



Using Case Studies to Investigate Cetacean Bycatch/Interaction Under-Reporting in Countries With Reporting Legislation

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Accurate reporting of cetacean bycatch in/interaction with fishing gear in fisher logbooks would be of immense scientific value; however, despite some countries having mandatory reporting laws, logbook reporting is widely considered unreliable and cetacean catches are thought to be under-reported. Despite this widespread notion of logbook unreliability, under-reporting has rarely been quantified. For this study, initially we compiled the first comprehensive legislation summary for countries which have cetacean bycatch/interaction reporting laws. We then used data provided by government and research agencies in three case study countries (New Zealand, United States, and Iceland) to test for differences between logbook and observer reported cetacean bycatch. Comparisons were made using paired *t*-tests and Wilcoxon tests with a set alpha of 0.05. Overall, cetacean bycatch recorded by observers was higher than that from fisher logbooks by an average of 774% in trawls, 7348% in nets, and 1725% in hook and line gears. When combining all years of data available, fisher logbook cetacean catch per unit efforts or average number of individuals caught were significantly less than those from observer data for all gear types that could be examined in all countries, except for lining in New Zealand. Overall, there was significant under-reporting in the case study countries despite differences in geographic location, cetacean species and density and EEZ size, suggesting these results would likely be similar in many countries with comparable, well-developed fishing industries. Under-reporting in logbooks, despite laws, was clearly quantified and it is known that fishers have little incentive to report and have concerns over negative repercussions to the industry over bycatch issues. If logbook reporting is to continue in some fisheries, clearer legislation, simplified reporting using new technology (such as smartphone apps) and combination with electronic monitoring cameras to verify compliance may improve reporting accuracy. The introduction of electronic monitoring, given its lower cost compared to observer programs and high accuracy, may be the most viable option to obtain reliable cetacean bycatch estimates, and could be considered to replace logbook reporting altogether.

Keywords: bycatch, under-reporting, entanglement, cetaceans, fisheries, observers, logbooks, CPUE

INTRODUCTION

Cetacean bycatch in or interaction with a wide array of fishing gear types is a global issue which is difficult to quantify and manage. Bycatch is defined as the capture of non-target species in fishing gear which died or were likely fatally injured (Hall, 1996). This is more often the case for small cetaceans that cannot free themselves from gear. Bycatch is considered one of the main causes of anthropogenic mortality in cetaceans and it was previously estimated that over 300,000 cetaceans are killed or seriously injured annually in fisheries world-wide (Read et al., 2006). Much of the fishing gear that has been implicated in such incidents, such as gillnets, is set in shallow waters with low visibility, or deep waters with low light, where it is very unlikely for cetaceans to see the gear in time to avoid it (Kastelein et al., 2001). Though odontocetes use echolocation and mysticetes use hearing and interpretation of sounds for orientation, the acoustic reflectivity of nets is relatively weak, meaning the animals may also have difficulty detecting them (Lien et al., 1990; Au and Jones, 1991; Mooney et al., 2007).

Due to the detectability issues for the cetaceans, bycatch and interaction with fishing gear poses the serious threat of extinction to several small, vulnerable cetacean populations, such as the vaquita (e.g., Taylor et al., 2017) and the North Atlantic right whale (e.g., Moore et al., 2021), by causing unsustainable mortality. Even when not fatal, entanglements can potentially have negative impacts on the individual, such as lowered reproductive success (Robbins and Mattila, 2001; Rolland et al., 2017), which can then impact the recruitment rate of the population.

It is imperative to understand the magnitude of cetacean bycatch and interaction issues in fisheries to implement sustainable fishing practices and conserve cetacean populations. Having fishers log all cetacean bycatch/interactions would be of immense scientific value, and therefore some countries have developed logbook reporting systems for their respective fisheries and have made this reporting mandatory by law; however, accurate and reliable reporting is rare, and few countries have systematically reported data (Read et al., 2006). Even in countries where reporting is mandatory, under-reporting of bycatch and interactions is still recognized as a serious issue (e.g., Cornish et al., 2004). This has led to the need for onboard observers to monitor and record bycatch/interactions, but this is a costly solution that is not viable for all fisheries (Reeves et al., 2013) and to-date it has proven difficult for many countries to be able to quantify bycatch in their fisheries and in turn make informed management decisions (Young and Iudicello, 2007). Understanding and managing cetacean bycatch has become a particularly important issue for governments worldwide since the United States of America (USA) began enforcing a rule in the Marine Mammal Protection Act stating that all imported fish products must come from fisheries that do not cause serious harm to marine mammal populations (NOAA, 2019). This rule came into effect on January 1, 2017 (Federal Register, 2016); however, an initial exemption period of 5 years was granted for countries to work on implementing proper marine mammal bycatch management (NOAA, 2019), which was later extended

by 1 year (Federal Register, 2020), meaning proper management practices need to be adopted by fisheries exporting their products to the United States by 2023.

In this study, we reviewed which countries, of the 30 with the largest fisheries industries (FAO, 2018), have laws requiring fishers to report cetacean bycatch/interactions, and then further reviewed the details of the legislation of each of these countries. We then used data from four of these countries; New Zealand, Iceland, United States, and Norway, for case studies investigating the amount of cetacean bycatch/interaction that is reported in different gear categories in each country. We then compared the reported cetacean bycatch/interaction rates in fisher logbooks to reported rates calculated from observer programs for three of these countries. Finally, we investigated logbook reporting over time and recommended strategies to improve cetacean bycatch/interaction monitoring, which could be used to improve upon systems already in place or implemented in countries that have yet to tackle cetacean bycatch management in their fisheries.

Countries With Cetacean Bycatch/Interaction Reporting Legislation

Twelve countries out of 30 were identified as having legislation that included mandatory cetacean bycatch/interaction reporting. The laws differ between the countries in terms of what size vessels have to report and what details must be reported. Below is a summary of the cetacean bycatch reporting laws for each country individually. We acknowledge that this list may not be complete and will update it, once new information is available to us, at this website: <https://heima.hafro.is/~gudjon/marinemammalbycatch.html>.

United States

The United States has a federal Marine Mammal Protection Act (MMPA) that was established in 1972 (U.S. Fish and Wildlife Service International Affairs, 2020). This act prohibits any take of marine mammals. Starting in 1994, under code § 1387, it became mandatory for all vessels fishing in a “Category I or II” fishery to apply for a “marine mammal authorization certificate” from the National Oceanic and Atmospheric Administration (NOAA) fisheries department which allows the vessel to incidentally take marine mammals without being in violation of the MMPA, so long as they are abiding to other regulations (Legal Information Institute, 2020). Category I “designates fisheries with frequent deaths and serious injuries [to marine mammals] incidental to commercial fishing” and Category II “designates fisheries with occasional deaths and serious injuries [to marine mammals]” (NOAA Fisheries, 2020a). In addition, under this same code, it became mandatory for all fishing vessels to report any death or serious injury of a marine mammal during fishing activities within 48 h of the incident (Legal Information Institute, 2020). The reports must include the vessel identification, the information of the owner, the name of the fishery, and the information about the incident including the species of marine mammal, the type of injury, and the date, time, and location. In addition to the mandatory reporting, NOAA has five hotlines for

the different regions of the country to report a marine mammal in distress, as well as a smartphone app (NOAA Fisheries, 2020b).

Canada

Canada's Fisheries Act, first established in 1985, later included Marine Mammal Regulations in 1993 (Government of Canada, 2020). These regulations govern the protection and harvest of marine mammals in Canadian waters. The regulations were further amended in 2018 to include Accidental Contact with Marine Mammals regulations. These regulations made it mandatory for all interactions between vehicles or fishing gear and marine mammals to be reported to the Minister of Fisheries or reported in a mandatory logbook, even if the animal did not appear to be injured or deceased (Government of Canada, 2018). The incidents should be reported no later than 48 h after the end of a fishing trip and must include the type of vehicle and/or type of fishing gear involved, the vessel name and owner, and specific information about the incident including species of marine mammal, date, time, location, and condition of the animal (Fisheries and Oceans Canada, 2020a). In addition to this mandatory reporting, Canada has eight hotlines set up in different regions of the country to report incidents of marine mammal entanglement where the animal is in need of professional assistance (Fisheries and Oceans Canada, 2020b).

Australia

Australia's Environment Protection and Biodiversity Conservation Act (EPBC) was implemented in 1999 (Australian Government Department of Agriculture Water and the Environment, 2020a). Under this act, all cetaceans are listed as protected species and the rules for all Commonwealth fisheries state "all interactions with EPBC Act-listed species, whether authorized or not, must be reported to the Department of the Environment and Energy" (Australian Government Department of Agriculture and Water Resources, 2018). All Australian Commonwealth fisheries are managed by the government's Australian Fisheries Management Authority (AFMA) which permits accredited fisheries to incidentally interact with protected species without it being a punishable offense under the EPBC, so long as these interactions are recorded in AFMA fishing logbook (AFMA, 2020). An interaction includes "any physical contact a person, boat or gear has with a protected species." In addition to incident reporting in logbooks, Australia also has nine agencies around the country which can be contacted in the event that a whale is witnessed entangled in fishing gear and is in need of professional assistance (Australian Government Department of Agriculture Water and the Environment, 2020b).

New Zealand

New Zealand implemented a Marine Mammal Protection Act, similar to the Act in United States, in 1978. Section 16 of this Act was created in 1996 and covers "Reporting of accidental death or injuries" which states that any person who incidentally kills or injures a marine mammal while fishing must both record the incident in the official logbook and submit a written report to the fishery officer within 48 h of returning to port (Parliamentary Counsel Office-New Zealand and Legislation, 1978). The reports

must include the location, species or animal description, and the circumstances of the event. Despite the Act covering deaths or injuries, the fisher logbook data collected by Fisheries New Zealand also contains reports of cetaceans caught alive and uninjured (Fisheries New Zealand, pers. comm. 13.05.2020). In addition to this mandatory reporting, the New Zealand Department of Conservation has a hotline to report marine mammals entangled in fishing gear and in distress (Department of Conservation, n.d.).

Sweden

Harbor porpoise (*Phocoena phocoena*) is listed as a protected species in Sweden (Naturvårdsverket, 2016). Any porpoises which are found dead or incidentally killed in Sweden belong to the state and must be reported as stated in Article 33 of the Swedish Hunting Ordinance (1987:905) (Sveriges Riksdag, 2020). The regulations are specifically in place for harbor porpoises only and do not include any other cetacean species that could be caught in Swedish waters. According to the Swedish Agency for Marine and Water Management (SwAM), it is not mandatory for fishers to report harbor porpoise bycatch in fishing logbooks (Havs-och vattenmyndighetens, 2018), but they are legally required to report this bycatch to the police or directly to the Swedish Museum of Natural History which is commissioned by SwAM to collect such reports (Naturhistoriska riksmuseet–Peter Mortensen, 2020). The reports must include the location (including coordinates), date, length of the animal, estimated weight of the animal (if possible), and optionally the depth of the fishing gear and the type of fishing gear (Naturhistoriska riksmuseet–Katarina Loso, 2020). Upon approval by the Swedish Museum of Natural History, compensation of 1000 Swedish krona (ca.100USD) is paid to anyone who collects and freezes a deceased harbor porpoise for their research (Naturhistoriska riksmuseet–Katarina Loso, 2019).

Finland

In Finland, Section 62 of the Finnish Fishing Act, first established in 1982, covers reporting of bycatch (Finlex, 2015). The legislation simply states that any bycatch of harbor porpoises must be immediately reported to the Finnish National Resources Centre. No other cetacean species are covered by this legislation, and it is not specified how the reports should be submitted. It is possible for bycatch to be recorded in logbooks and then the logbook information reported to the National Resources Centre, or it is possible to make an online report through the National Resource Centre webpage (Olli Loisa, pers. comm., 24.06.2020). The online report must include the name of the reporter or vessel, the date, time and location of the incident, the gender and age class of the animal (if known), and whether the animal was alive or deceased (Luonnonvarakeskus, 2020).

Norway

Norway has "Regulations on position reporting and electronic reporting for Norwegian fishing and catching vessels" which state under § 10 and § 12 that vessels with a length of 15 m or more fishing in Norwegian waters must electronically report all catch, including bycatch of marine mammals, to the Norwegian

Directorate of Fisheries (Nærings-og fiskeridepartementet, 2009). This mandatory reporting began in 2011 (Fiskeridirektoratet, pers. comm., 15.04.2021). The information required in the reports includes date, time, position, fishing zone, species, gear damage, number of animals, and weight. Most reports also include the gear type (though it is only mandatory to report when using a trawl) and mesh size (though it is only mandatory to report when using a trawl, Danish seine, or seine) (Nærings-og fiskeridepartementet, 2009). For recreational fishers and vessels below 15 m in length, they have the option to voluntarily use an app (“fritidsfiskeappen”) to report bycatch to the Directorate of Fisheries, but this is currently not mandatory by law (Fiskeridirektoratet, pers. comm., 09.07.2020).

Iceland

Iceland established the Fisheries Management Act in 1990. Under Article 17 of this Act, it is stated that all catch must be recorded in special logbooks which are provided by and submitted to the Directorate of Fisheries (FAOLEX Database, 2006). This must include information about all cetaceans. This logbook reporting system became electronic in 2009 and under Article 3 of the “Regulation on registration and electronic submission of catch information” states that all marine mammal bycatch must be reported in the electronic logbook, including date, ship identification, fishing gear type, location, species and number of animals (Atvinnuvega-og nýsköpunarráðuneyti, 2020).

France

Mandatory reporting of cetacean bycatch is relatively new in France. In 2018, the country passed the “Decree of September 6, 2018 amending the Order of July 1, 2011 setting the list of marine mammals protected on national territory and the terms of their protection” which states that all marine mammal bycatch must be reported in fishing logbooks (electronic for vessels 12 m and larger and paper for smaller vessels) for the purpose of scientific research (Ministère de l’Agriculture et de l’Alimentation, 2018). This came into effect 1 January 2019. The logbook reports must include the date, species, number of animals, estimated weight of each animal, and if the animal was discarded in the sea (Tachaires et al., 2018).

South Korea

The Korean Ministry of Oceans and Fisheries has a “Notice on Conservation and Management of Whale Resources.” This Notice was created in accordance with the Fisheries Act and Fisheries Resource Management Act for the “preservation and management of cetacean resources” in Korean waters [Ministry of Oceans and Fisheries Korea (Fisheries Resource Policy Division), 2018]. This notice states that any capture of a cetacean must be reported to the maritime police chief, regardless of if the animal was alive or died during the incident. If the bycatch is reported to the maritime police, the fishers can then legally sell the meat (Mills et al., 1997). Due to this, it is possible that “incidental” take in Korean waters may at times be intentional capture, which is then reported as bycatch in order to profit from the sales (Baker et al., 2006; Lukoschek et al., 2009). All Korean cetacean bycatch data is first confirmed by an inspector

(South Korea Ministry of Oceans and Fisheries, pers. comm. 08.05.2020) and is then reported to the International Whaling Commission (IWC). The available data in the progress reports include year, location, species, number of animals, life status of the animals, and fishing gear involved (IWC, 2020).

Chile

In September 2012, Article 7 of the Chilean General Law for Fisheries and Aquaculture was amended to include law no. 20.625 “Law on Discards and Bycatch” (Subsecretaría de Pesca y Acuicultura, 2020). Under this law, fishers are required to report bycatch of all marine mammals in vessel logbooks, which are electronic for commercial fishing vessels over 15 m and paper for artisanal vessels. The logbooks are collected by the National Fisheries and Aquaculture Service. The law states that all marine mammals are released when possible, and all reports of interaction incidents must include details about the vessel, location, date, number of animals caught, species, and life status (dead or alive) (Subsecretaría de Pesca y Acuicultura, pers. comm., 10.11.2020).

Japan

Since 2001, Article 91, Paragraph 2 of Japan’s Ministerial Ordinance on Fisheries Permits and Controls (in Ministry of Agriculture, Forestry and Fisheries Ordinance No. 5 of 1963) has included mandatory reporting of “baleen whale, etc.” bycatch in fixed fishing nets (Institute for Cetacean Research, 2011; Fisheries Agency Research Management Department, 2020). The law covers seven species of baleen whale and three species of toothed whale designated by the IWC. A bycatch report should be submitted for all incidents, including releasing the animal alive and must include the date and location, species (including a photograph), type of set net fishery and permit number, and length, gender, evidence of lactation, and measurements of fetus (where applicable) (Institute for Cetacean Research, 2011). It is also required to take a DNA sample and send it for testing to the Institute of Cetacean Research if the animal will be used. Once these actions are completed, it is permitted to sell the whale meat or use it for personal consumption. The Japanese Fisheries Resources Conservation Law also includes an additional three species of baleen whale and one species of toothed whale that must be reported, for which possession and sale are prohibited (Institute for Cetacean Research, 2011).

MATERIALS AND METHODS

The search for countries which have cetacean bycatch/interaction reporting laws was based on the top 30 countries with the largest fishing industries (FAO, 2018). An internet search was used to determine the fisheries governing body in each country and search their fisheries legislature for the keywords “mammal,” “bycatch,” “reporting,” and “log.” For countries where the relevant legislature could not be found or was not clear due to language barriers, the governing body was contacted directly through email to ask for further information.

The governments and relative ministries in each of the countries with cetacean bycatch reporting legislation were

contacted directly through email about this study to inquire about available data. For those countries where it was possible, data was requested from 2009 to 2019. Raw fisher-reported logbook data including year, species, number of animals, and gear type was provided directly from Fisheries New Zealand, National Oceanic and Atmospheric Administration (NOAA, United States), Fiskistofa (Directorate of Fisheries, Iceland) and Hafrannsóknastofnun (Marine and Freshwater Research Institute, Iceland), and Fiskeridirektoratet (Directorate of Fisheries, Norway). Fishing effort data per year was provided by Fisheries New Zealand, Fiskistofa and Hafrannsóknastofnun (Iceland), and Havforskninginstituttet (Norway). For the United States, effort data was provided by Pacific Fisheries Information Network, Western Pacific Fisheries Information Network, Alaska Fisheries Information Network, Gulf States Marine Fisheries Commission, and Atlantic States Marine Fisheries Commission, which included data for each state and territory (including Puerto Rico and the US Virgin Islands), except for Alabama, where permission was not granted to release this data. Fisher-reported cetacean bycatch/interactions per unit effort (“catch”) (CPUEs) per gear type were calculated based on kgs of catch (New Zealand, Norway, United States), number of trips (Iceland lump sucker gillnets), and number of net-nights (number of nets \times soak time) (Iceland cod and other gillnets). CPUE was also calculated for individual species per gear type category when data were sufficient. All fisher logbook CPUEs were calculated using all reports where gear type was specified, regardless of the reported life-status of the animal.

Cetacean bycatch data from observer programs in each of the case study countries were provided directly from the relevant government or research office (New Zealand, Iceland) or gathered from the NOAA official stock assessment reports (United States¹) similar to work conducted by Read et al. (2006) on earlier data. Minimum estimates of annual number of cetaceans caught were calculated from the stock assessment reports only considering data coming directly from observer programs and excluding supplementary data that is available in some reports, such as from strandings. Norwegian “reference fleet” data, which is used to estimate cetacean bycatch in Norwegian waters, were not available for comparison for this study.

To compare the two methods of quantifying bycatch (logbook vs. observer), pairwise *t*-test or Wilcoxon test comparisons between fisher logbook CPUE and observer CPUE were conducted for each gear category and species, where data were sufficient, for New Zealand and Iceland. Since the United States observer bycatch/interaction estimates were available in the form of estimated average number of individuals caught per year, based on 5-year time blocks, this data was compared to the average number of cetaceans caught per year in the fisher logbook data, based on the same 5-year time blocks, also using pairwise *t*-tests or Wilcoxon tests. Where data were sufficient, fisher and observer data were also split into “early time period” and “late time period” categories and compared in the same manner separately.

Additionally, *t*-tests were used to compare “early time period” vs. “late time period” fisher logbook CPUE for each gear category in order to investigate logbook reporting over time in each of the case study countries. All tests were performed using a set alpha of 0.05 in the statistical software R (R Core Team, 2019).

RESULTS

Reported cetacean bycatch/interactions by observers were on average 774% higher than fisher reported bycatch in trawls, 7348% higher in nets and 1725% higher in hook and lines. When broken down by individual countries, the average annual estimated cetacean CPUE based on observer data in New Zealand was 52% higher in trawl, 779% higher in passive netting, and 754% higher in lining compared to the CPUEs based on fisher logbook data (Table 1). In Iceland, the estimated CPUE based on inspector (observer) data was 329% higher in the lumpfish gillnet fishery and 26920% higher in the cod and others (cod+) gillnet fishery compared to CPUEs based on fisher logbook data. For the United States, the mean annual number of individuals estimated as bycatch/seriously injured based on observer data pooled into 5-year time blocks was on average 2696% higher in hook and lines, 1365% in nets, and 1495% in trawl when compared to the mean annual number of individuals in the same 5-year times blocks reported in fisher logbooks (Table 1). For Norway, CPUEs for the 15m+ vessel fishing fleet were calculated based on fisher logbooks for the first time, but there were no available data to compare this to the 15m+ vessel reference fleet. However, for seines ($n = 3$), trap ($n = 1$), and trawl ($n = 13$) gear categories, there were reports in the fisher logbooks that were not detected by the reference fleet (Norway Marine Research Institute, pers comm. 09.03.2021). Further results from statistical comparisons between fisher logbook data and observer data for each case study country are detailed below.

New Zealand

There were nine cetacean species reported as bycatch in the New Zealand exclusive economic zone between 2009 and 2019 in fisher logbooks (Table 2). There were also reports of unspecified dolphin/toothed whales, baleen whales, and beaked whales. New Zealand logbooks specify between the categories of “alive and uninjured,” “alive and injured,” and “deceased.” When combining all reports from all years the percent of individuals reported in each category were 2.1, 17.5, and 80.4% respectively. Reports came from six different gears (trawl, passive netting, lining, other lining, potting, and seine). There were seven cetacean species reported in the observer data, six of which were also reported in the fisher data and one of which was not [Risso’s dolphin (*Grampus griseus*)]. The observer data did not include bycatch records of minke whale (*Balaenoptera bonaerensis*), humpback whale (*Megaptera novaeangliae*) or fin whale (*Balaenoptera physalus*), which were reported in the fisher logbook data, though it did have records of unspecified baleen whales which may account for these species. The observer data consistently covered trawls (25.9–56.1% coverage per year), passive netting (0–10.2% coverage per year), and lining (1.8–11%

¹ <https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessment-reports-species-stock#cetaceans>

coverage per year), and rarely covered the other gears (other lining, potting, and seine). Despite observer coverage in lining, trawl and passive netting, as well as a low coverage in “other lining” and potting, there was no observed cetacean bycatch in any gear type in 2019.

Cetacean catch per unit effort (CPUE) was calculated for trawl, passive netting and lining gear types, as well as for three dolphin species for which the most data were available (common dolphins (*Delphinus delphis*) in trawl gear, Hector’s dolphins (*Cephalorhynchus hectori*) in passive netting gear, and dusky dolphins (*Lagenorhynchus obscurus*) in passive netting gear). The trawl category had the highest total number of individuals reported in fisher logbook data ($n = 202$). The fisher CPUE for trawl fisheries was significantly less than the observer CPUE for all years combined (2009–2019) ($p = 0.028$, $t = -2.16$) (Table 3). Data were also sufficient to split trawl data into an early time period (2009–2014) and a late time period (2015–2019). The fisher logbook trawl CPUE was significantly lower than the observer trawl CPUE for the earlier time period ($p = 0.004$, $t = -4.16$); however, there was no difference between the CPUEs for the later time period ($p = 0.68$, $t = 0.50$). When comparing the fisher logbook trawl CPUE for the early time period to the late time period, there was no significant difference between them ($p = 0.65$, $W = 18$) (Table 4). Comparison of the CPUEs for passive netting yielded similar results, with fisher logbook CPUE being significantly lower than observer CPUE for all years combined (2009–2019, excluding 2011 when there was no observer coverage) ($p = 0.0071$, $t = -3.03$), fisher logbook CPUE being significantly lower than observer CPUE in the earlier time

period (2009–2014, excluding 2011) ($p = 0.003$, $t = -5.34$), and there being no significant difference between the CPUEs in the later time period (2015–2019) ($p = 0.22$, $t = -0.86$) (Table 3). When comparing the fisher logbook CPUE for the earlier time period to the later time period, there was no significant difference between them ($p = 0.72$, $t = -0.38$) (Table 4).

The CPUEs for lining were not significantly different for all years combined (2009–2019, excluding 2010 and 2013 when there was no observer coverage) ($p = 0.43$, $V = 15$) (Table 3). It was not possible to compare the CPUEs for the early time period due to little observer data; however, CPUEs could be compared for the late time period (2015–2019). For the late time period, fisher logbook CPUE was significantly lower than observer CPUE ($p = 0.021$, $t = -2.95$). When comparing the fisher logbook CPUE for the early time period to the late time period, there was no significant difference between them ($p = 0.18$, $t = -1.47$) (Table 4).

The fisher logbook CPUE for common dolphins in trawl gear was significantly lower than the observer CPUE for all years combined (2009–2019) ($p = 0.011$, $t = -2.70$) (Table 5). The fisher logbook CPUE was also significantly lower in the early time period (2009–2014) ($p = 0.002$, $t = -5.05$), but was not significantly lower in the later time period (2015–2019) ($p = 0.49$, $t = -0.032$). The fisher logbook CPUE for Hector’s dolphins caught in passive net gear was also significantly lower than the observer CPUE for all years combined (2009–2019, excluding 2011 when there was no observer coverage) ($p = 0.018$, $t = -2.46$) and significantly lower in the earlier time period (2009–2014, excluding 2011) ($p = 0.012$, $t = 3.59$) (Table 5).

TABLE 1 | Average annual number of individual cetaceans reported as bycatch per year, average annual catch per unit effort (CPUE) based on 100 kg fish caught (New Zealand, Norway, United States), number of trips (Iceland lumpfish gillnet) or net-nights (Iceland cod+ gillnet), coefficient of variance (CV), and 95% confident intervals (CIs) calculated based on fisher logbook data and observer data CPUEs for each country and each gear type for which the average annual number of cetaceans caught was at least 1 animal.

Country	Gear-type	Group	Average number individuals reported per year	Average CPUE per year	Percent increase (%)	CV	CIs
New Zealand	Passive Netting	Fisher	5.1	1.04E-04		0.67	6.4E-05 – 1.5E-04
		Observer	1.7	9.14E-04	+779	0.87	4.2E-04 – 1.4E-03
	Trawl	Fisher	18.4	5.41E-06		0.54	3.7E-06 – 7.1E-06
		Observer	11.7	8.22E-06	+52	0.77	4.5E-06 – 1.2E-05
	Lining	Fisher	2.1	1.37E-05		1.00	4.6E-06 – 1.8E-05
		Observer	1.1	1.17E-04	+754	1.31	1.7E-05 – 2.2E-04
Iceland	Lumpfish gillnet	Fisher	107.8	2.96E-02		0.92	7.8E-03 – 5.2E-02
		Observer	7.7	1.27E-01	+329	0.51	7.5E-02 – 1.8E-01
	Cod+ gillnet	Fisher	54.0	2.92E-04		0.26	2.2E-04 – 3.7E-04
		Observer	30.3	7.89E-02	+26920	0.22	6.2E-02 – 9.6E-02
Norway	Gillnet	Fisher	1.1	2.87E-06		1.22	5.8E-07 – 5.2E-06
	Trawl	Fisher	1.4	1.74E-07		1.28	2.9E-08 – 3.2E-07
United States*	Trawl	Fisher	23.0	2.60E-06		0.31	16.8–29.3
		Observer	368.2	X	+1495	0.49	209.5–526.6
	Net	Fisher	26.7	2.78E-06		0.25	20.9–32.5
		Observer	391.5	X	+1365	0.54	205.3 – 577.9
	Hook and line	Fisher	6.1	6.76E-06		0.09	5.6 – 6.6
		Observer	170.0	X	+2696	0.47	99.3 – 240.8

*United States CV and CIs are based on average number of individuals reported based on 5-year time blocks, not CPUE, due to the observer data being available as raised number of individuals caught per the same time blocks.

TABLE 2 | Cetacean species included in cetacean bycatch/interaction reports from each country, with indication of if they were reported in both fisher logbook and observer data (F + O), fisher logbook data only (F), or observer data only (O).

Country	Common name	Scientific name	Reported in
New Zealand	Bottlenose dolphin	<i>Tursiops truncatus</i>	F + O
	Common dolphin	<i>Delphinus delphis</i>	F + O
	Dusky dolphin	<i>Lagenorhynchus obscurus</i>	F + O
	Hector's dolphin	<i>Cephalorhynchus hectori</i>	F + O
	Killer whale	<i>Orcinus orca</i>	F + O
	Pilot whale	<i>Globicephala</i> spp.	F + O
	Fin whale	<i>Balaenoptera physalus</i>	F
	Humpback whale	<i>Megaptera novaeangliae</i>	F
	Minke whale	<i>Balaenoptera acutorostrata</i>	F
	Risso's dolphin	<i>Grampus griseus</i>	O
Iceland	Harbor porpoise	<i>Phocoena phocoena</i>	F + O
	White-beaked dolphin	<i>Lagenorhynchus albirostris</i>	F + O
	Common dolphin	<i>Delphinus delphis</i>	F
	Risso's dolphin	<i>Grampus griseus</i>	F
	Cuvier's beaked whale	<i>Ziphius cavirostris</i>	F
	Northern bottlenose whale	<i>Hyperoodon ampullatus</i>	F
	Fin whale	<i>Balaenoptera physalus</i>	F
	Humpback whale	<i>Megaptera novaeangliae</i>	F
	Harbor porpoise	<i>Phocoena phocoena</i>	F + O
	Minke whale	<i>Balaenoptera acutorostrata</i>	F + O
Norway	Bottlenose dolphin	<i>Tursiops truncatus</i>	F
	Beluga whale	<i>Delphinapterus leucas</i>	F
	Killer whale	<i>Orcinus orca</i>	F
	Blue whale	<i>Balaenoptera musculus</i>	F
	Harbor porpoise	<i>Phocoena phocoena</i>	F + O
	Atlantic white-sided dolphin	<i>Lagenorhynchus acutus</i>	F + O
	Bottlenose dolphin	<i>Tursiops truncatus</i>	F + O
	Common dolphin	<i>Delphinus delphis</i>	F + O
	Dall's porpoise	<i>Phocoenoides dalli</i>	F + O
	Northern right whale dolphin	<i>Lissodelphis borealis</i>	F + O
United States	Pacific white sided dolphin	<i>Lagenorhynchus obliquidens</i>	F + O
	Risso's dolphin	<i>Grampus griseus</i>	F + O
	Rough-toothed dolphin	<i>Steno bredanensis</i>	F + O
	Beluga whale	<i>Delphinapterus leucas</i>	F + O
	Dwarf sperm whale	<i>Kogia sima</i>	F + O
	False killer whale	<i>Pseudorca crassidens</i>	F + O
	Killer whale	<i>Orcinus orca</i>	F + O
	Pilot whale	<i>Globicephala</i> spp.	F + O
	Sperm whale	<i>Physeter macrocephalus</i>	F + O
	Gray whale	<i>Eschrichtius robustus</i>	F + O
	Humpback whale	<i>Megaptera novaeangliae</i>	F + O
	Fin whale	<i>Balaenoptera physalus</i>	F + O
	Minke whale	<i>Balaenoptera acutorostrata</i>	F + O
	Spotted dolphin	<i>Stenella</i> spp.	F
	Bryde's whale	<i>Balaenoptera brydei</i>	F
	Pygmy sperm whale	<i>Kogia breviceps</i>	O

TABLE 3 | *p*-value results of paired *t*-test/Wilcoxon tests determining if fisher reported CPUE was significantly lower than observer reported CPUE (New Zealand, Iceland) and if fisher reported annual average number of individuals caught based on 5-year time blocks significantly differed from observer reported annual average number of individuals caught based on the same 5-year time blocks (United States) for each gear category where enough data were available.

Country	Gear category	Time period	Years	<i>p</i> -value	
New Zealand	Trawl	All	2009–2019	0.028	
		Early	2009–2014	0.004	
		Late	2015–2019	0.68	
	Passive netting	All	2009–2019 (ex. 2011)	0.007	
		Early	2009–2014 (ex. 2001)	0.003	
		Late	2015–2019	0.22	
		Lining	All	2009–2019 (ex. 2010, 2013)	0.43
	Iceland	Lumpfish gillnet	Early	X	X
			Late	2015–2019	0.021
		Cod+ gillnet	All	2014–2019	0.003
Early			2014–2016	0.006	
United States	Trawl	Late	2017–2019	0.1	
		All	2016–2019	0.001	
		Early	X	X	
	Net	Late	X	X	
		All time blocks	*	0.006	
		Hook and line	All time blocks	*	0.005

Significant *p*-values are in bold.

*United States data was based on average number of individuals caught for the 5-year time blocks 2009–2013, 2010–2014, 2011–2015, 2012–2016, and 2013–2017.

There was not enough observer reported bycatch of Hector's dolphins to compare the late time period. Oppositely, there was no significant difference in the CPUEs for dusky dolphins caught in passive netting for all years combined (2009–2019, excluding 2011 when there was no observer coverage) ($p = 0.28$, $V = 10$) and no significant difference between the CPUEs for the early time period (2009–2014, excluding 2011) ($p = 0.10$, $t = -1.54$) (Table 5). There was not enough observer reported bycatch of dusky dolphins in passive net gear to compare the late time period.

Iceland

There were eight cetacean species reported as bycatch in Icelandic fisher logbooks in the years where reporting could be considered complete (2014–2019) (Table 2). There were also reports of an unspecified dolphin and unspecified medium cetacean. Reports came from three different fishing gear categories (trawl, passive netting, and hook and line). There were 984 individual cetaceans reported as bycatch in all gear combined between 2009 and 2019; however, 647 of these individuals could be included in this study from the lumpfish gillnet fishery (2014–2019) and 216 of these individuals could be included in this study from the “cod

TABLE 4 | Average CPUE and *p*-value results of *t*-tests or Wilcoxon tests comparing fisher logbook CPUE over time for all gear types with sufficient data.

Country	Gear-type	Group	Years	Average CPUE	<i>p</i> -value
New Zealand	Passive Netting	Early	2009–2014	9.3487E-05	0.72
		Late	2015–2019	0.000111538	
	Trawl	Early	2009–2014	6.11667E-06	0.65
		Late	2015–2019	0.000004568	
	Lining	Early	2009–2014	6.92333E-06	0.18
		Late	2015–2019	1.63536E-05	
Iceland	Lumpfish gillnet	Early	2014–2016	0.011307951	0.14
Late	2017–2019	0.047988214			
Norway	Gillnet	Early	2011–2015	9.71898E-07	0.08
		Late	2016–2019	5.23959E-06	
	Trawl	Early	2011–2015	9.75392E-08	0.9
		Late	2016–2019	2.70052E-07	
United States	Trawl	Early	2009–2014	3.1251E-06	0.11
		Late	2015–2019	1.47519E-06	
	Net	Early	2009–2014	2.53633E-06	0.59
		Late	2015–2019	3.06044E-06	
	Hook and line	Early	2009–2014	6.41707E-06	0.17
		Late	2015–2019	9.2772E-06	

and others” (cod+) gillnet fishery (2016–2019). There were only two cetacean species reported in the inspector (observer) data [harbor porpoise (*Phocoena phocoena*) and white-beaked dolphin (*Lagenorhynchus albirostris*)]. Cetaceans were only observed by inspectors in two gillnet categories: lumpfish gillnetting

(0.74–2.82% coverage per year), and cod and other (cod+) gillnetting (0.15–0.25% coverage per year). There is also some inspector coverage on bottom trawls and long-lines (ICES, 2020); however, there has never been cetacean bycatch reported (Iceland Marine and Freshwater Research Institute, unpub. data). Cetacean catch per unit effort was calculated separately for each of the two gillnet fisheries that had inspector coverage (lumpfish and cod+). Inspectors started reporting marine mammal bycatch in the lumpfish fishery in 2014 and the cod+ fishery in 2016, therefore only data from these years onward could be used in CPUE comparisons. The fisher logbook CPUE for the lumpfish gillnet fishery was significantly less than the inspector reported CPUE for all years combined (2014–2019) (*p* = 0.003, *t* = -4.67) (Table 3). Data was also sufficient to split the lumpfish gillnet data into an early time period (2014–2016) and a late time period (2017–2019). The fisher logbook CPUE was significantly lower than the inspector CPUE for the early time period (*p* = 0.006, *t* = -9.27); however, there was no significant difference between the CPUEs for the late time period (*p* = 0.10, *t* = -1.94). When comparing the fisher logbook CPUE for the early time period to the late time period, there was no significant difference between them (*p* = 0.14, *t* = -2.17) (Table 4).

The fisher logbook CPUE was also significantly lower than the inspector reported CPUE for the cod+ gillnet fishery for all years combined (2016–2019) (*p* = 0.001, *t* = -9.29) (Table 3). There were not enough years of data to compare an early and late time period of the fisher and observer CPUEs or to compare the fisher logbook CPUE over time.

TABLE 5 | *p*-value results of paired *t*-test/Wilcoxon tests determining if fisher reported CPUE is significantly lower than observer reported CPUE (New Zealand) and if fisher reported annual average number of individuals caught based on 5-year time blocks is significantly lower than observer reported annual average number of individuals caught based on the same 5-year time blocks (United States) for the most commonly reported species in specific gear categories.

Country	Gear category	Species	Time period	Years	<i>p</i> -value
New Zealand	Trawl	Common dolphin (<i>Delphinus delphis</i>)	All	2009–2019	0.011
			Early	2009–2014	0.002
			Late	2015–2019	0.49
	Passive netting	Hector’s dolphin (<i>Cephalorhynchus hectori</i>)	All	2009–2019 (ex. 2011)	0.018
			Early	2009–2014 (ex. 2011)	0.012
			Late	X	X
	Passive netting	Dusky dolphin (<i>Lagenorhynchus obscurus</i>)	All	2009–2019 (ex. 2011)	0.28
			Early	2009–2014 (ex. 2011)	0.1
			Late	X	X
United States	Net	Bottlenose dolphin (<i>Tursiops truncatus</i>)	All (ex. 2012–2016 mean)	*	0.04
		Common dolphin (<i>Delphinus delphis</i>)	All (ex. 2012–2016 mean)	*	0.0004
		Harbor porpoise (<i>Phocoena phocoena</i>)	All (ex. 2011–2015 mean)	*	0.008
		Humpback whale (<i>Megaptera novaeangliae</i>)	All	*	0.00002**
		Pilot whale (<i>Globicephala</i> spp.)	All (ex. 2011–2015 mean)	*	0.32
	Trawl	Atlantic white-sided dolphin (<i>Lagenorhynchus acutus</i>)	All	*	0.02
		Bottlenose dolphin (<i>Tursiops truncatus</i>)	All (ex. 2011–2015 and 2012–2016 mean)	*	0.002
		Common dolphin (<i>Delphinus delphis</i>)	All (ex. 2012–2016 mean)	*	0.00007
	Hook & Line	False killer whale (<i>Pseudorca crassidens</i>)	All	*	0.009
		Pilot whale (<i>Globicephala</i> spp.)	All (ex. 2011–2015 mean)	*	0.0002

Significant *p*-values are in bold.

*United States data was based on average number of individuals caught for the 5-year time blocks 2009–2013, 2010–2014, 2011–2015, 2012–2016, and 2013–2017.

***p*-value showing mean annual humpback whale bycatch/interaction was significantly higher in the fisher logbook data compared to the observer data.

Norway

There were six cetacean species reported by Norwegian fishing vessels 15 m or greater (15m+) between 2011 and 2019 (Table 2). The reports came from five different gear types (Danish seine, purse seine, trawl, trap, and gillnet). There were only two species reported as bycatch by the 15m+ reference fleet (harbor porpoise and minke whale) and, additionally, reports simply labeled as “dolphin.” The reference fleet reports did not include orca (*Orcinus orca*), beluga (*Delphinapterus leucas*), blue whale (*Balaenoptera musculus*), or bottlenose dolphin (*Tursiops truncatus*) which were included in the fisher logbook data. Reports from the reference fleet were from two different gear categories (hook and line and gillnet). There was no available data on the effort of the 15m+ reference fleet, therefore it was not possible to statistically compare the fisher logbook CPUEs to the reference fleet CPUEs for these gear categories. However, it could be noted that there was cetacean bycatch reported in the fisher logbook data in the seine, trawl, and trap gear categories that were not detected by the reference fleet, though the fleet is covering these gear categories (Norway Marine Research Institute, pers. comm.). Fisher logbook gillnet and trawl CPUEs could be compared between an early time period (2011–2015) and a late time period (2016–2019) for each gear separately. Both the gillnet and trawl CPUEs did not differ significantly between the two time periods ($p = 0.08$, $W = 3$; $p = 0.90$, $W = 9$ respectively) (Table 4).

United States

There were 21 different cetacean species reported as bycatch/seriously injured in fisher logbooks in the United States between 2009 and 2017, matching the dates for which observer reports were available (Table 2). There were also reports of unidentified baleen whales, small cetaceans (porpoise or dolphin), toothed whales and beaked whales. The logbook reports came from four broad gear categories: trawl, pot and trap, hook and line, and net. The net category included all set nets and seine gear. There were 21 species reported as bycatch between 2009 and 2017 in observer data reported in the NOAA Marine Mammal Stock Assessment Reports². However, in the fisher logbook data, pilot whales were not split into the two known species (*Globicephala melas* and *Globicephala macrorhynchus*) so these species were also combined in the observer data (taking the total down to 20). Fisher logbook data included spinner dolphins (*Stenella longirostris*) and Bryde’s whales (*Balaenoptera edeni*) which were not in the observer reports. The observer reports included pygmy sperm whales (*Kogia breviceps*) which were not included in the fisher reports; however, the unidentified toothed whales in the fisher reports may account for this species.

United States observer bycatch data is reported as the mean annual number of individuals of each species caught based on the most recent 5 years of data. For comparison, the same means were calculated using the fisher logbook data for the same five 5-year time blocks (2009–2013, 2010–2014, 2011–2015, 2012–2016, and 2013–2017) for net, trawl, and hook and line gears. The mean

number of cetaceans reported as bycatch annually in the fisher logbook data was significantly lower than the observer estimates for the net, trawl and hook and line gear types ($p = 0.009$, $t = -3.9$; $p = 0.006$, $t = -4.4$; $p = 0.005$, $t = -4.6$ respectively) (Table 3).

CPUEs were calculated for the fisher logbook data and used to compare reporting over time. Data was sufficient to compare an early time period (2009–2014) with a late time period (2015–2019) for the net, trawl, and hook and line categories. There was no significant difference between the two time periods for any of the categories ($p = 0.59$, $t = -0.55$; $p = 0.11$, $t = 1.93$; $p = 0.17$, $W = 7$ respectively) (Table 4).

Comparisons were also made between the mean annual number of individuals of the most commonly reported species in the fisher logbook data (species reported in five or more years between 2009 and 2017), excluding means from time blocks where the observer report was not available. These were bottlenose dolphin (excluding 2012–2016 mean), common dolphin (excluding 2012–2016 mean), harbor porpoise (excluding 2011–2015 mean), humpback whale, and pilot whale spp. (excluding 2011–2015 mean) in the net category; Atlantic white-sided dolphin (*Lagenorhynchus acutus*), bottlenose dolphin (excluding 2011–2015 and 2012–2016 means) and common dolphin (excluding 2012–2016 mean) in the trawl category; and false killer whales (*Pseudorca crassidens*) and pilot whale spp. (excluding 2011–2015 mean) in the hook and line category.

In the net category, harbor porpoise, common dolphin, and bottlenose dolphin mean annual numbers of individuals reported as bycatch/serious injury were significantly lower in the fisher logbook data when compared to the estimated annual means from the observer data ($p = 0.008$, $t = -4.9$; $p = 0.0004$; $t = -14.0$; $p = 0.04$, $t = -2.6$ respectively) (Table 5). There was no significant difference between the mean annual number of pilot whale spp. calculated from fisher logbook data and the mean annual number calculated from observer data ($p = 0.32$, $t = 1.17$). The mean annual number of humpback whales calculated from fisher logbook data was significantly greater than the mean annual number estimated from observer data ($p = 0.00002$, $t = 20.7$). In the trawl category, the mean annual numbers of individuals reported as bycatch/serious injury in the fisher logbook data were significantly less than the estimated annual means from the observer data for all three species (Atlantic white-sided dolphin: $p = 0.02$, $t = -2.9$; bottlenose dolphin: $p = 0.002$, $t = -16.4$; common dolphin: $p = 0.00007$, $t = -24.6$) (Table 5). In the hook and line category, the mean annual numbers of individuals reported as bycatch/serious injury in the fisher logbook data were significantly less than the estimated annual means from the observer data for both species (false killer whale: $p = 0.009$, $t = -7.3$; pilot whale spp.: $p = 0.0002$, $t = -17.8$) (Table 5).

DISCUSSION

Out of the 30 countries with the largest fishing industries in the world (FAO, 2018), 12 were determined to have some form of cetacean bycatch/interaction reporting legislation. The legislation

²<https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessment-reports-species-stock>

ranged from very minimal (only harbor porpoises covered by law in Sweden and Finland and very little reporting) to well established (clear legislation and logbook reporting including all species e.g., in United States and New Zealand). Of these 12, ten of the countries were identified as also having some level of onboard observer coverage which they use to calculate cetacean bycatch/interaction CPUE, which varies by percent coverage and fisheries monitored (e.g., Hanrahan and Pelrine, 1997; Okuda et al., 2017; Muñoz et al., 2018; ICES, 2020; Ministry for Primary Industries New Zealand, 2020; National Marine Fisheries Service, 2020; Australian Fisheries Management Authority, 2021). Finland does not have any form of observer program (ICES, 2020) and no information could be found for South Korea, other than that all landed bycatch is verified by an inspector (South Korea Ministry of Oceans and Fisheries, pers. comm., 08.05.2020).

This study provides a broad, quantitative overview of the global issue of under-reporting of cetacean bycatch/interactions in fisher logbooks compared to observer programs using case studies of entire countries. Likely due to the difficult nature of accessing and/or compiling datasets for different countries, under-reporting of cetacean bycatch/interactions has not been investigated in this manner previously. When looking generally at the differences between fisher logbook and observer data from New Zealand, United States, and Iceland, the average bycatch of cetaceans per year (dead or alive) was underestimated by anywhere between 52 and 26920% for the three major gear types which could be examined (trawl, net, and hook and line). The differences were significant when combining data for all available years for all gear types that could be examined in each country, except for the lining category in New Zealand, despite an over 750% increase in CPUE calculated from observer data. Low observer coverage and zeros in the data may have affected the results in this case, particularly since fisher logbook CPUE was significantly lower than observer CPUE in the late time period comparison. Under-reporting of harbor porpoise bycatch in the gillnet fishery in Iceland was quantified previously through a questionnaire, which determined logbook data underestimated bycatch by a ratio of approximately 1:26 (Ólafsdóttir, 2010). Quantified cetacean under-reporting in logbooks has not been published for fisheries in the other case study countries. In addition, CPUE of cetaceans in Norway's 15m+ fishing fleet, though small, was quantified using logbook data for the first time. This determined that there is some amount of cetacean bycatch in Norway going unaccounted for that is likely underestimated given the trend in the other countries with well-developed fishing industries.

For cases where it was possible to split data into both early and late time periods for separate comparisons (trawl and passive netting in New Zealand, lumpfish gillnet in Iceland), in all cases the fisher logbook CPUEs were significantly lower than the observer CPUEs for the early time period but there were no significant differences between them in the late time period. We considered if this could be an indication that fisher reporting was increasing over time in these fisheries; however, when we compared the fisher logbook CPUEs from the early time period to the late time period there was no significant

differences and therefore no evidence for this. The most likely explanation is that small sample sizes and zeros in the data from late time periods affected the results. For example, observer CPUE in 2019 in New Zealand was zero for all gear types and Fisheries New Zealand could not provide an explanation for this. The logbook data from fishers could be a very valuable tool for gaining insight into cetacean bycatch and interaction with fishing gear; however, given the overall stark differences in reporting in logbooks versus estimations of bycatch calculated from observer data, there is vast room for improvement in logbook reporting if it is to still be considered a useful practice. The fact that the three countries for which comparisons could be made between cetacean bycatch/interaction data reported in fisher logbooks and bycatch estimates calculated from observer data differ in geographic location, cetacean species and size of exclusive economic zone [New Zealand: 1.2 million square nautical miles (Sea Around US, 2016), US: 3.4 million square nautical miles (NOAA, 2011), Iceland: 0.22 million square nautical miles (FAO, 2011)], overall the analysis of each country showed significant under-reporting, suggesting the case is likely similar in many other countries with well-developed commercial fishing industries, particularly using trawl, net, and hook and line gears. There was, however, variation in the CPUEs per gear type between each of the case study countries. This variation may be due to differences in number of cetacean species and overall density of cetaceans, the vulnerability of different cetacean species to bycatch and/or differences in observer coverage. Due in part to the different metrics of effort used to calculate CPUEs in each country, and the need to use average number of animals caught in the United States case study, the case study countries could not be directly compared to each other in the study to investigate the differences further.

One of the most likely causes of under-reporting of cetacean bycatch, even in mandatory logbooks, is the concerns fishers have of punishment or negative consequences to the fishing industry. For example, in Atlantic Canada, one-quarter of target participants for interviews discussing long-line bycatch refused the interview based on concerns of consequences and general distrust of the researchers (Carruthers and Neis, 2011). Similarly, in Iceland, nearly half of questionnaire respondents refused to answer a question about why they would not report cetacean bycatch or responded they were concerned about the potential negative consequences (Basran and Rasmussen, 2021). Particularly when endangered or critically endangered species are involved in bycatch incidents (such as the North Atlantic right whale), changes to or closures of fisheries can occur due to the serious implications to the stock if even one individual is removed (e.g., Merrick et al., 2001). Significant under-reporting in logbooks was also demonstrated for several different individual species in separate gear types in both New Zealand and the United States. These concerns over consequences, paired with the fact that filling out bycatch reports is extra work, usually with no reward, gives fishers very little incentive to report. Though, in the aforementioned 12 countries, not reporting cetacean bycatch is a punishable offense by law, violations are virtually impossible to track without independent observers and inspections. Differing legislature and different interpretations of

the laws by fishers may also influence under-reporting of cetacean bycatch/interactions. For example, in Iceland, the wording of the law lacks clarity on the matter of what life status of the animals need to be reported. Results from a questionnaire targeting Icelandic fishers revealed that those reporting cetaceans in their logbooks are only doing so if the animal is dead (Basran and Rasmussen, 2021), though fisheries scientists believe all catches, even if released alive, should be reported (Iceland Marine and Freshwater Research Institute. pers. comm. 03.12.2020). A similar issue arises in Norway, where the logbooks are designed to report landed catch, including bycatch of cetaceans, but it is not required for fishers to land cetacean bycatch (Norway Directorate of Fisheries, pers. comm. 14.07.2020). This suggests that even though the law states fishers should report all cetacean bycatch, not only will they not report injured animals, but they are also unlikely to report all deceased animals if they did not land them.

Though bycatch/interaction under-reporting is likely an issue for virtually all cetacean species, it has been noted that it is particularly an issue for large whale bycatch/interactions given their rare and difficult-to-observer nature (IWC, 2011). Most of the reports from all four case study countries involved dolphins and porpoises. Given that these species are the most likely to drown when they are caught in fishing gear, it can be suspected that fishers may be the most inclined to report these events. Both small whale and, particularly, large whale interactions with gear are less likely to be witnessed given that these species may be able to break away from entangling gear, meaning many incidents will go unreported (Robbins and Mattila, 2001; IWC, 2011). This is particularly true for pot/trap and gillnet gears which are left in the water, unattended, for longer periods of time and are well known for entangling whales (Johnson et al., 2005). For example, in Iceland, a study based on scarring estimated that a minimum of 25% of humpback whales have been entangled previously (Basran et al., 2019) and additionally 15% of questionnaire respondents witnessed humpback whales interact with their fishing gear (Basran and Rasmussen, 2021). Furthermore, there have been reports of humpback whale deaths due to entanglement in interviews with fishing vessel captains (Basran and Rasmussen, 2021), and based on examination of stranded animals (Víkingsson et al., 2004, 2005; Víkingsson, 2011). Despite this evidence, there was only one humpback whale reported as bycatch in the Icelandic fisher logbooks between 2009 and 2019 (Iceland Marine Research Institute, unpub. data). Similarly in the Gulf of Maine, United States, it was estimated based on scarring that a minimum of 50% of humpback whales (Robbins and Mattila, 2004; Robbins, 2009) and 83% of North Atlantic right whales have been entangled previously (Knowlton et al., 2012); however, there were only 32 humpback whales (averaging 2.9 individuals reported per year) and no North Atlantic right whales reported in the logbooks (2009–2019) despite the law being clear about reporting all interactions leading to injury or death, and the injury category including a sub-code “released trailing gear.” Though many of the incidents may have gone unwitnessed, it is likely a number of them were witnessed but unreported, as demonstrated by the questionnaires and interviews previously conducted in Iceland.

Due to the unreliability of logbook reporting, observer programs are needed to estimate cetacean bycatch/interaction with fishing gear more accurately; however, there are barriers to observer programs being widely used in all fishing nations. Firstly, observer programs can be very costly, with the latest report from the United States stating it costed 79.5 million USD for observer coverage in 54 fisheries (National Marine Fisheries Service, 2020) and therefore it is unlikely that they will be implemented in all fisheries globally that are high-risk of catching cetaceans. Additionally, sufficient observer effort must be used in order to produce accurate estimates. A computer simulation, assuming unbiased observer programs and requiring 90% of the simulated observer samples to estimate bycatch within 10% of the actual number, estimated that coverage must be at least 20% to accurately estimate bycatch of common species and 50% to accurately estimate bycatch of rarer species (Babcock et al., 2003). The observer coverage in New Zealand was an average of 44% per year for trawl gear, which should be sufficient for accurate estimates; however, averaged 5% for both passive netting and lining gears, suggesting the observer estimates could be under-representing the total catch of cetaceans, particularly for cases involving large whales or rare species (Read et al., 2006), given the low coverage. This could be of particular concern for the endangered Hector's dolphin which was most reported in passive netting gear. Observer coverage in Iceland only averaged 2% for the lumpfish gillnet fishery and 0.2% for the cod+ gillnet fishery meaning that the observer coverage is likely not enough to accurately estimate bycatch of cetaceans. Given the vast expanse, complicated management, and diversity of the United States fishing industries, estimating the overall observer coverage for each gear category was not possible in this study. Individual fisheries have anywhere from zero observer coverage (such as several gillnet and seine fisheries that are classified as low incidence of cetacean mortality (“Category III”³) to 100% observer coverage [such as the shallow-set longline fishery in Hawaii (NOAA, 2018)]. In Norway, a “reference fleet” is used for bycatch estimation, where vessel operators are paid a small fee for accurate reporting (Clegg and Williams, 2020). In addition, the Norwegian Directorate of Fisheries maritime service has onboard inspectors which assess bycatch among other things (Fiskeridirektoratet, 2017). Cetacean bycatch has not been investigated or publicly reported on for the Norway large vessel/high seas reference fleet (for which it is mandatory for all vessels to report cetacean bycatch), and neither these data, nor data from maritime service inspectors, were available for this study. There were 16 vessels in the large vessel reference fleet in 2019 using bottom gillnet, longline, demersal seine, purse seine, bottom trawl and shrimp trawl gear types (Clegg and Williams, 2020).

It is important to consider that differences in the training and duties of observers may affect the resulting cetacean bycatch estimates. In New Zealand, the United States, and Iceland, the main observer programs collect data on fishing activity,

³<https://www.fisheries.noaa.gov/national/marine-mammal-protection/list-fisheries-summary-tables#table-1-category-iii>

fish catch (including biological measurements and sample collection), fish discards, and marine mammal, seabird, and reptile bycatch (Fiskistofa, 2010; Christensen-Dalsgaard et al., 2019; Ministry for Primary Industries New Zealand, 2020; NOAA Fisheries, 2021b). Additionally, New Zealand's Department of Conservation and Alaska's Marine Mammal Observer Program collect dedicated protected species or marine mammal data through observers (Department of Conservation New Zealand Government, 2020a,b; NOAA Fisheries, 2021a). It has been previously determined that observers that have other duties in addition to recording marine mammal bycatch, under-report bycatch (therefore the bycatch estimates are negatively biased) (Bravington and Bisack, 1996). Randomization of observer coverage is also important to consider when estimating bycatch. In the case of Iceland, it is known that the observer coverage is often not random but based on vessels who have had unusual data or low compliance with fishing laws (Christensen-Dalsgaard et al., 2019). Additionally, using landed catch as the metric of effort, as is done in the United States, relies on accurate reporting of the catch, and if landed catch is under-estimated, marine mammal bycatch estimates could be positively biased (Bravington and Bisack, 1996).

RECOMMENDATIONS AND CONCLUSION

Though, in theory, bycatch reporting in mandatory fisher logbooks could be a cost-effective, scientifically valuable way to monitor cetacean bycatch, results from this study showed significant under-reporting and support that logbooks are not reliable. In all four case study countries, fisher logbooks did contain more cetacean species than observer data, which may be an indicator that fishers have more information, particularly about rare events, than observer programs can detect without very high coverage. However, fishers may have difficulty accurately identifying species (e.g., Stoller, 2020) and there is currently no widely used system in place, such as electronic monitoring, to verify the reports in fisher logbook data. Given this, it should be carefully considered if the use of such logbooks should be continued or implemented in the future. If logbook use is to continue, it is recommended that clarification of reporting laws would be a first step to improving logbook reporting. Secondly, countries could consider introducing simple reporting of cetacean bycatch/interactions using a mobile phone app where fishers could pre-fill their vessel and fishing gear information and, in the case of cetacean bycatch/interaction, open the app and take a picture or video of the event as supplementary material for the report. A reporting app is likely to be more successful on larger commercial vessels with several crew members, of which one could have time to record the incident, opposed to small vessels with one or few crew members. Though this does not address fishers' concerns over repercussion for reporting, it may increase reporting from those who find their current system to be a hassle.

Another way to estimate cetacean bycatch is by using a "reference fleet," where the vessels are compensated for reporting.

This is the strategy used in Norway, and fisheries scientists there believe their reference fleet program yields them accurate bycatch data (Norway Marine Research Institute, pers. comm., 11.12.2019). However, biases in data from a select set of vessels should be considered before choosing to use a reference fleet opposed to other monitoring methods.

We recommended that the most viable option to collect cetacean bycatch data is to equip more fishing vessels with electronic monitoring cameras, as has already been tested in the United States and New Zealand, as well as other countries with bycatch reporting legislation (Australia, Canada, and Sweden), which could lower the cost and improve the coverage of bycatch observation compared to observer programs (Course et al., 2020; van Helmond et al., 2020), as well as improve the accuracy of bycatch estimation compared to fisher logbooks. In Denmark, it was determined that, compared to their observer programs, the use of electronic monitoring was 6.7 times less expensive while likely providing more accurate results than those from general fisheries observer programs where the observers have several jobs onboard (Kindt-Larsen et al., 2012). The cameras monitoring harbor porpoise bycatch were shown to be effective and reliable in trials in gillnet fisheries, where it was noted that they were able to capture bycatch that fell out of the net before it made it onboard (Kindt-Larsen et al., 2012). If the use of mandatory logbooks is to continue in certain fisheries, the use of monitoring cameras may improve reporting through the "observer effect" (e.g., Burns and Kerr, 2008; Porter, 2010; van Helmond et al., 2020), where the accuracy of fisher-reported data greatly increases when there is a way to verify it. Therefore, even if the cameras were to malfunction or not have the ability to identify all bycatch, or if only some of the footage is reviewed as verification, the fisher reports should be a more reliable source of information (Course et al., 2020). This has been shown in Australia, where logbook reporting of marine mammal bycatch significantly increased in the gillnet hook and trap sector of a scalefish and shark fishery after implementation of camera monitoring (Emery et al., 2019). Offering some compensation to fishers for turning in accurate reports could be considered in conjunction with camera monitoring to provide incentive to fishers to support the program. If an annual check of cetacean bycatch from the video footage closely matched the logbooks, then the vessel could be compensated in some way, such as a rebate on mandatory fishing license and operation fees or an additional share of the fishing quota. This could be a way to build a better relationship between fishers and scientists and gather accurate bycatch information.

Under-reporting of cetacean bycatch/interaction in fisher logbooks, despite reporting legislation, was clearly quantified for separate gear types for the first time in the case studies presented here, by comparing these data to data from established observer programs. This issue is a detriment to fisheries and cetacean population management. Given the high costs of observer programs and the suggestion that some fishers/fisheries express concerns for having an observer on board for health, safety and financial reasons (e.g., Hulac, 2020; Moore, 2020 – National Fisherman – 25.02.2020), electronic monitoring could be a viable

option to eliminate the need for many observers onboard vessels and provide an intermediate solution, balancing the views of government, scientists and fishers, in addition to gathering more accurate data in an unbiased manner. Electronic monitoring can be used in conjunction with logbook reporting as a way to improve and verify reports or could be considered to replace logbook reporting altogether.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: The authors of this article were granted data from government agencies and research institutes upon request, with the stipulation not to share this data with any third-parties. The authors can provide information on how to request this same

data to interested parties. Requests to access these datasets should be directed to CJB.

AUTHOR CONTRIBUTIONS

CJB and GMS compiled the data and wrote the manuscript. CJB analyzed the data. Both authors contributed to the article and approved the submitted version.

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