2014) were compared with yearly statistics from 2014–2021 provided by the Sarawak Department of Fisheries to the authors, to determine whether the number of registered fishers had changed significantly over the years of the study. While some variations occurred, the numbers from Department of Fisheries Malaysia (2014) were considered most representative of the study period.

Annual bycatch rates were estimated by dividing the total extrapolated cetacean bycatch by the mean number of career years of the fishers who reported bycatch in their fishing gear. Crude mortality estimates of the bycaught animals were calculated by multiplying the total extrapolated bycatch by the proportion of entangled animals reported to be found dead. In summary, the minimum estimated total cetacean bycatch over the span of interviewees' careers was calculated for each village (Table 4) as follows:

Total cetacean bycatch $= (DC/FI)*F$

Where DC = the number of fishers reporting at least one incident of cetacean bycatch.

FI = the number of fishers interviewed, and.

F = the total number of licensed fishers in the village.

The maximum Potential Biological Removal (PBR) through human caused mortality was calculated for Irrawaddy dolphins using previously published abundance estimates (Minton et al., 2013), estimated life history parameters for Irrawaddy dolphins (Moore, 2015), and the formula developed by Wade (1998):

$$PBR = N_{min} \tfrac{1}{2} R_{max} F_R$$

Where N_{min} = the minimum population estimate of the stock,

½ R_{max} = one-half the maximum theoretical or estimated net productivity rate of the stock at a small population size, and.

F_R = a recovery factor between 0.1 and 1.

3. Results

A total of 297 interviews with 286 individual fishers from eight villages were conducted throughout the study period. One hundred and thirty-eight (138) interviews were conducted in 2011–2014, and an additional 159 interviews were conducted in 2016–2019. Eleven individuals were interviewed twice, with intervals between interviews ranging from one month to eight years. Responses from both sets of interviews were examined for consistency. While there were some slight variations in responses that may have been linked to changes in personal circumstances, or newly acquired experiences, for the most part answers were consistent with respect to fishers' level of experience, gears used, and experience of entanglements and bycatch. For this reason, we used only the more recent interview for each of these respondents, as it included information on the outcome of reported entanglements, as well as a more recent perspective on their interactions with cetaceans.

The majority (75.9%, n = 217) of the 286 individual respondents reportedly rely on fishing as their primary source of income. Collectively respondents represent at least 10% of the total number of fishers registered with the Department of Fisheries Malaysia in the region. Registration with the Department indicates that the individual has valid fishing license issued by Department of Fisheries that enables him or her to fish along the coast, receive government subsidies and sell his or her catch (Department of Fisheries Malaysia, 2014; Mohamed Omar, 2017).

Interviewees were almost all male (96.9%, n = 277), aged between 25 and 88 years, with a mean age of 50.27 (±11.7) years. The majority of the 286 respondents (82.9%, n = 237) had more than 15 years of experience, while 8.4% had 5–15 years of experience, and only 7.3% had less than five years of experience. Four respondents declined to reveal their age.

3.1. Fishing gears and target species

Respondents reported using the following types of fishing gear (in order of frequency): gillnets (including set nets and drift nets), trammel nets, longlines, trawl nets, handlines, crab traps, stake nets and cast nets. These gears are used seasonally to target different species, as indicated in Table 3. Gillnets and trammel nets were by far the most frequently used gears, accounting for over 75% of the responses, and both used during the peak fishing season between March/April and September/October.

3.2. Fishing effort

Respondents' reported frequency of fishing effort was analysed separately for high season and low season. The high season was defined as the period during the Southwest monsoon (April to September) characterised by low precipitation; and low season as the Northeast monsoon (October to March), a period characterised by increased rainfall and rough seas in all but the most sheltered waterways. Of the 277 respondents reporting on seasonality of their fishing effort, 62.1% of the fishers (n = 172) stated that they went out to fish daily during high season, while 4.7% (n = 13) alternated between days, and seven respondents reported fishing only once or twice a week. Thirty per cent of

Table 3
Types of fishing gear, mesh size, time of use and target species of respective fishing gears obtained from interview surveys of eight villages in Kuching Bay.

Type of gear	Percentage of respondents using this gear (n = 286)	Mesh size range (inches)	Time of use (season, tidal state)	Target species
Gillnet	49.1%	1–7	April to September (75.2% of respondents) Tidal (24.8% of respondents)	Spanish mackerel, threadfin, pomfret, Indian mackerel, croakers, pipefish, hair-fin anchovy, lizardfish, shark, longfin herrings, ray, prawns
Trammel net	27.9%	1.5–4	March to December	Mainly prawns but can also target all types of fish
Trawl net	3.3%	0.5–1.5	March and April	Smaller prawns and anchovies
Longline	7.8%	n/a	No particular time	Ray, Atlantic tripletail, queenfish
Handline	5.1%	n/a	No particular time	Red snapper, Spanish mackerel, eel-catfish
Crab trap	3.3%	n/a	No particular time	Crab

respondents (n = 84) indicated that they did not have any fixed schedule for fishing, letting the weather dictate their schedule. When weather conditions were unfavourable, they preferred to fish in rivers.

By contrast, during the low season (also known as off-season or "*musim landas*" locally), 31.2% (n = 68) of fishers stated that they fished daily but only in protected waters of rivers and estuaries. A total of 14.7% (n = 32) only fished when weather conditions permitted, 30.7% (n = 67) only fished twice a week or less, while 23.4% (n = 51) did not go out to sea at all during this period.

A fishing trip was defined as 'a single excursion with a time frame starting from when the fishers leave the jetty to their return to the jetty'. Regardless of the season, 43.6% of respondents reported that their fishing trips typically lasted between 1 and 6 h (n = 125), while 38% reported that they lasted 7–11 h (n = 109) (Fig. 3).

3.3. Cetacean sightings

Almost all respondents (98.6%, n = 282) stated that they had observed cetaceans at some point during their fishing career. When asked about the frequency of cetacean sightings in the past year, 95.8% (n = 274) of respondents reported seeing cetaceans several times per week or per month. Most fishers encounter cetaceans during their fishing activities or while traveling to and from their fishing sites (Fig. 4).

Fig. 5 depicts the location of cetacean sightings as reported by the fishers in relation to their villages. Interviewees' responses to where they observed cetaceans demonstrated that cetaceans are seen throughout the study area with a concentration of reported sightings in river mouths. Fishers' reported cetacean sighting locations also provide insight into their presumed fishing effort. While fishers from most villages stay within fairly well-defined areas directly offshore from their base locations, the fishers from Muara Tebas seem to range further than those from other villages.

3.4. Cetacean-fishery interactions

Of the 286 respondents, 37% (n = 106) reported that they experienced interactions with cetaceans with adverse outcomes, while 63% (n = 180) respondents had never experienced negative interactions. Reported fisheries interactions with cetaceans included a range of behaviours and outcomes with a total of 134 specified responses, falling into the following categories (note that respondents were able to provide more than one answer):

Depredation: Cetacean consumption of bait or target catch was reported by 48.5% of respondents (n = 65). Two fishermen, each from Telaga Air village and Goebilt village, reported that marine mammals are a nuisance, and their presence might 'chase' or 'scare' fishes away from targeted fishing areas.

Net damage: Net damage caused by marine mammals was reported by 47% of fishers in all villages (n = 63). Irrawaddy dolphins were most frequently implicated by the fishers, followed by finless porpoises. Drift nets (both attended and unattended), trammel nets and trawl nets with mesh sizes between two and seven inches were the types of fishing gear most frequently reported to be damaged due to the interaction with cetaceans. Fishers believed that the cetaceans were feeding on the catch from the nets, resulting in visible tears when they hauled in their nets. Depredation and net damage showed a significant correlation in GLM analysis to village location (Table 2) with fishers from Bako and Santubong most frequently reporting this negative interaction.

Boat or propeller strike: 3% (n = 4) of fishers reported knowingly striking a cetacean with their boat or propeller. This interaction was only reported from Santubong and Salak villages.

Disrupted fishing operations: 1.5% (n = 2) of fishers reported having to stop or reduce their fishing effort due to the presence of cetaceans.

However, most fishers also reported what they perceived as positive interactions including the following:

Feeding on discarded catch: Of the 257 interviewees that responded, 53% (n = 136) reported feeding cetaceans with the discarded fish they threw into the water as they hauled in their nets. This practice was significantly correlated to village location (Table 2), and was most frequent in Bako, Pasir Pandak and Santubong. While fishers reported feeding all four cetacean species that occur in the area, Irrawaddy dolphins were the most frequently mentioned species. The fish species most often discarded and fed to cetaceans include all types of anchovies and small 'scrap' fishes such as pipefish, lizardfish, croakers, Spanish mackerels, squids, and shrimps.

Indicator of fish availability: Of the 275 fishers who responded to questions about their perception of the importance of cetaceans, 31.3% (n = 86) believed that the presence of cetaceans might indicate fish availability and help to guide the fishers to productive fishing areas. Most of the fishers from Bako and Santubong villages reported this perception.

Entertainment and tourism: 12.4% (n = 34) of respondents viewed cetaceans as entertainment during their fishing operations. In addition, 33.8% (n = 93) said that cetaceans are important for tourism, as dolphin watching operations mainly target Irrawaddy dolphins in the Salak-Santubong estuaries. The GLM analysis did not reveal any correlation between this perception and fishers' age or village (Table 2).

3.5. Cetacean bycatch

Fishers provided mixed responses to the questions relating to bycatch. Of the 263 respondents that answered this question, 60.9% (n

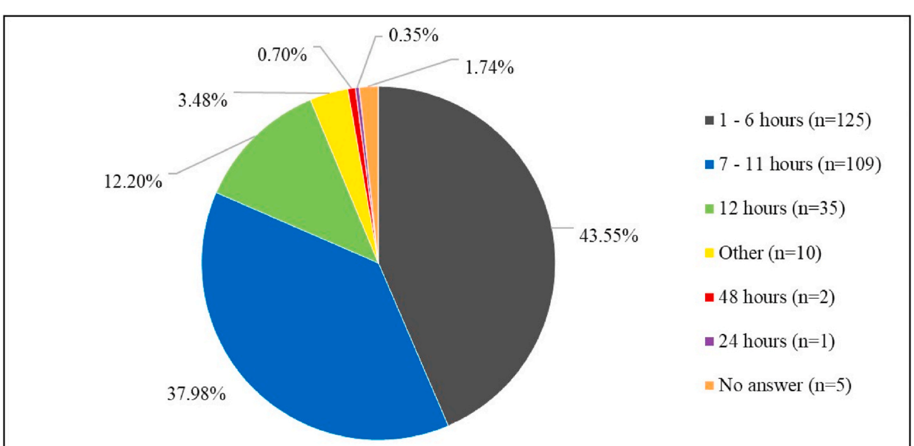

Fig. 3. Duration of a single fishing operation (hours spent fishing, number of respondents, percentage of respondents reported that length of fishing operation).

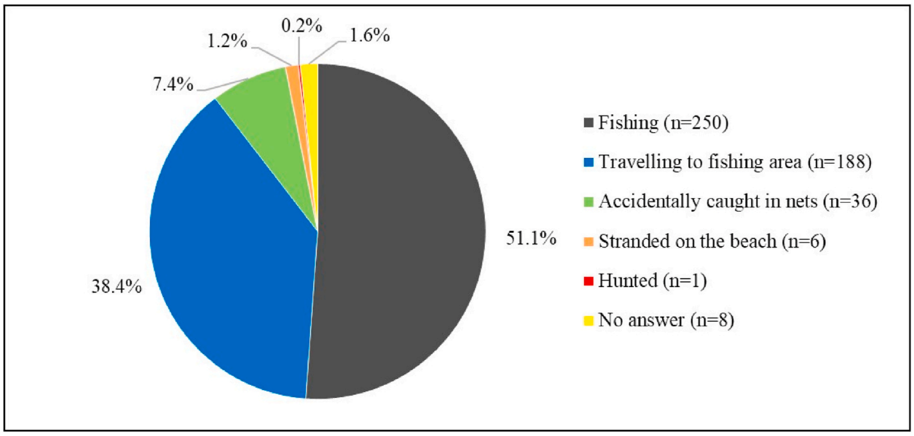

Fig. 4. Circumstances during which fishers report observations of cetaceans, including frequency of and percentage of reported observation circumstances.

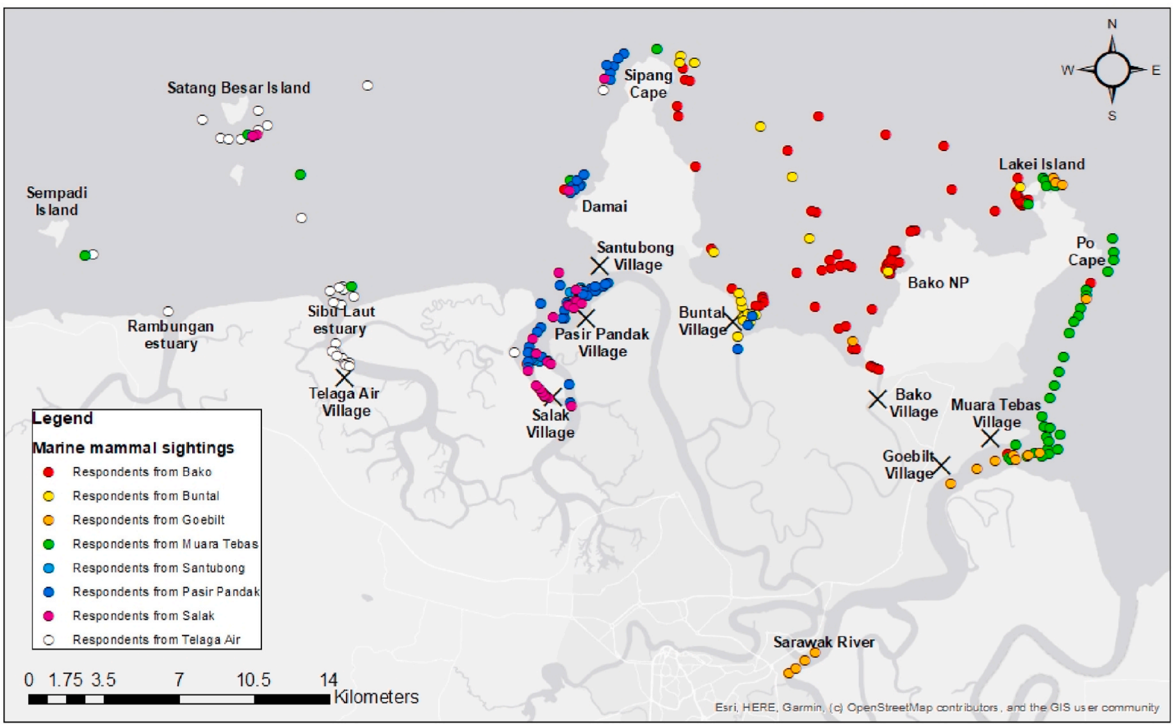

Fig. 5. Map depicting the locations where cetaceans were observed recorded through participatory mapping of fishers from eight coastal villages in Kuching Bay (e.g., Seary et al., 2021).

= 160) reported that they had never discovered a cetacean in their fishing gear. However, 30.4% (n = 80) reported they rarely (once or twice per lifetime) caught cetaceans, 7.9% (n = 21) occasionally (two to five times per lifetime) and only two respondents had frequently (more than five times per lifetime) caught cetaceans in their gear. In the GLM analysis, bycatch rates were significantly correlated to village (Table 2) with fishers from Bako, Muara Tebas and Pasir Pandak reporting the highest bycatch rates over their fishing careers (see Table 4). All reported cetacean bycatch incidents that could be assigned to a specific type of fishing gear were associated with gillnets with mesh sizes ranging from 1.5 to 7.75 inches.

Data on the outcome of reported entanglements were only available from interviews conducted from 2016 to 2019. Of those who reported having found a cetacean in their gear (n = 103), only 62 respondents reported on the animal's condition. Of these, 58.1% (n = 36) reported that the animal was still alive and was released, while 47% (n = 29) claimed that the animal was already dead upon discovery (three respondents reported entanglements resulting in both live releases and mortality).

Respondents who provided information on species (n = 166) indicated that all four cetacean species commonly found in Kuching Bay are involved in bycatch. Irrawaddy dolphins were the species most frequently reported (72.9%, n = 153) followed by finless porpoises (16.2%, n = 34), humpback dolphins (7.1%, n = 15), and bottlenose dolphins (2.4%, n = 5) (respondents were able to indicate more than one species).

3.6. Bycatch estimates

Of the 286 respondents, 103 (36%) reported that they experienced bycaught cetaceans at some point in their career. To calculate the more conservative annual bycatch rate, we assumed that each fisher's reported bycatch involved a minimum of one individual cetacean over his career, yielding an average individual bycatch rate of 0.36 dolphins per

Table 4
Total number of licensed fishers registered in the study area (Department of Fisheries Malaysia, 2014), numbers and percentages of fishers interviewed, number of fishers that reported bycatch of at least one dolphin at some point in their career, bycatch rate and extrapolated minimum cetacean bycatch from eight coastal villages of Kuching Bay, Sarawak obtained from interview data.

Village	Number of licensed fishers (F)	Number of fishers interviewed (FI)	Percentages of fishers interviewed	Number of fishers reporting at least one incident of cetacean bycatch (DC)	Bycatch rate per fisher (BR) = (DC/FI)	Estimated total of cetacean bycatch (BR*F)
Santubong	76	29	38.2%	6	0.21	16
Telaga Air	229	40	17.5%	12	0.30	69
Bako	272	57	20.9%	27	0.47	129
Buntal	192	33	17.2%	10	0.30	58
Muara Tebas	284	40	14.1%	20	0.50	142
Pasir Pandak	114	38	33.3%	16	0.42	48
Salak	200	29	14.5%	6	0.21	41
Goebilt	198	20	10.1%	6	0.30	59
TOTAL	**1565**	**286**	**18.3%**	**103**	**0.36**	**564**

fisher over his career. This rate was applied to the total population of all eight villages to generate a minimum estimate of 564 bycaught animals for the entire study area over the course of the careers of the fishers that were interviewed (see Table 4). To estimate the number of cetaceans bycaught each year, the total was divided by the mean number of career years of fishers who reported bycatch. The mean number of career years was calculated by assuming that fishers started their careers at approximately 20 years of age (e.g., Talib et al., 2007; Kadir and Sohor, 2009), and subtracting 20 from the mean age of fishers who reported having experienced bycatch. The total cetacean bycatch estimate was then divided by the resulting value of 29.53 years to generate a crude annual bycatch estimate of 19 individual cetaceans per year.

A second, less conservative individual bycatch estimate was generated by assigning a value of one, three or five cetacean catches to fishers depending on their reported bycatch incidents over time. This approach yielded an average individual bycatch rate of 0.57 dolphins per fisher. When this rate was applied to the total number of registered fishers in all eight villages (n = 1565) it yielded a minimum estimate of 892 bycaught animals for the entire study area over 29.53 years, and an annual bycatch rate of 30 cetaceans per year.

Applying the fishermen's reported mortality rate of 47%, to the most conservative annual rate of 19 bycaught cetaceans, it is likely that roughly nine individual cetaceans were killed through bycatch each year. Irrawaddy dolphins were predicted to have the highest potential mortality (72.9% of total bycatch) with a minimum estimate of seven mortalities per year, followed by finless porpoises with two individuals, humpback dolphins with 0.6 individuals and bottlenose dolphins with 0.2 individuals. In the less conservative approach, it is likely that 14 individual cetaceans were killed through bycatch each year: ten Irrawaddy dolphins, two finless porpoises, one humpback dolphin and 0.3 bottlenose dolphins.

The maximum PBR was calculated for the most frequently bycaught species, the Irrawaddy dolphin, which has also been demonstrated to be a resident population in the study area (Minton et al., 2013; Peter et al., 2023). Using the minimum abundance estimate of 151 individuals (the lower bound of the 95% confidence interval generated through mark-recapture models in Minton et al., 2013), and an Rmax of 0.038, determined by Moore (2015) to be the most appropriate value for *Orcaella brevirostris*, and a recovery factor (F_R) value of 0.1 (the value recommended by Taylor et al. (2003) for any population with an Nmin <1500), the PBR for the population of Irrawaddy dolphins in Kuching Bay is estimated to be only 0.29 dolphins per year. Assuming a less pessimistic recovery factor of 0.5 raises the PBR to 1.43 animals per year, and assuming that the population is already at its full capacity and should be maintained at its current level, yields a PBR estimate of 2.9 animals per year. In all cases, even the most conservative annual bycatch estimate of seven Irrawaddy dolphins per year exceeds this value.

3.7. *Response to bycatch*

When asked what they would do if they discovered a live cetacean in their gear, 94.7% (n = 214) of the 226 respondents stated that they would release it back to sea, while 4.9% (n = 11) said they would consume it, and 3% (n = 7) respondents would sell it (some respondents gave multiple answers). Age and village location were statistically significant to the responses of bycatch response (Table 2) in GLM analysis, as only fishers from Bako, Muara Tebas, Pasir Pandak, Salak and Goebilt reported selling or consuming live bycaught cetaceans.

By contrast, when asked how they would respond if they found a dead cetacean in their fishing gear, 57.1% (n = 116) of the 203 respondents reported that they would bring the animal back to sell or consume it, while 39.9% (n = 81) said that they would discard the carcass back to sea or bury it. Only 3% (n = 6) would report the incident to the authorities. There was no correlation of the responses to the respondent's age and village location in GLM analysis (Table 2).

3.8. *Local perceptions*

Of 278 respondents, 80.6% (n = 224) were aware that cetaceans are protected by law and that catching them is illegal with consequences of prison sentences and fines. The remaining 19% (n = 53) were not aware of the laws. Location proved to be a significant variable concerning the awareness of laws pertaining to cetaceans (Table 2), with respondents from Santubong, Bako and Salak villages more aware of the law than other villages.

Of the 266 fishers who reported their perception of trends in dolphin abundance, 53% (n = 141) felt that there are fewer cetaceans now than in the past, while 25.9% (n = 69) stated there is no change and 21.1% (n = 56) believed there are more cetaceans now. Fishers provided a variety of reasons for their points of view (see Fig. 6). Waste runoff from development, as well as aquaculture-based pollution was the most frequently reported reason for decline. Entanglement was the second most cited perceived cause of decline. The perceived changes in cetacean abundance were not correlated with age or village location in GLM analysis (Table 2).

Although most respondents stated that the cetacean populations are decreasing, 21.1% perceived an increase in the numbers of dolphins. Fishers with this perspective believed that the increase is due to legal protections that prevent disturbance and hunting, plentiful food resources, or observations of calves that indicate healthy reproduction.

4. Discussion and conclusions

Globally, gillnets are the gear most frequently implicated in the entanglement of cetaceans, particularly small coastal species whose habitat overlaps with artisanal gillnet fisheries (Lopez et al., 2003; Read

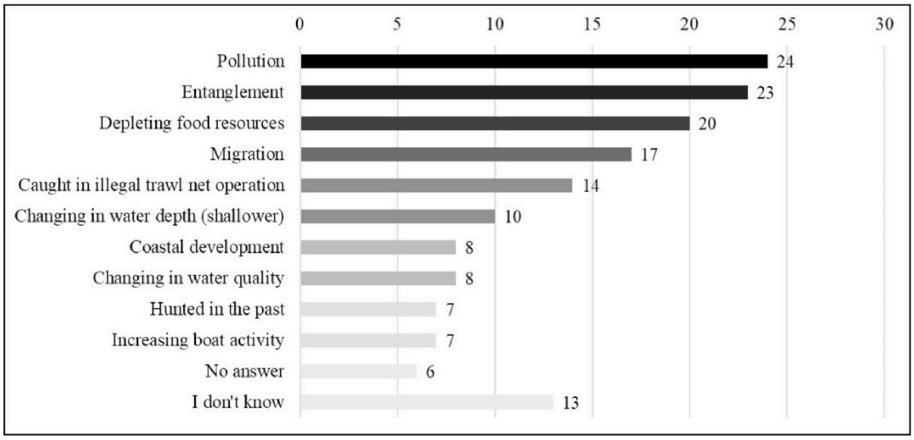

Fig. 6. Fishers' opinion on the activities or conditions that contributed to a perceived decline of cetacean abundance in Kuching Bay.

et al., 2006; Read, 2008; Reeves et al., 2013; Whitty, 2016; Brownell et al., 2019; Kuit et al., 2019). This study supports other studies showing that gillnets (including set nets and drift nets) are the most commonly used fishing gear in Kuching Bay (e.g., Peter et al., 2016a). While 70% of active gillnets observed during cetacean surveys conducted between 2011 and 2013 were attended by fishers who positioned their boats within 100 m of the nets, roughly 30% were unattended (Peter et al., 2016a). During interviews, fishers reported that unattended nets may be left for several hours or overnight (up to 12 h) on the outgoing tide to catch fish being swept out with the current. Whitty (2016) associated prolonged soak times of unattended fishing gears with high bycatch rates. Longer soak times increase the opportunity for interactions between nets and cetaceans, and, if left unattended, fishers have no opportunity to release an entangled cetacean before it dies.

The results reported here indicate that there is likely severe under-reporting of bycatch when it occurs. Between 2001 and 2020, a total of 65 stranding and entanglement cases throughout Sarawak were reported to Sarawak Dolphin Project or retrieved from online news and social media platforms (e.g., Facebook) (SDP unpublished data). Of these, 19 cases were from Kuching Bay. While the team makes every effort to monitor reports from government/non-governmental agencies, local news, and social media to obtain information about cetacean strandings and entanglements, questionnaire results indicate that only a fraction of at least 564 estimated bycatch events (dead or alive) were reported. Although it is common for bycatch to be under-reported for a number of reasons (e.g., Northridge et al., 2017), in Sarawak, there are no formal mechanisms for fishers to record bycatch or to monitor cetacean interactions through logbooks or any other form of self-reporting or inspection (Jaaman et al., 2009).

Nearly 60% of reported entanglement events involved live animals that fishers were reportedly able to disentangle and release. Although potentially encouraging, repeated exposure to fishing gear and sub-lethal entanglements are likely to cause injuries and severe stress (Dolman and Moore, 2017; Rolland et al., 2019). While disentanglement and release should not be seen as a solution to bycatch, training for fishers on safe and humane handling and release practices (e.g., Hamer and Minton, 2020) would likely enhance chances of post-release survival. Recent studies have shown that bottlenose dolphins (*Tursiops truncatus*) that are carefully handled and released can have good survival outcomes and continue to play an important role in their population units (McHugh et al., 2021).

4.1. Potential sources of bias in the data

Mortality estimates derived from the interview data in this study may be biased as these are based on the relatively small sample size of responses obtained during the second interview period (2016–2019). Memory decay and biased responses by interviewees may also cause substantial errors in interview survey data (Fowler, 2009; Moore et al., 2010). Furthermore, as most of the fishers (80.6%) are aware that cetaceans are totally protected under Sarawak's Wild Life Protection Ordinance (1998), fishers may fear negative consequences if they report bycatch, thus leading to likely under-reporting. Of the 11 respondents who were interviewed twice, although there were some slight variations in responses that may have been linked to changes in personal circumstances, or newly acquired experiences, for the most part answers were consistent with respect to fishers' level of experience, gears used, and experience of entanglements and bycatch. At the same time, using an individual fisher's reported bycatch rate as the value from which annual bycatch rates for the entire area are calculated carries a risk that two or more fishers that work on the same small boat have reported the same entanglement event, which could potentially lead to an over-estimation of total bycatch.

Bycatch estimates are also likely to be biased downward because they do not take into account the unquantified, but likely low levels of additional fishing pressure from the six additional villages near Kuching Bay where interviews were not conducted.

Finally, while our findings indicate that Irrawaddy dolphins are the most frequently caught species, fishers appear to have difficulty distinguishing between Irrawaddy dolphins and finless porpoises even with the aid of species identification guides. Both species are referred to as "*empesut*" in all villages of Kuching Bay, and this confusion is likely to affect the reliability of species designations, although not the overall bycatch estimates.

Future studies should try to incorporate a means of validation (Jones et al., 2008; Moore et al., 2010) and increase the sample sizes upon which mortality estimates can be based. Traditional onboard observer programmes are not a feasible option for ground-truthing of results in a fishery that is predominated by small open-decked fiberglass boats of 10 m or less in length and can only accommodate a maximum of two to four crew (see Fig. 2). Remote electronic monitoring (REM) with small cameras mounted on boats could be a useful means to ground truth the survey results and quantify incidental catches in artisanal fisheries (e.g., Bartholomew et al., 2018). Small portable and solar-powered systems are now available and could be appropriate for use in Sarawak. In addition, self-reported data or e-logbooks by fishers on fishing effort and bycatch when observers are not present is also another way to verify the interview-based estimates (e.g., Luck et al., 2020).

4.2. Local perceptions

Some fishers (n = 24) believed that the waste runoff from coastal development and aquaculture caused a cetacean population to decline over the past decade. There is some evidence to support this perception, as coastal construction and shrimp culture are degrading water quality in the area (Ling et al., 2010). According to Rosli et al. (2012), water quality in the tributaries along the Salak River is moderately or slightly polluted. High levels of Chemical Oxygen Demand (COD) and lead (Pb) were recorded, which may originate from untreated or partially treated sewage systems. Additionally, a 2014 study documented a high prevalence of skin disease in Irrawaddy dolphins in the Kuching Bay, possibly linked to environmental degradation that leaves dolphins vulnerable to bacteria and pathogens in sewage discharge, which enter through wounds and prey ingestion resulting in decreased fitness and death (Van Bressem et al., 2014).

Respondents reported that they most frequently observe cetaceans along the coast of Salak-Santubong Bay, throughout the Bako-Buntal Bay and along the coast of Muara Tebas village (Fig. 1). These sighting locations reported by the fishers mirror the distribution of cetaceans as reported by Minton et al. (2011), Minton et al. (2013), Peter et al. (2016b) and Zulkifli Poh et al. (2016), which demonstrated that Irrawaddy dolphins have a statistically significant affiliation with shallow estuarine habitats that are influenced by tidal shifts, while finless porpoises, humpback dolphins and bottlenose dolphins are found in more saline waters slightly further offshore. The areas indicated by the fishers also overlap with the areas identified as the areas of highest bycatch risk in a 2020 assessment using the Bycatch Risk Analysis GIS toolbox (Hines et al., 2020). These are the areas that should be prioritised for management measures.

Respondents perceived entanglement in fishing gear as the second most likely factor to contribute to cetacean mortality, although studies elsewhere indicate that it is likely to be the most significant cause. While a minority of fishers reported negative encounters or issues with cetaceans, a majority reported positive perceptions, often described a mutually beneficial relationship, where cetacean presence is perceived to indicate fish availability which then guides the fishers in changing fishing grounds. This supports findings of other studies on *Orcaella* sp. in India (D'Lima et al., 2014), as well as Laos and Myanmar (Stacey and Hvenegaard, 2002; Smith et al., 2009). Together with the species' perceived ability to generate tourism income for coastal communities, the 'entertainment' they provide for fishers at sea, and long-held cultural lore, these positive perceptions should help motivate fishers to participate in bycatch mitigation trials and other efforts to address bycatch.

4.3. Implications for conservation management

The results of this study should be used to design and implement mitigation measures to reduce bycatch to a level at or below the calculated sustainable limits for these populations. Given the high rates of live-release from fishing gear, an immediate priority should be the provision of training and resources that promote safe handling and release of live bycatch. The collaboration with fishers participating in interviews and live-release training could also be leveraged to begin robust trials of mitigation methods. Although reducing bycatch in artisanal gillnet fisheries is notoriously difficult (e.g., Northridge et al., 2017; FAO, 2021), a number of methods have been trialled with some success. Management options in the gillnet fisheries in Kuching Bay could include time-area closures (e.g., Beest et al., 2017; FAO, 2021), similar to what is planned for the management of tiger prawns in Kuala Baram, Sarawak (Abdullah et al., 2022), switching to longlines (Berninsone et al., 2020), and making nets more 'visible' to cetaceans with acoustic deterrent devices or 'pingers' (e.g., Dawson et al., 2013; Amano et al., 2017), lights (Bielli et al., 2020) or reflective beads (Kratzer et al., 2020). Discussions are underway with the International Whaling Commission's Bycatch Mitigation Initiative to seek support for trials that would evaluate the effectiveness of acoustic deterrents (pingers) in conjunction with the use of sound traps or similar passive acoustic methods to monitor cetacean presence around nets (e.g., Omeyer et al., 2020; Yayasan Konservasi RASI, 2021). Based on the results of these trials, methods that effectively reduce bycatch can be scaled up to the entire fishery to reduce bycatch on these Endangered and Vulnerable cetacean populations.

Interview-based surveys are effective for obtaining large volumes of data on artisanal fisheries at a relatively low cost compared to direct observations at sea (e.g., Moore et al., 2010). In small-scale artisanal fisheries, such as those employed in the Kuching Bay, Sarawak, it may be the only cost-effective and feasible means of obtaining preliminary bycatch rates for endangered coastal cetacean populations. While this study has provided a rough minimum estimate of cetacean bycatch, empirical validation of the data derived from interviews through other methods is recommended. Additionally, continued collection of interview data with adaptations to allow more accurate estimation of bycatch mortality rates for the populations of cetaceans in Kuching Bay will allow the detection of trends in bycatch rates over time, an effort that should go hand-in-hand with continued line transect and photo-identification surveys to ensure that the impact of bycatch can be accurately assessed against up-to-date abundance estimates. This level of cetacean population and bycatch monitoring is an essential component of fisheries management that can help the fisheries sector to comply with Sarawak's Biodiversity Master Plan (Tang et al., 2022), Malaysia's National Policy on Biological Diversity 2016–2025 (Ministry of Natural Resources and Environment, 2016), as well as international fisheries import and export rules, such as the US Marine Mammal Protection Act (MMPA) Import rule (NOAA, 2016), which is posing a challenge for fisheries throughout the ASEAN region (e.g. Johnson et al., 2017; Kaewnuratchadasorn, 2023).

Author contributions statement

GM, CP and AAT conceived the ideas and designed methodology; SA, CP, JN, and ANZP collected the data; SA, CP, GM, and AM analysed the data; SA, CP, and GM led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2023.106592.

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