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Estimates of humpback (Megaptera novaeanglia), minke (Balaenoptera acutorostrata) and killer (Orcinus orca) whale fishing gear interactions in Norwegian fisheries suggest low anthropogenic mortality

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Estimates of humpback (*Megaptera novaeanglia*), minke (*Balaenoptera acutorostrata*) and killer (*Orcinus orca*) whale fishing gear interactions in Norwegian fisheries suggest low anthropogenic mortality

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Key words: Humpback whale, minke whale, killer whale, bycatch, purse seine, marine mammals, fishing gear interactions, anthropogenic mortality

Abbreviations

CV	Coefficient of variation
CI	Confidence interval, always 95% unless otherwise noted
LOA	Length overall
NSS	Norwegian spring spawning (herring)
PBR	Potential Biological Removal
SSU	Sea Surveillance Unit
CG	Coast Guard
HSRF	High Seas Reference Fleet
IMR	Institute of Marine Research (in Norway)
BCa	Bias-Corrected and Accelerated

ABSTRACT

Electronic fish logs from reference vessels and fishery inspector logbooks were used to estimate fishing gear interaction rates for humpback (*Megaptera novaeangliae*), minke (*Balaenoptera acutorostrata*) and killer (*Orcinus orca*) whales in Norwegian pelagic fisheries from 2010 to 2020. Estimated rates were applied to fisheries data to estimate fleet-wide non-observed totals. Reference fleet data indicated that there were two minke whale catches, one taken in a trawl and one on a longline. Data from both sources indicated that there were no cetacean entanglements in Danish seines. The fishery inspector logbooks indicated that entrapments of humpbacks and killer whales occurred infrequently in purse seine fisheries, but with a large peak in 2017. Estimates showed that in an 11-year period, a total of 77 humpback whales (95% confidence interval CI 43 – 177) and 121 killer whales (95% CI 75 – 232) were entrapped in purse seines, with an estimated mortality of 5% (CV 0.69, 0.0% – 11.8%) and 6% (CV 0.48, 95% CI 0.3% – 11.9%), respectively. Estimates also showed that in a 10-year period, 12 and 45 minke whales (95% CI 0 – 36, 0 – 139) were bycaught on longlines and trawl, respectively. The average yearly mortality rates over the study period were thus approximately 0.67 killer whales, 0.35 humpback whales and 5.7 minke whales per year. Given the Potential Biological Removal sustainability limits of 98 humpbacks, 161 killer whales and 1,498 minke whales per year, it may be concluded that the average yearly mortality incurred to these whale populations in Norwegian waters by Norwegian pelagic fisheries does not constitute a significant risk to either of these species. The 2017 peak was most likely caused by the dynamic Norwegian Spring Spawning herring (*Clupea harengus*) stock overwintering in narrow fjords, causing a substantial spatial and temporal overlap between whales feeding and fishermen operating purse seines.

INTRODUCTION

Fisheries bycatch, defined as the unintentional catch of non-targeted species, is currently the most severe threat to marine mammals globally (Read et al., 2006) and threatens several populations of cetaceans with immediate extinction (Collins et al., 2010; Weir et al., 2011; Knowlton et al., 2012; Jaramillo-Legorreta et al., 2019; Roberts et al., 2019). Most of the global marine mammal bycatches are caused by different forms of gillnets (Read et al., 2006; Reeves et al., 2013; Brownell Jr et al., 2019), but the use of purse seines on mixed schools of small cetaceans and yellowfin tuna (*Thunnus albacares)* in the eastern tropical Pacific has demonstrated that this type of fishing gear also has the potential to kill large numbers of cetaceans (Perrin, 1968; Perrin, 1969). However, in other areas, and globally, purse seines are regarded as having a lower risk of catching marine mammals compared with static gear such as gillnets (Lewison et al., 2004; Wise et al., 2007).

In Norway, purse seines constitute the main fishing gear used for harvesting Norwegian Spring Spawning (NSS) herring (*Clupea harengus*) on the spawning and wintering grounds. The spawning grounds are off the Norwegian coast between 62^o and 69^o N. The wintering grounds are typically further north, between 69^o and 71^o N. When purse seine fisheries occur in these offshore waters, close interactions with cetaceans are rare, although feeding aggregations of humpback (*Megaptera novaeangliae*) and killer whales (*Orcinus orca*) at herring schools in Northern Norway have been observed (Jourdain and Vongraven, 2017). However, in the period 2012 – 2018, the NSS herring changed wintering grounds and congregated in a number of sheltered fjords in Northern Norway. Shifts in herring wintering grounds typically occur in years when the first time/repeat spawner ratio peaks (Huse et al., 2010). This enormous biomass of herring (the spawning stock is about four million metric tons, (Salthaug et al., 2020), concentrated in a restricted area, attracted large numbers of humpback and killer whales. During that time, and in these narrow fjords, interactions between large cetaceans and purse seine fisheries were frequent. In 2019, the NSS herring again shifted wintering grounds to more open waters, and the frequent interactions between cetaceans and purse seine fisheries ceased. Recently, it has also been discovered that some humpback whales may not undertake their seasonal southward migration to lower latitudes at all, and instead spend the entire year in North-Atlantic waters (Ramm, 2020). It is possible that a prolonged presence in Norwegian coastal waters throughout the year may expose them to risk of entanglements in fisheries that they previously avoided by leaving the area.

In this article, we account for the incidental entrapment, entanglement or bycatch (henceforth referred to collectively only as "bycatch") of cetaceans in Norwegian pelagic fisheries by large vessels (length overall LOA of 15 meters or more) with an emphasis on humpback and killer whales bycaught in seine nets, and minke whales bycaught on longlines and in trawls. The post-incident response conducted by the coast guard, fishery inspectors or fishermen themselves, to release humpback and killer whales bycaught in seine nets is described. Bycatch rates and associated mortality rates are estimated and scaled up to total bycatch and mortality estimates using fishery data. Finally, estimates are compared against the Potential Biological Removal (Wade, 1998) for the relevant species.

The abundance estimates for humpback, minke and killer whales in the North-East Atlantic are 10,708 animals (CV 0.38, 95% CI 4,906 – 23,370), 104692 animals (CV 0.172, 95% CI 74,915 -146,304 and 15,056 animals (CV 0.29, 95% CI 8,423 – 26,914), respectively. These estimates are based on multi-year Norwegian shipboard surveys from 2014 – 2018 (Leonard and Øien, 2020). Killer whales are resident in Norwegian waters throughout the year and follow the migration of herring (Similä et al., 1996; Vogel, 2020). Humpback and minke whales are present on their feeding grounds in Norwegian waters from late spring to early winter, when they depart to start their long journeys to breeding grounds in lower latitudes. Humpbacks on their southward migrations from the Barents Sea to lower latitudes may stop on their way to feed on wintering herring before they resume their southward migration.

2 METHODS

2.1 Data collection and preparation

Data on all pelagic fishing operations conducted by large vessels were obtained from the Norwegian Directorate of Fisheries. A fishing operation refers to any activity associated with using a single fishing gear to catch fish, e.g. the towing of a trawl, the deployment of a seine net or the use of longlines. Since 2011, large fishing vessels operating in Norway have been required to electronically log all fishing activities. These electronic logbooks are highly detailed and include positional data as well as information on the type and number of fishing gears used, and the duration and depths they were used at. Catch data are available from before 2011 from fish tickets, but these are *landing* data and contains much coarser gear and position information.

Bycatch data was obtained from three sources:

1) Inspector logbooks – fishery inspectors from the Sea Surveillance Unit (SSU), a subdivision of the Directorate of Fisheries, stay on fishing vessels for up to the whole duration of a fishing trip. The duties of the inspector include making sure that the vessel operates in a legal manner and to document bycatches, discards and other potential code violations. Inspectors also record sightings of marine mammals and in particular, marine mammal entanglements in fishing gear. In addition to on-board inspectors, the SSU also operates a roaming vessel M/S Rind that patrols the Norwegian coastline, performing unscheduled and opportunistic inspections. Coast guard (CG) vessels may also undertake fishery inspections opportunistically. The CG and the SSU cooperate closely, and both regularly send copies of their logbooks to the Institute of Marine Research (IMR).
2) Entanglement records maintained by the Norwegian Directorate of Fisheries. Since 2016, following the aforementioned large and unexpected increase in the number of humpback and killer whale entanglements in purse seine fisheries in the northern parts of Norway, all Norwegian fishing vessels have been required to report marine mammal bycatches to the Directorate.
3) High Seas Reference Fleet (HSRF) data. The HSRF is a group of about 30 concurrent vessels, chosen to be as representative as possible for large fishing vessels in all of Norway (Clegg and Williams, 2020). Since 2006, the HSRF has reported highly detailed fishery data to the IMR, similar to the electronic logbooks described above. However, this reporting specifically includes marine mammal bycatches, and is subject to a much stricter quality control.

Bycatch records from these three sources were used to collate a complete record of interactions between cetaceans and pelagic fishing gears. The final data set contained the dates, GPS coordinates, gear type, species and number of animals involved, the outcome for those animals (whether they survived the interaction or not, if this could be ascertained), as well as a short description of how the incident occurred, and how the whales were ultimately released from the fishing gear (where applicable). In several cases, bycatches were also documented with pictures and/or videos. Data from all sources were cross-referenced to identify and merge any duplicate entries.

2.2 Estimating bycatch rates and totals

Bycatch rates were calculated in slightly different ways, depending on the source of bycatch data. Each method is described here in turn. For sources one and two (i.e., inspector logbooks/Directorate entanglement records), all bycatch locations were plotted on a map, and areas of high bycatch risk were identified using a hierarchical clustering algorithm. To also include isolated bycatches that occurred far from any other bycatch incident, the entire coastal region, minus the high bycatch areas, was also used as a distinct area. Thus, all bycatches that were not included in a high bycatch area were pooled in this larger area. Spatial polygons were created for each of these areas and used to assign an area tag to all data records from reported GPS positions. Bycatch and fishery data were then used to calculate area-specific estimates of bycatch rates and totals, using a traditional ratio estimator (Cochran, 1977):

The estimated bycatch rate $\hat{R}_h$ in area *h*, is given by

$$\hat{R}_h = \frac{\bar{y}_h}{\bar{x}_h} \tag{1}$$

The estimated total bycatch $\hat{Y}_h$ is similarly given as

$$\hat{Y}_h = \hat{R}_h X_h \tag{2}$$

where, $\bar{y}_h$= the average number of bycaught whales in area *h*, $\bar{x}_h$= average fishing effort among inspected vessels in area *h*, X_h= fishing effort in area h among all vessels. We used different measures as proxies for fishing effort, depending on the type of fishery. For seine fisheries, fishing effort was defined as the number of fishing operations. For trawls and longlines, fishing effort was defined as the product of fishing time (in decimal days) and number of gears used (e.g., number of hooks on a line).

To obtain fishing effort for individual areas in 2006-2011 (before the advent of electronic logbooks), we used the average yearly proportion of total effort to catch in each area in 2011 – 2020 to estimate effort for years before 2011. The estimated yearly fishing effort $\hat{Z}_h$ for some area *h* in year *i* was then

$$\hat{Z}_{h,i} = \left(\sum V_i\right) \bar{W}_h \tag{3}$$

where *V* = total catch in 2010, $\bar{W}_h$ = average yearly fishing effort in area *h*, calculated from data collected from 2011 to 2020.

For the third source of data, the numbers of reported bycatches were so low for all species that they could only be split by type of gear (i.e., trawl or longline). Bycatch rates and totals were calculated for each species and gear type using equations 1 and 2, but with $\bar{x}_h$ defined as the average fishing effort in the HSRF, and using only one area, corresponding to the North East Atlantic. To calculate bycatch rates using the third definition of fishing effort (see above), the average yearly fishing effort (i.e. fishing time * number of gears) was used for all years where those data variables were lacking (i.e before 2011).

All analyses were done in R (R Core Team, 2020). We used the sf R package (Pebesma, 2018) for spatial analyses. Estimates were calculated with the *survey* R package (Lumley, 2004; Lumley, 2020). Coefficients of variation (CVs) and 95% confidence intervals (CIs) and were obtained through bootstrapping using the *boot* R package (Davison and Hinkley, 1997; Canty and Ripley, 2020). In the bootstrapping procedure, we resampled with replacement either from entanglement and inspection / fishing effort data, or from haul-level HSRF data, and re-calculated all total estimates from the bootstrap samples in the manner described above. CVs and bias corrected (BCa) CIs were obtained from the resulting distribution of 10,000 bootstrap estimates.

2.3 Evaluating the sustainability of estimated bycatch totals
The PBR for any given marine mammal population is given by the equation

$$PBR = N_{min} * 0.5 * R_{max} * F_r \tag{4}$$

where N_{min} is the minimum population estimate, R_{max} is the maximum growth rate, and F_r is a recovery factor that allows one to take into account further information on the conservation status of the species in question. For cetaceans, R_{max} = 0.04 is a feasible default, suggested in Wade (1998). For PBR calculations in this paper, we used R_{max} = 0.04, F_r = 1, and N_{min} = 4,906 (humpbacks), 74,915 (minke) and 8,423 (killer whales). F_r = 1 was used for all species because the abundances of humpback and minke whales have shown an increasing or stable trend in recent surveys, and there is no indication of depletion of the killer whale abundance (Leonard and Øien, 2020; Solvang et al., 2020). The PBR for humpback whales in Norwegian waters, based on the most recent data, is therefore 98 animals and the corresponding value for killer whales is 168 animals. The PBR for minke whales in the North East Atlantic is 1,498 animals.

RESULTS
The electronic logbooks contained 3,126,117 reports from 2011 to 2020, with one report corresponding roughly to one fishing operation. Of these reports, purse seines, longlines and trawls comprised approximately 4%, 15% and 55%, respectively. The total effort of fisheries using these three gear types is shown for each year for *all* large vessels and for the HSRF in Figure 1, panels C to E. These panels also show the estimated effort for both groups of vessels for years prior to 2011, as indicated by the dashed line segments. The overall coverage of the HSRF as a sample of all fishing operations conducted by large Norwegian vessels was 1.9%, with coverage for individual years ranging from 1.4% to 2.7%. Overall coverages in terms of effort for longlines, purse seines and trawls were 15%, 2% and 1%, respectively. The overall coverage of the SSU and the CG for purse seine fishing operations was 2.2%. Coverage for individual years is shown in Figure 1A, with the top line indicating the combined total of SSU and CG inspections. Figure 1B similarly shows the combined SSU and CG coverage for two Norwegian fjords (Figure 2B, Area 3) that became bycatch hot spots in 2016 – 2018 when large whales followed the migrating herring into those fjords.

The bycatch data showed that there were 113 registered cetacean bycatches across 70 separate bycatch incidents. Thirty-five incidents involved a total of 66 killer whales, 30 incidents involved a total of 43 humpbacks. There were two incidents involving minke whales. One minke whale was caught in a trawl and another was entangled on a longline (Figure 2, sites 4 and 5). Figure 2 shows the locations of seine, longline and trawl fisheries in the HSRF and seine fisheries inspected by the SSU or the CG, with numbers 1 – 5 indicating general areas where cetaceans were bycaught. There were also three cases of humpbacks getting entangled in buoy ropes from bottom-set gillnets or fish traps. There were no reports of entanglements in Danish seines. The majority of bycatches involving humpback and killer whales occurred in northern Troms county, from 65.9 to 70.0°N, between 2016 and 2018, and most of them in two fjords

Kaldfjord and *Kvænangen* (Area 3 in Figure 2). Figure 3 shows Area 3 and in greater detail, and also shows individual bycatch locations, colored and circled according to groups assigned by the clustering algorithm. The circled groups were designated "bycatch hot spots". All other groups were combined into one continuous area. Both minke whales, five killer whales and three humpback whales were bycaught outside these hot spots, with up to several years between each bycatch incident.

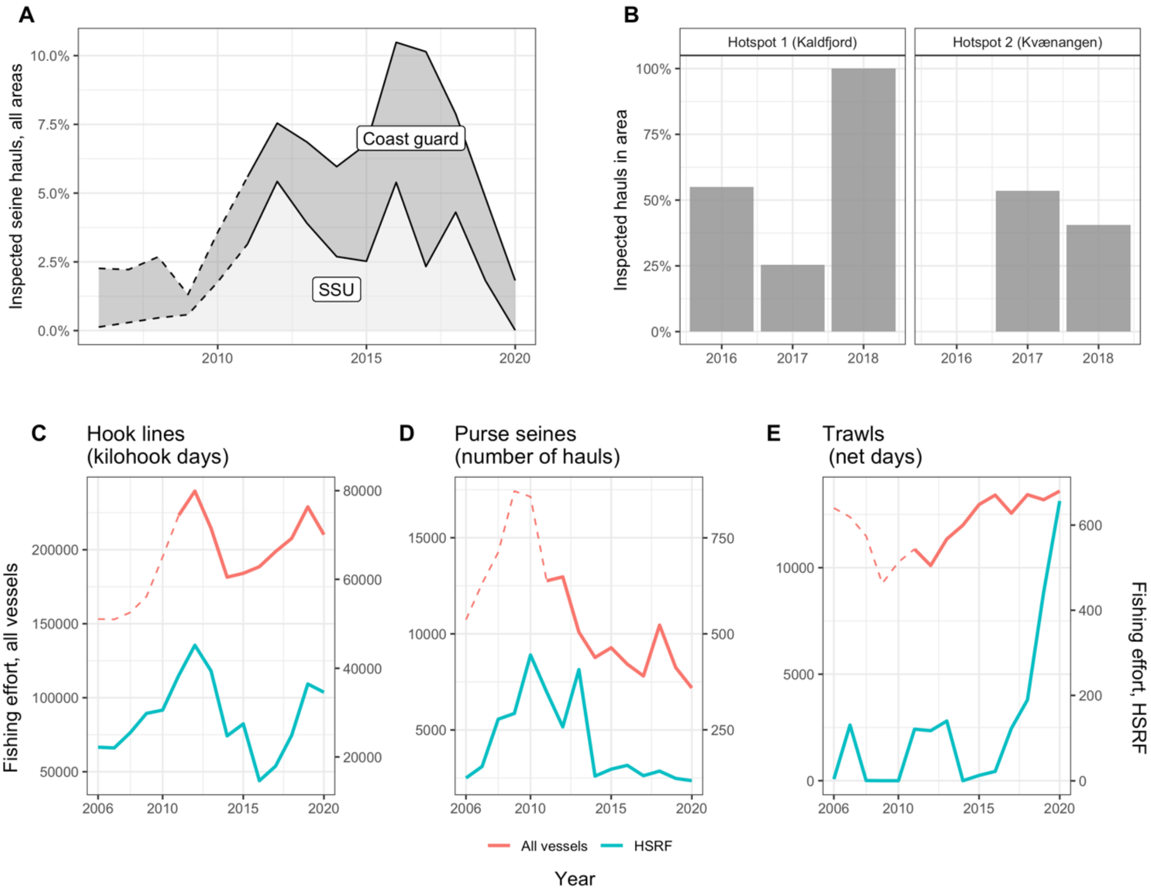

Figure 1: A) Stacked line chart indicating the proportions of seine fishing trips conducted by all large fishing vessels that were inspected by the CG or the SSU between 2006 to 2020. B) Proportions of seine trips inspected by CG and SSU in two bycatch hot spots (Figure 2) in 2016 - 2018. C-E) Comparison of fishing effort in different pelagic fishing gears among all large vessels (red) and reference vessels (cyan). Dashed lines indicate years for which fishing effort was estimated using reported catch from fish tickets.

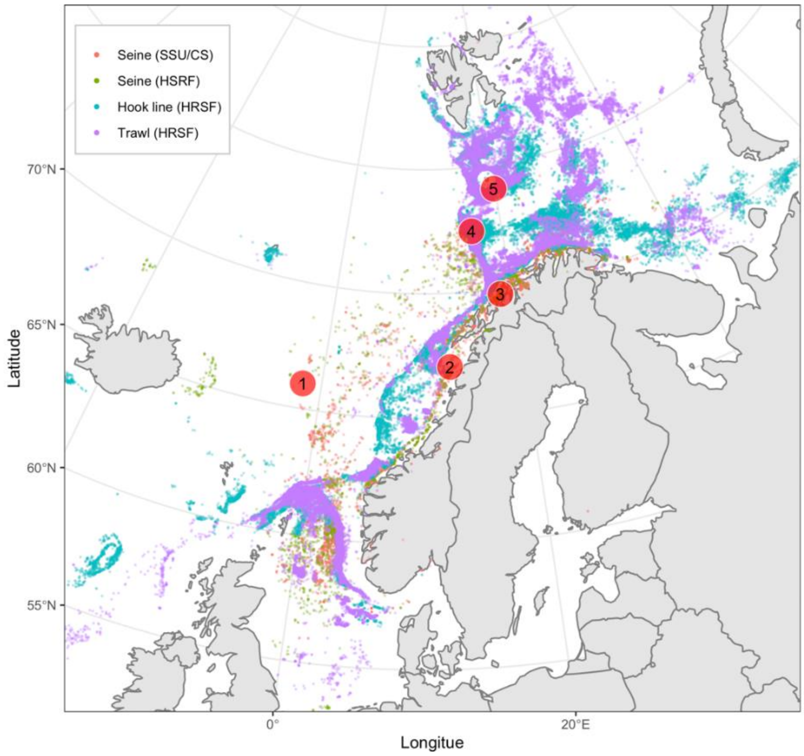

Figure 2: North-East Atlantic and Barents Sea, showing all, HRSF and SSU/CS activity between 2006 and 2020 in this area. Dots indicate fishing locations of the type indicated by the plot legend. Red, numbered marks indicate bycatch locations.

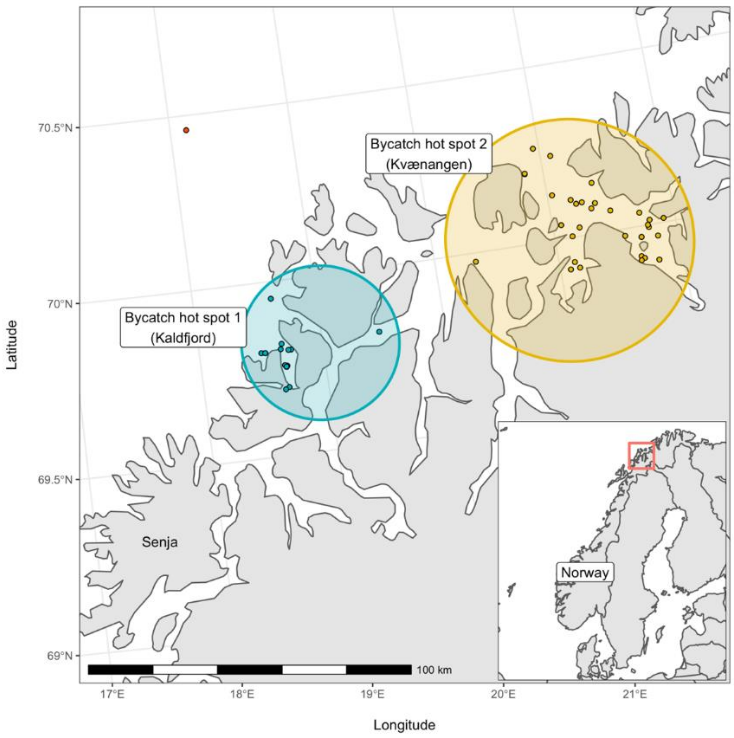

Figure 3: Map showing individual bycatch incidents in Troms county in 2016 – 2018. Each dot represents one bycatch location, where one or more humpback or killer whales were entrapped in a purse seine net. The shaded circles represent different bycatch "hot spots", and the color of individual dots indicate to which of these areas they were assigned.

Overall estimates of total bycatch (i.e., $\hat{Y}_h$, equation 2) for cetaceans in Norwegian pelagic fisheries, are given in Table 1, as estimates per species and gear type. Table 1 also shows the reported bycatch totals in the two hot spots shown in Figure 3. Bycatches of humpback and killer whales in these hot spots in the three years from 2016 to 2018 make up approximately 50% of the total bycatch for all areas in the eleven years from 2010 to 2020. Minke whale total bycatch estimates were about three times higher in trawl fisheries compared to longlines.

Table 1: Reported hot spot bycatches and bycatch estimates for other areas (with CVs and 95% CIs) in Norwegian pelagic fisheries. Total bycatch refers to years 2010 – 2020 for humpbacks and killer whales, and 2011 – 2020 for minke whales.

Species	Gear type	Region(s)	Total bycatch	CV	95% CI
Humpback	Seine	Hot spots	38	-	-
Humpback	Seine	All, except hot spots	39	0.93	5 – 139
Killer whale	Seine	Hot spots	63	-	-
Killer whale	Seine	All, except hot spots	58	0.86	12 – 169
Minke whale	Trawl	All	45	0.97	0 – 139
Minke whale	Longline	All	12	0.96	0 – 36

Table 2 shows total bycatch as the sum of reported bycatch in the two hot spots and the bycatch estimates for all other areas. Table 2 also shows the average yearly bycatch and the estimated mortality associated with purse seine bycatches for humpback and killer whales. SSU/CG observer data indicated that most bycaught animals were successfully removed from the nets. However, two humpback whales and four orcas died as a result of getting entrapped in purse seine nets. The estimated mortalities from bycatches in purse seine nets across all areas (i.e. including Kaldfjord and Kvænangen) were 6% (CV 0.48, 95% CI 0.3% – 11.9%) and 5% (CV 0.69, 95% CI 0% – 11.75%) for killer and humpback whales, respectively. Based on the estimated yearly average bycatch given in Table 2, the average yearly mortality rates in the study period would then be approximately 0.35 humpback whales and 0.66 killer whales, or about one humpback and one killer whale killed in purse seines every 34 and 18 months, respectively.

Table 2: Total bycatch across all gear types as a sum of reported and estimated bycatch and bycatch associated mortality estimates for each species. The results are presented as numbers with 95% confidence intervals in parentheses.

Species	Total bycatch	Average yearly bycatch	Estimated bycatch mortality
Humpback	77 (43 – 177)	7.0 (3.9 – 16.1)	0.05 (0.00 – 0.12)
Killer whale	121 (75 – 232)	11.0 (6.8 – 21.1)	0.06 (0.03 – 0.12)
Minke whale	57 (0 – 157)	5.7 (0 – 15.7)	-

DISCUSSION

Choice of stratification, and bias and reliability of estimates

Unstratified, overall ratio and total estimates do not take into account that entanglement rates may differ between different fisheries, regions, seasons or other relevant variables. Generally, single or multi-variable stratifications allow more refined estimates that are more truly representative of the real world. Unfortunately, the low number of cetacean entanglement observations reported in HSRF data and in the SSU and CG logbooks did not allow for very fine stratifications since most strata in any stratification would have a rate of zero entanglements.

The ratio estimator that was used to produce our entanglement estimates assumes that data originate from a random sample. To satisfy this assumption, every single fishing operation undertaken in each of the Norwegian pelagic fisheries examined must have an equal probability of being inspected within its gear group. For the SSU and CG observer data, this was not the case. SSU and CG inspections were *not* random. The process of selecting which vessels and thereby, which fishing operations, to inspect was based on an internal risk assessment, where fisheries and vessels that were likely to have large bycatch or discard rates, a large proportion of undersized fish, or any other code violation were inspected more frequently. Tips and knowledge of previous offenses factor into these risk assessments. This means that the ratio estimator would produce biased estimates when applied to SSU and CG inspector data. However, given the mode of operation of the SSU and CG, it can be expected, by design, that the discovery rate of marine mammal entanglements is much higher than the relatively low inspection coverage of approximately 2.5-10% would suggest. For these reasons, bycatch estimates derived from opportunistic inspector data using a ratio estimator must be *positively* biased, and it is likely that this bias is very large, i.e. that a large proportion of bycatches are discovered and logged. Thus, bycatch estimates for humpback and killer whales reported here should be considered *maximum estimates*, and with this important caveat in mind. The actual numbers of humpback and killer whale entanglements are most likely *considerably lower* than what our estimates may indicate. The HSRF data are also not truly random, since observations are clustered by fishing vessel.

It should also be noted that all point estimates given in this paper have a very high CV due to the extremely low observed bycatch rates. Caution must be exercised in the use and interpretation of these estimates. They are presented here to document that the total bycatch risk to large cetaceans in Norwegian pelagic fisheries is very low, even when taking estimation uncertainty into account.

Causes of entanglements

The entanglement rates of humpbacks and killer whales in purse seines must be seen in the context of the seasonal movements of the very dynamic NSS herring stock. When the herring stock moved into the narrow fjords, a substantial spatial and temporal overlap occurred between whales feeding on herring and fishermen operating fishing gear at the same time. This was particularly evident between 2016 and 2018. In this period, there were frequently several vessels operating purse seines in close proximity to each other, with groups of whales interspersed around the area. Killer whales may have even learned to associate the sound of of active purse seiners with the idea of increased prey availability. Mul et al. (2020) recently demonstrated through simulations that killer whale movements were biased towards fishing activities, especially if they were within 20 km of a fishing vessel (which would be very likely in a fjord, especially a narrow one like Kaldfjord). Additionally, the geography and the small area of the fjords may have limited the effective ability of the whales to disperse away from fishing vessels, e.g. after they were done feeding. All these factors may have contributed to the large peak in entanglements that occurred between 2016 – 2018, and in particular in 2017. The strong relationship between cetacean entanglement rates and herring amassing in fjords is further supported by the abrupt absence of any such entanglements after the herring moved further north along the coast (in 2019 and 2020 up to this writing). It is difficult if not impossible to predict the erratic seasonal migrations of the herring stock from year to year, but if the herring stock were to return to fjords such as Kaldfjord, it is likely that cetaceans would follow suit, potentially causing an increase in entanglements.

Mortality and sustainability of entanglements
Before 2016, there were not many reported cases of cetacean entanglements in purse seines, and such incidents most likely only occurred very rarely. At that time, there were still no government directives or official rules in place governing how to handle cetacean entrapments or entanglements, and it was up to the fishermen to deal with such situations themselves. It is possible, but not documented, that this would lead to securing the catch being prioritized over releasing the cetaceans from the seine net. It is therefore possible that the mortality associated with entanglements before 2016 was higher than our estimates of 5% and 6%. However, in the few purse seine entrapment cases that have been reported before 2016, the entangled whales were successfully released in all cases. With the abrupt increase in entrapments in 2016 and 2017, the Norwegian Directorate of Fisheries issued a new rule stating that the wellbeing of any entrapped or entangled cetaceans is to be prioritized over the catch. This entailed that a purse seine full of herring would have to be opened up again if there were cetaceans inside that could not otherwise be removed in a timely fashion, even if that meant that the catch would also escape. This new regulatory decision fell under the purview of the SSU and the CG. SSU inspectors and CG personnel were then given large whale entanglement response training. This training was tutored by David Mattila, IWC, and in line with IWC's best practice guidelines for entanglement responders. However, with the limited data set presented here, it was not possible to evaluate whether there was any change in the mortality resulting from an entanglement before and after this training.

Average mortality estimates of 0.35 humpback and 0.66 killer whales per year correspond to 0.007% and 0.008% of the respective abundance estimates for these whale species. Both mortality estimates are well within the PBR limits of 98 humpback and 161 killer whales per year. Even in the peak year 2017, the yearly total mortality for both species would be within the PBR. The 5.7 minke whales taken as bycatch annually similarly constitute a negligible part of the PBR of 1,498 animals. However, formally, this removal should be accounted for in the quota for commercial harvest of minke whales calculated under the IWC Revised Management Procedure.

Based on these results, we conclude that the mortality incurred to these whale populations by Norwegian pelagic fisheries does not constitute a significant risk to either of these populations. It is possible that entrapments in purse seines may have welfare implications/other adverse effects on individual whales, e.g. from stress induced or physical wounds incurred by being entrapped and subsequently released from a purse seine.

DATA AVAILABILITY
Data will be shared on reasonable request to the corresponding author.

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REFERENCES

Brownell Jr, R. L., Reeves, R. R., Read, A. J., Smith, B. D., Thomas, P. O., Ralls, K., Amano, M., et al. 2019. Bycatch in gillnet fisheries threatens Critically Endangered small cetaceans and other aquatic megafauna. Endangered Species Research, 40: 285-296. http://dx.doi.org/10.3354/esr00994

Canty, A., and Ripley, B. 2020. Boot: Bootstrap R (S-Plus) Functions: R Package Version 1.3-25. https://cran.r-project.org/package=boot

Clegg, T., and Williams, T. 2020. Monitoring bycatches in Norwegian fisheries—Species registered by the Norwegian Reference Fleet 2015-2018. Rapport fra havforskningen. https://www.hi.no/en/hi/nettrapporter/rapport-fra-havforskningen-en-2020-8

Cochran, W. G. 1977. Sampling techniques, John Wiley & Sons, New York.

Collins, T., Boumba, R., Thonio, J., Parnell, R., Vanleeuwe, H., Ngouessono, S., and Rosenbaum, H. 2010. The Atlantic humpback dolphin (Sousa teuszii) in Gabon and Congo: cause for optimism or concern. Scientific Committee Document SC/62/SM9, International Whaling Commission.

Davison, A. C., and Hinkley, D. V. 1997. Bootstrap methods and their application, Cambridge university press. https://doi.org/10.1017/CBO9780511802843

Huse, G., Fernö, A., and Holst, J. C. 2010. Establishment of new wintering areas in herring co-occurs with peaks in the 'first time/repeat spawner'ratio. Marine Ecology Progress Series, 409: 189-198. http://dx.doi.org/10.3354/meps08620

Jaramillo-Legorreta, A. M., Cardenas-Hinojosa, G., Nieto-Garcia, E., Rojas-Bracho, L., Thomas, L., Ver Hoef, J. M., Moore, J., et al. 2019. Decline towards extinction of Mexico's vaquita porpoise (Phocoena sinus). Royal Society open science, 6: 190598. http://dx.doi.org/10.1098/rsos.190598

Jourdain, E., and Vongraven, D. 2017. Humpback whale (Megaptera novaeangliae) and killer whale (Orcinus orca) feeding aggregations for foraging on herring (Clupea harengus) in Northern Norway. Mammalian Biology, 86: 27-32. http://dx.doi.org/10.1016/j.mambio.2017.03.006

Knowlton, A. R., Hamilton, P. K., Marx, M. K., Pettis, H. M., and Kraus, S. D. 2012. Monitoring North Atlantic right whale Eubalaena glacialis entanglement rates: a 30 yr retrospective. Marine Ecology Progress Series, 466: 293-302. http://dx.doi.org/10.3354/meps09923

Leonard, D., and Øien, N. 2020. Estimated abundances of cetacean species in the Northeast Atlantic from two multiyear surveys conducted by Norwegian vessels between 2002–2013. NAMMCO Scientific Publications, 11. https://doi.org/10.7557/3.4695

Lewison, R. L., Crowder, L. B., Read, A. J., and Freeman, S. A. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends in Ecology & Evolution, 19: 598-604. https://doi.org/10.1016/j.tree.2004.09.004

Lumley, T. 2004. Analysis of complex survey samples. Journal of Statistical Software, 9: 1-19. http://dx.doi.org/10.18637/jss.v009.i08

Lumley, T. 2020. Survey: analysis of complex survey samples. R package version, 4.0. https://cran.r-project.org/package=survey

Mul, E., Blanchet, M.-A., McClintock, B. T., Grecian, W. J., Biuw, M., and Rikardsen, A. 2020. Killer whales are attracted to herring fishing vessels. Marine Ecology Progress Series, 652: 1-13. https://doi.org/10.3354/meps13481

Pebesma, E. J. 2018. Simple features for R: Standardized support for spatial vector data. The R Journal, 10: 439. https://doi.org/10.32614/RJ-2018-009
Perrin, W. F. 1968. PORPOISE AND TUNA. Sea Frontiers, 14: 166-&.
Perrin, W. F. 1969. The problem of porpoise mortality in the US tropical tuna fishery. *In* Proceedings of the Sixth Annual Conference on Biological Sonar & Diving Mammals, Stanford Research Institute, Palo Alto CA.
R Core Team 2020. R: A language and environment for statistical computing. https://www.R-project.org/
Ramm, T. 2020. Hungry during migration? Humpback whale movement from the Barents Sea to a feeding stopover in northern Norway revealed by photo-ID analysis. UiT Norges arktiske universitet. https://hdl.handle.net/10037/19109
Read, A. J., Drinker, P., and Northridge, S. 2006. Bycatch of marine mammals in US and global fisheries. Conservation Biology, 20: 163-169. https://doi.org/10.1111/j.1523-1739.2006.00338.x
Reeves, R. R., McClellan, K., and Werner, T. B. 2013. Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011. Endangered Species Research, 20: 71-97. http://dx.doi.org/10.3354/esr00481
Roberts, J., Webber, D., Roe, W., Edwards, C., and Doonan, I. 2019. Spatial risk assessment of threats to Hector’s and Māui dolphins (Cephalorhynchus hectori). New Zealand Aquatic Environment and Biodiversity Report No. 214. Wellington, New Zealand: Ministry of Fisheries. https://www.mpi.govt.nz/dmsdocument/35007/direct
Salthaug, A., Stenevik, E. K., Vatnehol, S., Anthonypillai, V., Ona, E., and Slotte, A. 2020. Distribution and abundance of Norwegian spring-spawning herring during the spawning season in 2020. https://www.hi.no/resources/Survey-Report-NSS-Herring-Spawning-Survey-2020.pdf
Similä, T., Holst, J. C., and Christensen, I. 1996. Occurrence and diet of killer whales in northern Norway: seasonal patterns relative to the distribution and abundance of Norwegian spring-spawning herring. Canadian Journal of Fisheries and Aquatic Sciences, 53: 769-779. https://doi.org/10.1139/f95-253
Solvang, H. K., Skaug, H. J., and Øien, N. 2020. Abundance of common minke whales in the Northeast Atlantic based on survey data collected over the period 2014-2019. . Scientific Committee Document SC/68c, International Whaling Commission.
Vogel, E. F. 2020. The influence of herring (Clupea harengus) biomass and distribution on killer whale (Orcinus orca) movements on the Norwegian shelf. UiT Norges arktiske universitet. https://hdl.handle.net/10037/19221
Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science, 14: 1-37. https://doi.org/10.1111/j.1748-7692.1998.tb00688.x
Weir, C. R., Van Waerebeek, K., Jefferson, T. A., and Collins, T. 2011. West Africa’s Atlantic humpback dolphin (Sousa teuszii): endemic, enigmatic and soon Endangered? African Zoology, 46: 1-17. https://doi.org/10.3377/004.046.0101
Wise, L., Silva, A., Ferreira, M., Silva, M. A., and Sequeira, M. 2007. Interactions between small cetaceans and the purse-seine fishery in western Portuguese waters. Scientia Marina, 71: 405-412. https://doi.org/10.3989/scimar.2007.71n2405