Bycatch Estimates of Dugongs and Dolphins: Results from an Interview Survey of Fishermen in Brunei Bay, Malaysia

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Abstract

Bycatch refers to the unintentional capture of non-targeted animals during fishing activities. Worldwide, bycatch poses a significant threat to marine mammal species. In the Southeast Asian region, information on bycatch is particularly scarce, and there is little indication that the issue is adequately addressed anywhere in the region. To address this knowledge gap, we conducted face-to-face interview surveys across fishing communities in the Malaysian side of the Brunei Bay. We collected two datasets of marine mammal bycatch incidences from two different groups of fishermen (N=90 of 356 reported dugong data, 0.3%, and N=62 of 146 reported dolphin data, 0.4%), to estimate the levels of mortalities of the marine mammals. More than four fifths (82.1%) of respondents reported that they have accidentally captured at least one marine mammal (25.0% dugong and 42.5% dolphin) throughout their lifetime as a fisherman, with the highest frequency of occurrence being reported by fishers using gillnets (53.5% and 38.7%, respectively). Our interview results suggest an annual bycatch of 0.22 (95% CI = 0.13 to 0.32) for dugongs and 0.65 (95% CI = 0.40 to 0.88) for dolphins in the Malaysian Brunei Bay. Findings from this study provides important data to guide fisheries resource managers in providing protection and conservation efforts the endangered marine mammal populations.

Keywords: Local ecological knowledge (LEK), endangered marine mammals, dugong, dolphin, Brunei Bay

Introduction

Brunei Darussalam and East Malaysia (Sabah, Sarawak, and Federal Territory Labuan) share the Bay of Brunei, with about 30% of the Bay sited within Bruneian territory, and the remaining 70% within Malaysian territory. The Bay, with a width of 250, 000 hectares consists of large estuaries, coral, rainforests, seagrasses, and lagoons, making it a vital nursery ground for marine animals, such as dugongs, turtles, dolphins, and commercial fishes including shrimps in the Southeast Asian Region (Vo et al., 2013; Joseph et al., 2018; Mahmud et al., 2018). The Bay used to be rich in food resources for various kinds of marine mammals since it had a large number of fish resources (Joseph et al., 2016).

Ponnampalam (2012) stated that out of the 31 species of marine mammals in Southeast Asia, at least 27 cetaceans and one sirenian species were recorded in East Malaysian territory, which may be resident and pass through the Malaysian site of Brunei Bay. The most common species that have been sighted in coastal waters are the *Orcaella brevirostris* (Irrawaddy Dolphin) and *Sousa chinensis* (Indo-Pacific Humpback Dolphin) (Jaaman et al., 2001; Mahmud, 2016; Raman, 2017; Muda, 2018). As for the deeper waters of the Bay, the most abundant cetaceans found are the *Tursiops aduncus* (Indo-Pacific Bottlenose Dolphin), *Stenella longirostris* (Long Snout Spinner Dolphin), and *Stenella attenuata* (Pantropical Spotted Dolphin) (Jaaman et al., 2001; Raman, 2017; Muda, 2018). Besides, there have been numerous sightings of dugongs by fishers in Kudat, Sandakan, and Semporna, and viable populations are thought to exist in the Malaysian waters of Brunei Bay, which are between Labuan and Lawas (Jaaman et al., 1999; Briscoe et al., 2014).

However, the survival of marine mammals in the area is jeopardised due to human activities. Jaaman et al. (2008) reported that fishermen around Borneo Island use marine mammals for various purposes. In specific locations, dolphins and dugongs are killed, inadvertently in fisheries targeting other species and purposefully for human food or use in cultural and traditional ceremonies (Jaaman et al., 2008; Rajamani, 2013; Raman, 2017). Some fishermen said they consumed the animals for family meals, while others indicated that they traded or used the flesh as shark bait, and some others reported that they simply release/ discard the animals. It is because there seems to be a general belief that disturbing or harming the dolphin will bring bad luck. Some of the fishermen claimed that the dugong is mainly used for its flesh and medicinal purposes, such as asthma and back pain treatment by using the combination made from boiling tusk shavings, dugong blubber is consumed to strengthen and calm the body, and dugong tears are sometimes collected and used to make love charms and fragrances.

Unfortunately, information on the population status, risks, and mortality of marine mammals trapped in artisanal fishing remains poor, particularly in Borneo, since they are not routinely observed or recorded. This is because fisheries comprise numerous target species, and almost everything taken has value, either for commercial sale or personal consumption (Jaaman, 2006). In these circumstances, researchers have progressively leaned on local fishermen's knowledge to understand better artisanal fisheries and their interaction with coastal ecosystems (Hind, 2015; Leithäuser & Holzhacker, 2020; Bernos et al., 2021). Although there will always be differences in the patterns, degrees, and reliability of local knowledge among study systems, informants who spend a lot of time in landscapes containing the studied species may have knowledge that is useful for ecological and conservation management (Moore et al., 2010; Burton & Riley, 2018; Ghanbari & Turvey, 2022). Besides, making formal boat-based survey is expensive and time-consuming and need well-trained researchers with expertise because many marine mammal species are scattered across large geographic areas (Maunder & Punt, 2004). In such cases, knowledge gathered from untrained locals who share the same environments as marine aquatic animals may provide an alternative, potentially helpful source of data on species status and threats, particularly in areas where formal scientific research has been limited, but large human populations exist (Pilcher et al., 2017).

Thus, a large-scale local ecological knowledge (LEK) study of local marine fishers across Borneo was done using a questionnaire-based interview technique to address the present dearth of data on marine mammal interaction with fisheries in the Malaysian Bay of Brunei. The goal of this project was to estimate a minimum bycatch rate of dugong and dolphin, which can provide a new baseline of regional fishing methods, activities and spatial patterns of fisheries interactions with marine mammals to increase the evidence base for marine mammal conservation and management in the Brunei Bay, particularly throughout Malaysian waters.

Materials and Methods

Survey area

The study was conducted on the Malaysian side around Brunei Bay (Figure 1), located on the northwest coast of Borneo Island (4^{0}'45'to 5^{0}'02'N, 114^{0}58'-115^{0}10''to115^{0}10'E). The Bay comes under two countries, which is Malaysia (Sabah, Sarawak, and Labuan Federal Territory) and Brunei Darussalam; only 30% of the bay is located in the Brunei region, while the rest is within Malaysia's territorial waters (Mahmud, 2016). The area of interest has been known as one of the critical habitats for marine mammals in Borneo because of their biodiversity richness (Jaaman et al., 2013), which comprises seagrass beds, coral reefs, estuarine systems, extensive mangrove forest with associated mud-flats and sand-flats (Jaaman et al., 2010; Ahmad-Kamil et al., 2013). Based on their provinces and orientation toward the bay, the study area was stratified into five main districts: Lawas, Sipitang, Weston, Menumbuk, and Labuan.

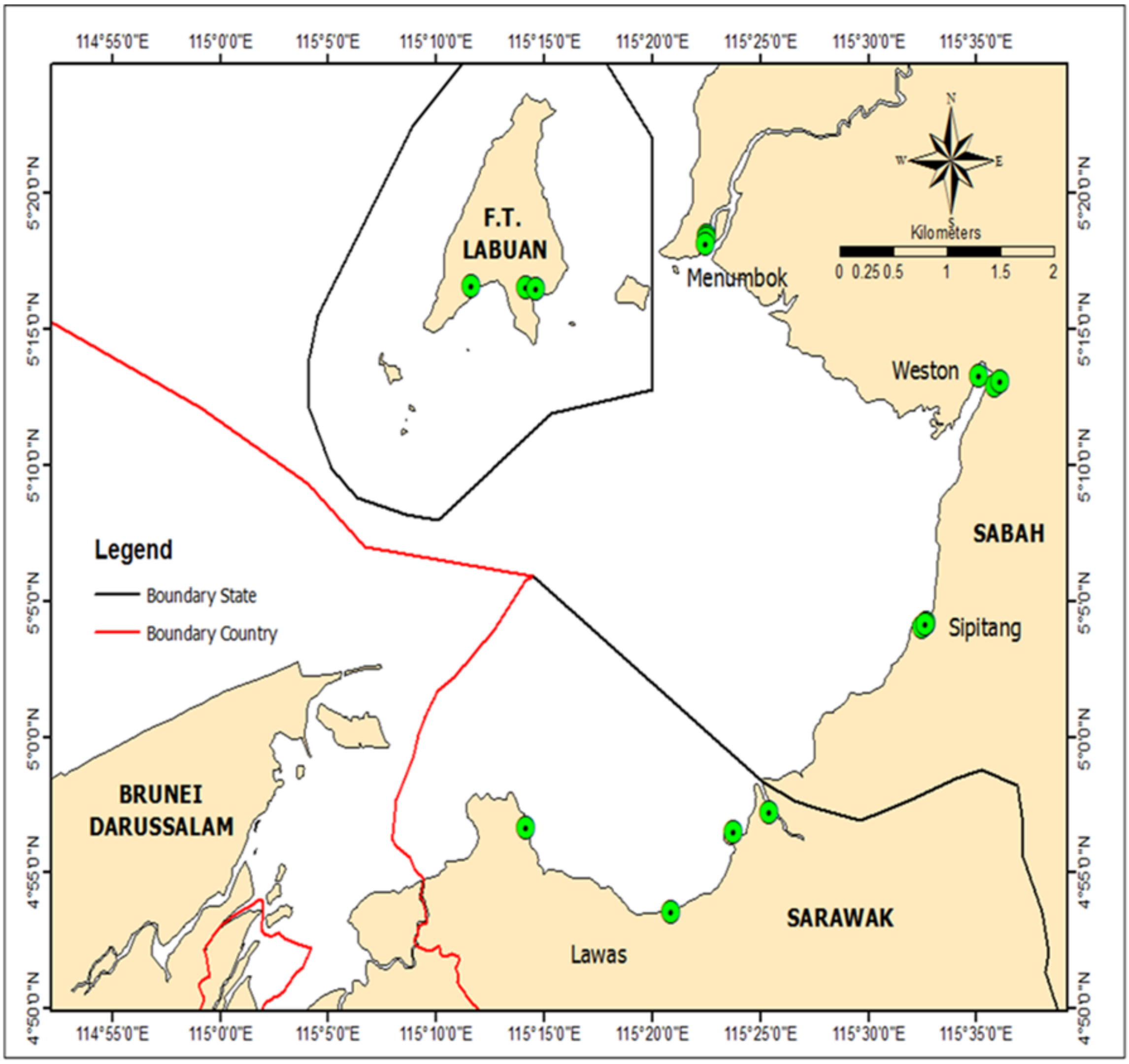

Figure 1. Map showing Brunei Bay, surrounded by Malaysia (Sarawak, Sabah and Labuan Federal Territory), and Brunei Darussalam. The green dotted-circles indicate the sites of fishing communities. Adapted from Raman (2017)

Fishers' LEK Survey

This study collected data on the fishers' LEK through a semi-structured sstandardised questionnaire-based interview survey. Conducted in the natural environment, such as fisher villages, landing jetties, and fish markets, piloted in November 2018.

The questionnaire was selected and translated from CMS-UNEP Standardized Dugong Catch/Bycatch with minor adjustments to suit local arrangements and achieve the aim of the study. The interview survey followed standard field interview procedures and suggestions from the CMS-UNEP project manual (CMS-UNEP, 2010). Paper copies of the Brunei Bay map, marine mammal guidebook (Jefferson et al., 1992; Jefferson et al., 2013), the graphic poster of marine mammals (published by UMT) and a fishing gear poster (from the FAO website) were used to aid the fishermen to confirm their answer. Besides, validation questions were also asked to assess the reliability of the answer given.

Following the acapproach outlined by Jaaman et al. (2009), before conducting the interviews, local authorities such as the officers from the Department of Fisheries and village leaders were informed and consulted to ensure adherenceto cultural guidelines. Initial contacts with fishermen were established by visiting their villages, meeting with them and their families, and seeking their consent to participate in the survey. The fishermen were then selected for interviews using a random sampling technique. These initial contacts are essential to achieve full cooperation (Hines et al., 2005; 2008), which leads to more reliable participant responses. The proper introductory statement was also given to explain the purpose of this study, and was guaranteed that all data would be anonymous. The interview will only be conducted if the fishermen consent to participate in this survey. Straightforward and general questions were first asked, followed by more profound and challenging questions towards the end of the interview to soptimise the conversations (CMS-UNEP, 2010). An open dialogue was also held to better understand the level of ecological knowledge the respondent possessed. The interview survey took about 25±5 minutes, with 3 to 5 days at each stratum to complete, which depends on the respondent's feedback.

Analysis of bycatch rates

The questionnaire used in the study consisted of 47 questions covering various aspects of local fisheries, including fishing gear commonly used, awareness of, and responses toward marine mammal bycatch. Questions about bycatch consisted of whether, how many, when, and where informants have experienced marine mammal incidental catch events, which marine mammal species and gear type were involved in these events and the informant's response to any bycatch events they had experienced. All databases were then compiled in Microsoft Excel and analysed using Statistical Package for Social Science (SPSS).

The interview data were used to calculate a 'minimum' rate of marine mammal (dugong and dolphin) bycatch in the Malaysian Brunei Bay. Data were then separated into the fishing region and gear type, employing hook and lines, seine, trawl, gillnets, and stakes. The boats sampled are assumed to be represented within each stratum; i.e. the proportion of boats reporting bycatch and calculated bycatch rates may be extrapolated to the total fleets.

The fishermen were asked whether they were involved in any bycatch events during those fishing years. If the answer was positive, they were asked how many animals they had caught the year before. Those who reported no bycatch were then asked how many animals they had caught in the previous 5 or 10 years. The minimum value was taken from the responses ranging from 1 to 2, 2 to 5, and 5 to 10, and the number of animals taken was used to estimate annual bycatch rates.

Generally, the annual bycatch of marine mammals was calculated by dividing the number of animals caught by the estimated year of incidents (following Jaaman et al., 2009). Thus, the total annual bycatch of marine mammals was a cumulative value of the yearly bycatch according to the respective variable (i.e. region, gear-type). For example, if three dugongs were caught, two in five years and the other was caught in the last two years. The calculation should be as Equation 1:

$$Total\ number\ of\ animals\ caught\ per\ year = \sum \frac{number\ of\ animal\ caught}{years} \qquad \textbf{(Equation 1)}$$

Meanwhile, the overall mean annual bycatch per boat (Equation 2) is given by the total number of animals caught per year divided by the number of interviews:

$$Mean\ annual\ by-catch\ per\ boat = \frac{total\ number\ of\ animals\ caught\ per\ year}{total\ number\ of\ interviews} \qquad \textbf{(Equation 2)}$$

Separate totals were estimated for dugongs and dolphins, as the number of respondents for both marine mammals differed. Bycatch rate estimates for the fleet total were then calculated using the number of boats in each region and gear type, published in the fisheries statistics of Malaysia in 2018 (DOFM, 2018) as a rising factor.

The mean bycatch per trip was derived from the estimated number of fishing trips every month. Most respondents said they fish daily (excluding the weather factor). Fishermen using trawls and seine nets might make up 20 trips per month since they stayed at sea for up to three days at a time. Therefore, boats using hook and lines, gillnets, and fish stakes are anticipated to make an average of 26 trips per month (following Jaaman, Lah-Anyi & Pierce, 2008).

To stimulate the data, confidence limits of the number of bycatches were determined using a bootstrap approach, which involved repeatedly re-sampling with replacement from N sets of interviews to create additional N sets. This study, 10,000 repetitions were employed, each producing an estimate of by-caught animals in each stratum, then raised to the whole fleet level. Interviews were stratified by region and gear type, and confidence limits for each region and gear type were calculated individually. By running a version of the algorithm in which all strata were sampled, the total bycatch was saved, and the confidence limits for the total across all regions and gear types were determined by bootstrap analysis, which was also repeatedly 10,000 times.

Analysis of factors that affect the reported incidence of marine mammals bycatch was based on Generalised Linear Models (GLM), fitted using SPSS software. The response variables were the presence (1) or absence (0) of bycatch of (a) dugong and (b) dolphin. The explanatory variables considered were region and gear type, all nominal variables. The models were run using a logit-link function, assuming a binomial distribution for the response variable.

The initial models had the formula (Equation 3):

$$(Y1) \sim \alpha + as.factor(region) + as.factor(gear - type) + \varepsilon_i \qquad \textbf{(Equation 3)}$$

Where Y1 is the occurrence of bycatch, α is the intercept, ε_i is the residual (unexplained information or noise, $\varepsilon_i \sim N(0, \sigma^2)$). In each case, the best-fitted model was identified using stepwise removal of non-significant terms until no further decrease in the Akaike Information Criterion (AIC) value was seen. The individual probability (p-value) associated with each explanatory variable in the final model was used to identify significant effects on the occurrence of bycatch.

Similar analyses were conducted on the variation in the number of marine mammals reported caught. As the incidence of bycatch was rare, they were then modelled with a Poisson distribution. However, the number of caught animals per year varied widely, ranging from 0.1 to 1 (i.e. the distribution was "over-dispersed). In this case, a quasi-Poisson distribution that includes a dispersion parameter and a logit link function was assumed for the response variables.

Results

Interviewee profile

A total of 364 interviews were conducted along Brunei Bay, covering Malaysian sites: Sabah, Sarawak and Federal Territory Labuan. The fishers were between 17 and 82 years old, with an average of 29.17 (SD=15.83) years of working experience in fisheries, with a strength of association between the correlation coefficient ($r=0.83$, $p<0.05$) between age and years of working experience. Besides, they were exclusively male (89.8%), and most of them from the fishers' family backgrounds (93.1%). Most of the interviewees (95.6%) reported fisheries as their primary activity, with more than half (64.0%) reporting that they depend on the daily haul as their source of income.

Most fishers (89.6%) owned the vessel in which they operated outboard motors with an average of 8.42m (SD=13.12) length of the vessel and 61.03 (SD=129.43) horsepower. Gillnets were the most frequently used fishing gear (46.2%), followed by seine nets (28.8%), stakes (8.8%), hook and lines (8.2%), and trawls (8.0%). The chi-square test showed a significant difference between the fishing gear used along the Malaysian Brunei Bay ($\chi^2=213.115$, df=4, N=364, $p<0.05$). All of the interviewed fishermen stated that they have seen at least one marine mammal in their lifetime, and most of them (n = 206/251, 82.1%) showed knowledge in the difference between the marine mammal species. From the interview data in the study area, 356 boats were sampled that provided data on dugongs, while only 146 boats provided data on dolphins.

Dugong bycatch rate estimate

Out of 356 boats sampled around The Bay of Brunei, Malaysia, fishermen from 90 (25.3%) boats indicated experiencing dugong bycatch (Table 4.9); 34.4% (N=31/90) of them were reported from the respondent around Lawas, 15.5% (N=14/90) from Sipitang, 34.4% (N=31/90) from Weston, 14.4% (N=13/90) from Menumbuk, and 1.1% (N=1/90) from Labuan. As for fishing gear used, as much as 8.9% (N=8/90) bycatches came from hook and line users, 21.1% (N=19/90) from seiners, 3.3% (N=3/90) from trawlers, 53.3% (N=48/90) from gillnetters, and 13.3% (N=12/90) from stakes.

This present study recorded at least 0.02 individuals of dugong trapped in gear annually (with an average of 0.0001 catch per boat), as stated in Table 1. By raising the interview data to fleet total, an estimated 0.22 dugongs (95% CI=0.13-0.32) were incidentally caught per year, an equivalent of two individuals of dugongs caught per 10 years by the Malaysian fishing fleets in Brunei Bay (Table 2). This value shows that it is acceptable for dugong bycatch estimated in Malaysian Brunei Bay since the landing is below the “adequate level” of no more than 2% from a total of 53 individuals of dugongs in Sabah as recommended by the Second Meeting of Parties to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas [ASCOBANS]) (Rajamani & Marsh, 2010).

Table 1. Summary of interview-based estimates of dugong bycatch

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
Lawas	**Hook and lines**	5	8	3	26	130	1560
	Seines	3	36	6	20	60	720
	Trawl	24	0	0	20	480	5760
	Gillnets	380	70	17	26	9880	118560
	Stakes	33	16	5	26	858	10296
	All gears	445	130	31		11408	136896
Sipitang	**Hook and lines**	403	5	1	26	10478	125736
	Seines	19	19	7	20	380	4560
	Trawl	5	13	1	20	100	1200
	Gillnets	494	23	5	26	12844	154128
	Stakes	27	1	0	26	702	8424
	All gears	948	61	14		24504	294048

Table 1. Continued

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
Weston	**Hook and lines**	62	3	2	26	1612	19344
	Seines	0	6	4	20	0	0
	Trawl	0	3	3	20	0	0
	Gillnets	685	36	16	26	17810	213720
	Stakes	252	7	7	26	6552	78624
	All gears	999	55	31		25974	311688
Menumbuk	**Hook and lines**	250	1	1	26	6500	78000
	Seines	15	13	2	20	300	3600
	Trawl	35	5	0	20	700	8400
	Gillnets	675	48	10	26	17550	210600
	Stakes	20	12	0	26	520	6240
	All gears	995	79	13		25570	306840
Labuan	**Hook and lines**	119	2	1	26	3094	37128
	Seines	7	6	0	20	140	1680
	Trawl	0	12	0	20	0	0
	Gillnets	123	8	0	26	3198	38376
	Stakes	52	3	0	26	1352	16224
	All gears	301	31	1		7784	93408
All sites	**Hook and lines**	839	19	8	26	21814	261768
	Seines	44	80	19	20	880	10560
	Trawl	64	33	3	20	1280	15360
	Gillnets	2357	185	48	26	61282	735384
	Stakes	384	39	12	26	9984	119808
	All gears	3688	356	90		95240	1142880

Table 1. Continued

		DUGONG BYCATCH				
Survey area	**Fishing gear**	**Number of boats with bycatch**	**Number of animals caught annually**	**Mean annual bycatch per boat**	**Mean annual bycatch per fleet total**	**Mean annual bycatch per 1000 trips**
Lawas	**Hook and lines**	3	0.0197	0.0025	0.0123	0.0079
	Seines	6	0.0385	0.0011	0.0032	0.0045
	Trawl	0	-	-	-	-
	Gillnets	17	0.0269	0.0004	0.1460	0.0012
	Stakes	5	0.0744	0.0047	0.1535	0.0149
	All gears	31	0.0355	0.0003	0.1215	0.0009
Sipitang	**Hook and lines**	1	0.0042	0.0008	0.3385	0.0027
	Seines	7	0.0138	0.0007	0.0138	0.0030
	Trawl	1	0.0051	0.0004	0.0020	0.0016
	Gillnets	5	0.0076	0.0003	0.1632	0.0011
	Stakes	0	0.0000	0.0000	0.0000	0.0000
	All gears	14	0.0086	0.0001	0.1337	0.0005
Weston	**Hook and lines**	2	0.0437	0.0146	0.9031	0.0467
	Seines	4	0.0396	0.0066	-	-
	Trawl	3	0.0194	0.0065	-	-
	Gillnets	16	0.0255	0.0007	0.4852	0.0023
	Stakes	7	0.0592	0.0085	2.1312	0.0271
	All gears	31	0.0320	0.0006	0.5812	0.0019
Menumbuk	**Hook and lines**	1	0.0333	0.0333	8.3250	0.1067
	Seines	2	0.0203	0.0016	0.0234	0.0065
	Trawl	0	-	-	-	-
	Gillnets	10	0.0113	0.0002	0.1589	0.0008
	Stakes	0	-	-	-	-
	All gears	13	0.0090	0.0001	0.1134	0.0004
Labuan	**Hook and lines**	1	0.0135	0.0068	0.8033	0.0216
	Seines	0	-	-	-	-
	Trawl	0	-	-	-	-
	Gillnets	0	-	-	-	-
	Stakes	0	-	-	-	-
	All gears	1	0.0009	0.0000	0.0087	0.0001
All sites	**Hook and lines**	8	0.0195	0.0010	0.8611	0.0033
	Seines	19	0.0252	0.0003	0.0139	0.0013
	Trawl	3	0.0038	0.0001	0.0074	0.0005
	Gillnets	48	0.0190	0.0001	0.2421	0.0003
	Stakes	12	0.0411	0.0011	0.4047	0.0034
	All gears	90	0.0215	0.0001	0.2227	0.0002

Table 2. Estimated annual number of dugong bycatch, with bootstrap estimates of 95% confidence intervals

		INTERVIEWS		
Fishing region	**Fishing gear**	**Estimated annual bycatch for fleet total**	**95% CI (Lower Limit)**	**95% CI (Upper Limit)**
Lawas	**Hook and lines**	0.0123	0.0000	0.0264
	Seines	0.0032	0.0003	0.0087
	Trawl	-	-	-
	Gillnets	0.1460	0.0417	0.3271
	Stakes	0.1535	0.0069	0.4500
	All gears	0.1215	0.0321	0.2027
Sipitang	**Hook and lines**	0.3385	0.0000	0.1194
	Seines	0.0138	0.0044	0.0263
	Trawl	0.0020	0.0000	0.0064
	Gillnets	0.1632	0.0377	0.3196
	Stakes	-	-	-
	All gears	0.1337	0.0272	0.1806
Weston	**Hook and lines**	0.9031	0.0000	1.7222
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	0.4852	0.2873	0.7127
	Stakes	2.1312	1.4777	2.8500
	All gears	0.5812	0.4175	0.8818
Menumbuk	**Hook and lines**	8.3250	-	-
	Seines	0.0234	0.0000	0.3320
	Trawl	-	-	-
	Gillnets	0.1589	0.0594	0.2794
	Stakes	-	-	-
	All gears	0.1134	0.0486	0.4585
Labuan	**Hook and lines**	0.8033	0.0000	0.6081
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	-	-	-
	Stakes	-	-	-
	All gears	0.0087	0.0000	0.1723
All sites	**Hook and lines**	0.8611	0.3443	0.1428
	Seines	0.0139	0.0043	0.0298
	Trawl	0.0074	0.0000	0.0174
	Gillnets	0.2421	0.1345	0.4174
	Stakes	0.4047	0.0912	1.0058
	All gears	0.2227	0.1341	0.3292

A logistic model (Binomial Generalized Linear Model with logit-link function) was then fitted and estimated using multivariate linear to predict dugong bycatch occurrences with the area of occurrences and fishing gear used. The model's intercept was significant, corresponding to Labuan and gillnets at -3.32, $p < 0.05$. Instead, the model was confirmed to have significant individual effects only on the area but not the fishing gear used. From Table 3, we can see that Weston and Sipitang showed substantial effects on bycatch occurrence at $p < 0.05$. The result shows that the odds of bycatch occurrence " ("YES"" category) is 3.52 times greater for Weston than in other areas, despite the fishing gear used.

Table 3. Results from binomial logit-link GLM for variation in dugong bycatch events between different areas and boats in the Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	Z-value	P-value
Dugong bycatch	**Area = Lawas**	2.0152 (1.0508)	1.918	0.0551
	Area = Menumbuk	1.6382 (1.0748)	1.524	0.1275
	Area = Sipitang	2.1239 (1.0701)	1.985	0.0472
	Area = Weston	3.5191 (1.0661)	3.301	0.0010
	Gear = Hook and lines	0.8808 (0.5450)	1.646	0.0997
	Gear = Seines	0.0992 (0.3334)	0.298	0.7660
	Gear = Trawls	-0.8811 (0.6814)	-1.293	0.1956
	Gear = Others	0.3685 (0.4154)	0.887	0.3751

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold.

The quasi-Poisson GLM for variation in numbers of dugong bycatch included effects of bycatch area and gear-used type. Again, only the area of occurrence significantly impacted the number of dugongs reported caught. As we can see from Table 4, Lawas and Weston show statistically significant effects at $p<0.05$. it has been said that the expected log count for dugong caught in Lawas increases by 2.13 and 3.11 in Weston compared to Labuan. Again, no significant effects on the number of dugongs reported caught in the fishing gear used.

Table 4. Results from quasi-Poisson GLM for variation in numbers of dugong reported caught incidentally between different areas and boats in Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	t-value	P-val
Dugong bycatch	**Area = Lawas**	2.1291 (1.0859)	1.961	0.05
	Area = Menumbuk	1.5795 (1.1100)	1.423	0.16
	Area = Sipitang	2.0988 (1.0976)	1.912	0.06
	Area = Weston	3.1110 (1.0845)	2.877	0.00
	Gear = Hook and lines	0.4323 (0.3650)	1.186	0.24
	Gear = Seines	0.2101 (0.2450)	0.858	0.39
	Gear = Trawls	**-0.6230 (0.5651)**	**-1.102**	**0.27**
	Gear = Others	**0.0852 (0.3150)**	**0.270**	**0.79**

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold

Dolphin bycatch

A total of 146 boats were sampled, of which 62 (42.5%) boats indicated the occurrence of incidental catch of dolphins (Table 5). In contrast to dugong, the highest dolphin bycatch events were reported around Lawas (N=25/62, 40.3%), followed by Menumbuk (N=11/62, 17.7%), Weston (N=10/62, 16.1%), Sipitang (N=7/62, 11.3%) and Labuan (N=9/62, 14.5%), reported caught in all fishing gear types, but the highest was shown by the gillnets (N=24/62, 38.7%).

About 0.03 individuals of dolphins were reported caught incidentally in fishing gear per year, with an average catch of 0.0002 per boat. Table 5 sthat Lawas had the highest number of boats reporting dolphins bycatch, the number of dolphins reported caught, mean annual bycatch per boat, estimated annual bycatch per fleet total, and estimated mean bycatch per 1000 fishing trips.

By raising the interview data to fleet total, an estimated 0.65 (95% CI=0.40-0.88) dolphins were caught incidentally per year, or seven individuals of dolphins were caught per 10 years in the Malaysian Brunei Bay. Assuming dolphin species caught in Borneo are Irrawaddy dolphin, Indo-pacific humpback dolphin, and Indo-pacific finless porpoise and that species population in Borneo is estimated to be 153 individuals (Minton *et al*., 2016), 2% of the population for maximum acceptable annual bycatch is approximately three individuals (or 0.003 bycatches per 1000 trips). Therefore, the figure from bootstrap estimates (Table 6) proved to have an acceptable enough value for the total dolphin bycatch in Malaysian Brunei Bay.

Table 5. Summary of interview-based estimates of dolphins bycatch

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with Bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
Lawas	**Hook and lines**	5	3	3	26	130	1560
	Seines	3	10	10	20	60	720
	Trawl	24	0	0	20	480	5760
	Gillnets	380	12	11	26	9880	118560
	Stakes	33	1	1	20	660	7920
	All gears	445	26	25		11210	134520
Sipitang	**Hook and lines**	403	1	3	26	10478	125736
	Seines	19	11	5	20	380	4560
	Trawl	5	4	0	20	100	1200
	Gillnets	494	9	2	26	12844	154128
	Stakes	27	0	0	20	540	6480
	All gears	948	25	10		24342	292104
Weston	**Hook and lines**	62	3	3	26	1612	19344
	Seines	0	2	1	20	0	0
	Trawl	0	0	0	20	0	0
	Gillnets	685	12	5	26	17810	213720
	Stakes	252	7	4	20	5040	60480
	All gears	999	24	13		24462	293544
Menumbuk	**Hook and lines**	250	2	3	26	6500	78000
	Seines	15	6	0	20	300	3600
	Trawl	35	3	0	20	700	8400
	Gillnets	675	35	6	26	17550	210600
	Stakes	20	9	5	20	400	4800
	All gears	995	55	14		25450	305400
Labuan	**Hook and lines**	119	1	1	26	3094	37128
	Seines	7	3	3	20	140	1680
	Trawl	0	8	5	20	0	0
	Gillnets	123	1	0	26	3198	38376
	Stakes	52	3	0	20	1040	12480
	All gears	301	16	9		7472	89664

Table 5. Continued

		INTERVIEWS			ESTIMATED FISHING TRIPS		
Survey area	**Fishing gear**	**Total number of boats**	**Number of interviews**	**Number of boats with Bycatch**	**Monthly per boat**	**Monthly total**	**Annual total**
All sites	**Hook and lines**	839	10	4	26	21814	261768
	Seines	44	32	19	20	880	10560
	Trawl	64	15	5	20	1280	15360
	Gillnets	2357	69	24	26	61282	735384
	Stakes	384	20	10	20	7680	92160
	All gears	3688	146	62		92936	1115232

		DOLPHIN BYCATCHES				
Survey area	**Fishing gear**	**Number of boats with bycatch**	**Number of animals caught annually**	**Mean annual bycatch per boat**	**Mean annual bycatch per fleet total**	**Mean annual bycatch per 1000 trips**
Lawas	**Hook and lines**	3	0.0980	0.0327	0.1633	0.1047
	Seines	10	0.0622	0.0062	0.0187	0.0259
	Trawl	0	-	-	-	-
	Gillnets	11	0.0594	0.0050	1.8810	0.0159
	Stakes	1	0.1200	0.1200	3.9600	0.5000
	All gears	25	0.0673	0.0130	1.0471	0.0078
Sipitang	**Hook and lines**	3	-	-	-	-
	Seines	5	0.0241	0.0022	0.0416	0.0091
	Trawl	0	-	-	-	-
	Gillnets	2	0.0110	0.0012	0.6038	0.0039
	Stakes	0	-	-	-	-
	All gears	10	0.0144	0.0014	0.2271	0.0008

Table 5. Continued

		DOLPHIN BYCATCHES				
Survey area	**Fishing gear**	**Number of boats with bycatch**	**Number of animals caught annually**	**Mean annual bycatch per boat**	**Mean annual bycatch per fleet total**	**Mean annual bycatch per 1000 trips**
Weston	**Hook and lines**	3	-	-	-	-
	Seines	1	0.0102	0.0051	-	-
	Trawl	0	-	-	-	-
	Gillnets	5	0.0112	0.0009	0.6393	0.0030
	Stakes	4	0.0286	0.0041	1.0296	0.0170
	All gears	13	0.0148	0.0021	0.6186	0.0021
Menumbuk	**Hook and lines**	3	-	-	-	-
	Seines	0	-	-	-	-
	Trawl	0	-	-	-	-
	Gillnets	6	0.0095	0.0003	0.1832	0.0009
	Stakes	5	0.0684	0.0076	0.1520	0.0317
	All gears	14	0.0172	0.0014	0.1408	0.0005
Labuan	**Hook and lines**	1	0.0270	0.0270	3.2130	0.0865
	Seines	3	0.0474	0.0158	0.1106	0.0658
	Trawl	5	0.0256	0.0032	-	-
	Gillnets	0	-	-	-	-
	Stakes	0	-	-	-	-
	All gears	9	0.0234	0.0063	0.2217	0.0025
All sites	**Hook and lines**	4	0.0321	0.0032	2.6932	0.0103
	Seines	19	0.0328	0.0010	0.0451	0.0043
	Trawl	5	0.0137	0.0009	0.0585	0.0038
	Gillnets	24	0.0185	0.0003	0.6319	0.0009
	Stakes	10	0.0468	0.0023	0.8986	0.0098
	All gears	62	0.0259	0.0002	0.6542	0.0006

Table 6. Estimated annual number of dolphin bycatch, with bootstrap estimates of 95% confidence intervals

		INTERVIEWS		
Fishing region	**Fishing gear**	**Estimated annual bycatch for fleet total**	**95% CI (Lower Limit)**	**95% CI (Upper Limit)**
Lawas	**Hook and lines**	0.1633	0.0900	0.2000
	Seines	0.0187	0.0120	0.0260
	Trawl	-	-	-
	Gillnets	1.8810	1.2290	2.5810
	Stakes	3.9600	-	-
	All gears	1.0471	0.5610	1.5810
Sipitang	**Hook and lines**	-	-	-
	Seines	0.0416	0.0110	0.0790
	Trawl	-	-	-
	Gillnets	0.6038	0.0000	1.4840
	Stakes	-	-	-
	All gears	0.2271	0.0110	0.5730
Weston	**Hook and lines**	-	-	-
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	0.6393	0.1740	1.2040
	Stakes	1.0296	0.2570	1.8000
	All gears	0.6186	0.2790	0.9930
Menumbuk	**Hook and lines**	-	-	-
	Seines	-	-	-
	Trawl	-	-	-
	Gillnets	0.1832	0.0420	0.3760
	Stakes	0.1520	0.0410	0.2760
	All gears	0.1408	0.0480	0.2700
Labuan	**Hook and lines**	3.2130	-	-
	Seines	0.1106	0.0780	0.1370
	Trawl	-	-	-
	Gillnets	-	-	-
	Stakes	-	-	-
	All gears	0.2217	0.0060	0.7150
All sites	**Hook and lines**	2.6932	0.3239	5.4915
	Seines	0.0451	0.0290	0.0630
	Trawl	0.0585	0.0164	0.1059
	Gillnets	0.6319	0.3876	0.9114
	Stakes	0.8986	0.3937	1.4703
	All gears	0.6542	0.4022	0.8806

Using binomial GLM, only the region significantly affected the overall reported incidence of dolphin bycatches in the Malaysian Brunei Bay. The final model was statistically significant, $\chi^2(8) = 56.86, p < 0.05$. The model explained 43.0% (Nagelkerke R^2) of the variance in bycatch occurrence and correctly classified 57.5% of cases. Lawas and Menumbuk were reported to have significant effects on bycatch occurrences, and the results show that the odds of having dolphin bycatch occurrence ” (“YES"” category) for both areas are two times greater than in the other regions. There were no effects of fishing gear on bycatch events (Table 7).

The quasi-Poisson GLM for variation in dolphin numbers reported caught in the Malaysian Brunei Bay. Again, the only areas of occurrences shown to affect dolphins caught, with Lawas and Menumbuk significantly tend to have double the number of dolphins caught compared to the other areas since both have higher occurrences of bycatch. Fishing gear used seems to have no significant effect on the number of dolphins caught (Table 8).

Table 7. Results from binomial logit-link GLM for variation in dolphin bycatch events between different areas and boats in Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	Z-value	P-value
Dolphin bycatch	**Area = Lawas**	2.9939 (1.2393)	2.416	0.0157
	Area = Menumbuk	-1.7309 (0.7466)	-2.318	0.0204
	Area = Sipitang	-1.3810 (0.7796)	-1.771	0.0766
	Area = Weston	-0.6892 (0.8043)	-0.857	0.3915
	Gear = hook and lines	-0.7433 (0.9872)	-0.753	0.4515
	Gear = Seines	0.7853 (0.5921)	1.326	0.1847
	Gear = Trawls	-0.1878 (0.8147)	-0.231	0.8177
	Gear = Others	0.8647 (0.5926)	1.459	0.1445

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold

Table 8. Results from quasi-Poisson GLM for variation in numbers of dolphins reported caught incidentally between different areas and boats in Malaysian Brunei Bay

Response variable	Explanatory variable	Coefficient (Std Error)	t-value	P-value
Dolphin bycatch	**Area = Lawas**	1.0983 (0.3677)	2.987	**0.0033**
	Area = Menumbuk	-1.1656 (0.4236)	-2.752	**0.0067**
	Area = Sipitang	-0.4811 (0.4349)	-1.107	0.2705
	Area = Weston	-0.5038 (0.4319)	-1.167	0.2454
	Gear = hook and lines	0.0709 (0.3364)	0.211	0.8333
	Gear = Seines	0.1185 (0.2240)	0.529	0.5977
	Gear = Trawls	-0.3823 (0.4975)	-0.768	0.4436
	Gear = Others	0.4400 (0.3101)	1.419	0.1582

*Table lists all explanatory variables in the final models. Significant terms are indicated in bold

Discussion

Jaaman (2006) has mentioned that the amount of marine mammal bycatch in Southeast Asian fisheries was significantly higher than previously thought. There is no evidence that this problem has been adequately monitored anywhere in the area, especially around the Malaysian Brunei Bay. Both datasets (dugong and dolphin) used in this study found significant differences in marine mammal bycatch incidents in the survey area but no difference in the fishing gear used. Thus, this may indicate that the bycatch incidents may differ because of the number of marine mammals that occur, which may occur in all types of gear. Despite other large fleets utilising different kinds of equipment, most bycatches were found to occur in a gillnet. This is expected to be a widespread fishing gear in Malaysia and other emerging countries since the commercial usage of gillnets was sparked by the development of nylon nets in the 1960s (Marsh et al., 2011). Gillnets are not only less expensive, but they are also easier to handle, last longer, require less maintenance, and can catch a large number of fish efficiently since they are invisible in waters (Marsh et al., 2011; Briscoe et al., 2014; Raman, 2017). Thus, these efforts to document the magnitude of bycatches should, in general, focus on gillnets fisheries since gillnets have been srecognised as the leading cause of cetaceans and dugong bycatches worldwide (Reeves et al., 2013; Raman, 2017).

In the case of marine mammal bycatches, boat fishing in the Malaysian Brunei Bay, , reported a higher number of incidents involving dolphins than dugongs. The results differ from previous studies (e.g. Jaaman, 2006; Raman, 2017). This may be because of the number of marine mammal occurrences since most young fishermen stated that they rarely saw dugong, and at most never saw dugong at all, compared to dolphins. Although many fishermen claim that cetaceans are far more competent than dugongs in avoiding fishing nets, they can sometimes become caught when the animals aggressively pursue their meal (Reeves et al., 2013). Jaaman et al. (2009) stated that dugongs were more vulnerable to fishing gear than cetaceans. Several factors may have influenced this. First, gillnets are commonly used to catch fish in shallow locations with strong tidal fluctuations, such as seagrass meadows. Raman (2017) mentioned that an area with a seagrass bed is the preferable location for dugongs, so it is possible that the dugongs were likely to be captured or trapped, especially at night. Cetaceans caught in nets generally battled vigorously and were likelier to release themselves, but dugong was frequently discovered dead.

Taking into account the marine mammal population around Borneo is as follows: the dugong population was estimated to be around 53 individuals (Rajamani and Marsh, 2010), while the cetacean population was about 153 (Minton et al., 2016). Assuming that marine mammal bycatches reported in the bay come from the same populations and the 2% of anthropogenic removal (ASCOBANS, 1997) is exclusively from bycatches in fisheries, there will be an upper limit of one dugong and three cetaceans or a total of four marine mammals caught annually. The estimated annual number of 0.22 dugongs (95% CI=0.13-0.32) and 0.65 dolphins (95%=0.40-0.88) were found to lie below the maximum value of annual bycatch. Therefore, this study's figure from bootstrap estimates proved to have an acceptable enough value for marine mammal bycatch in Malaysian waters of Brunei Bay.

As we all know that the estimate of the bycatching rate and the number of animals taken annually is based on an interview survey, which is obviously subject to a range of errors and biases. Furthermore, the Summary of Annual Fisheries Statistics Sabah 2019 (DOFS, 2019) used in the estimates is not up to date because the number of fishermen, boats, and fishing gear published in the summary is based on a listing made in 2018. The number of full-time fishermen is probably an underestimation; the number of illegal immigrants active in the industry has not been ascertained but could run into thousands. Many unlicensed boats and gear of the traditional types and part-time fishermen were observed during the survey but were not listed (no estimate) in the summary. But at most, the data can be thought of as providing a rough indication of the scope of the problem. Furthermore, all the mentioned issues need to be addressed since updated information on the life history parameters, on-site catching monitoring data, and an accurate estimate of the absolute abundance of cetaceans and dugongs in the regions are essential to determine the reliability and sustainability of the bycatch catch estimates.

A previous study suggested that the placement of observers on board fishing boats is the most reliable method for collecting information regarding marine mammal bycatch (Moore et al., 2010; Moore et al., 2021; Wade et al., 2021), but such a monitoring program is lacking in Malaysia. Besides, fishermen frequently refused to voluntarily accept observers' boarding, especially in boats employing fishing gear that are known to catch cetaceans. Even within the European Union, many governments of the Member States have not established routine monitoring of marine mammal catches and kills in fisheries (Morizur et al., 1999; Lopez et al., 2003) despite an obligation to do this under Article 12.4 of the Habitats Directive (92/43/EEC).

Here are the suggestions to address the issue of fisheries bycatch that might be suitable for adoption in the remote Malaysian side of the Brunei Bay. The first recommendation is community participation. Engaging fisheries communities in bycatch mitigation programs can be highly relevant because the involvement is voluntary, especially in small-scale fisheries such as the Brunei Bay. Previous studies have demonstrated that engaging people from fisheries communities can strengthen the implementation of long-term solutions to human conflicts with marine mammals (Farr et al., 2018; Berkstrom et al., 2019). The authorities must embrace the connection to reclaim full involvement and commitment from local communities. As such, responsible parties should assist the people in need, care for their welfare, and ensure their opinions are heard. The general conflicts of human-marine mammals, especially marine mammal bycatch, can be overcome by creating capacity through this win-win situation.

It is advised that management, enforcement agencies, and community leaders work promptly to develop a joint and committed monitoring program to uncover substantial direct or indirect captures of marine mammals in the Brunei Bay. This approach should reduce dangers via education, backed up by stiff consequences for violating regulations. However, this must be done with caution since legislation enforcement preventing direct captures or landing of incidental catches of marine mammals has made gathering information on such takes more difficult in several nations (Mintzer, 2018; Bering et al., 2022). Furthermore, educating the fisheries communities about fishing rules and environmental conservation is critical since enforcing the law across a vast region may be difficult and expensive. If such communities must reduce or discontinue fishing, other livelihoods such as mariculture or ecotourism should be supported. Furthermore, these communities should also have a significant role in managing, conserving, and utilising natural resources. These kinds of alternative enforcement would encourage the communities' involvement in species monitoring.

On the other hand, marine mammal-fisheries issues in the Brunei Bay can be effectively solved by an integrated framework between the state and its neighbouring nations. Malaysian state integration can significantly bring together some necessary components in fisheries interaction with marine mammal evaluation and alleviation. A robust platform should be given for people to discuss the crucial issues that may be addressed to a higher constitution, such as the Brunei Darussalam territory. This can be seen from the achievement of the UMT Marine Mammals team, founded by the First Institute of Oceanography, China, which managed to reach an agreement with the Brunei Government to undertake marine mammal research in Bruneian territory in the Brunei Bay (e.g. Haji-Ismail et al., 2021; Azizul et al., 2022). This can later be followed by identifying the specific mechanism of achieving a cross-sectoral integration of legislation. However, this study proposes that the integration should not only be limited to the Brunei Bay itself, but it should be expanded to the other parts of Borneo, such as the Balikpapan Bay (East Kalimantan), the Derawan Island (North Kalimantan), the Kumai/Kotawaringin (Central Kalimantan), or Karimata Bay (West Kalimantan) by conducting an international collaboration with the 'Indonesian's research team, as well as the other parts of Malaysia.

Conclusion

Rapid assessment of the interview survey allowed us to collect considerable information about the scharacterisation of artisanal fisheries and their interaction regarding bycatch mortality over a large geographic area at a relatively low cost. We believe this approach has the potential to become an important conservation tool for studying bycatch and their interaction with artisanal fisheries. However, methodological improvement to the interview survey protocol should be implemented to increase the reliability of the data.

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