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Assessing incidental bycatch of seabirds in Norwegian coastal commercial fisheries: Empirical and methodological lessons

Kirstin Fangel [a,*], Øystein Aas [a], Jon Helge Vølstad [b], Kim Magnus Bærum [a], Signe Christensen-Dalsgaard [c], Kjell Nedreaas [b], Modulf Overvik [d], Line Camilla Wold [a], Tycho Anker-Nilssen [c]

[a] *Norwegian Institute for Nature Research, Fakkelgården, NO-2624 Lillehammer, Norway*

[b] *Institute of Marine Research, PO Box 1870 Nordnes, NO-5817 Bergen, Norway*

[c] *Norwegian Institute for Nature Research, PO Box 5685 Sluppen, NO-7485 Trondheim, Norway*

[d] *Directorate of Fisheries, PO Box 185 Sentrum, NO-5804 Bergen, Norway*

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ABSTRACT

With diminishing seabird populations and little knowledge on incidental bycatch in fisheries in the Northeast Atlantic, this study aimed to screen seabird bycatch in Norwegian coastal fisheries in 2009. The purpose was to 1) quantify magnitude of seabird bycatch rates and estimate total bycatch from the entire fleet by different estimators 2) evaluate data from an access point survey against monitoring data from a reference fleet as methods for collecting data on bycatch mortality of seabirds and 3) give advice on further bycatch studies. The study focused on three small-vessel fisheries (<15 m LOA) outside Northern Norway; the coastal cod (gillnet and manual longline) and lumpfish (gillnet) fisheries and the more offshore Greenland halibut longline fishery. We found no correlation between landed catch and bycatch and upscaling was made based on number of fishing trips. In these fisheries, northern fulmars *Fulmarus glacialis* outnumbered the other species and constituted almost half of the overall bycatch, totalling about 5500 (mostly on longlines) of the >11 000 birds estimated caught. The black guillemot *Cepphus grylle*also stood out as a numerous victim, constituting almost two thirds of the >3000 birds estimated to have drowned in lumpfish gillnets. The two methods were both considered to hold merit and yielded approximately similar estimates of the bycatch in the coastal cod fisheries, however BPUE differs. Further studies are recommended especially on the lumpfish gillnet and Greenland halibut longline fisheries and on temporal and spatial variations in bycatch. More studies are also needed to model effects on seabirds at the population level.

1. Introduction

A large proportion of the seabird species in the Northeast Atlantic are in decline (e.g. ICES, 2013), and many populations inhabiting Norwegian waters have been significantly reduced over the last decades (Barrett et al., 2006, 2014). The situation is especially severe for pelagic species such as northern fulmar *Fulmarus glacialis*, common guillemot *Uria aalge*, Atlantic

* Corresponding author. Tel.: +47 47 82 90 90.
E-mail addresses: kirstin.fangel@nina.no (K. Fangel), oystein.aas@nina.no (Ø. Aas), jon.helge.voelstad@imr.no (J.H. Vølstad), kim.barum@nina.no (K.M. Bærum), signe.dalsgaard@nina.no (S. Christensen-Dalsgaard), kjell.nedreaas@imr.no (K. Nedreaas), modulf.overvik@fiskeridir.no (M. Overvik), line.wold@nina.no (L.C. Wold), tycho.anker-nilssen@nina.no (T. Anker-Nilssen).

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puffin *Fratercula arctica* and black-legged kittiwake *Rissa tridactyla* (Kålås et al., 2010). Thus, there is an urgent need to assess anthropogenic mortality factors that potentially have negative impact on the bird populations (NMR, 2010). One such factor may be unintentional bycatch in marine fisheries.

Most studies of incidental seabird bycatch in fisheries have focused on longline fisheries in the southern hemisphere (Brothers et al., 1999; Tasker et al., 2000; Belda and Sánchez, 2001; Cooper et al., 2001; Baker and Wise, 2005; Anderson et al., 2011), and trawling (Sullivan et al., 2006; Croxall, 2008). There are thus gaps in the literature on bycatch in gillnet fisheries (Tasker et al., 2000; Žydelis et al., 2009), and from the northern hemisphere (but see Dunn and Steel, 2001; Løkkeborg and Robertson, 2002; Løkkeborg, 2003). A few recent studies show, however, that some species might suffer significant mortality from drowning in gillnets (Žydelis et al., 2009; Sonntag et al., 2012; Žydelis et al., 2013). There are also a few older reports of extraordinary events of high bycatch in the Northeast Atlantic (Vader et al., 1990; Strann et al., 1991; Bustnes et al., 1993).

A major reason for limited knowledge about seabird bycatch mortality in marine fisheries is challenges with cost-efficient monitoring. The literature includes many non-representative approaches. These include beached bird surveys, ringed bird recoveries and other non-systematic observations of bycatch (Žydelis et al., 2009). To be able to assess bycatch-induced mortality more systematically, representative and cost-effective approaches are needed. Potential methods include (but are not limited to) interview surveys, independent and randomized observations on vessels, experimental fishing and the use of systematic reports from reference vessels. In addition, standardized reporting on fishing effort and key data on the seabirds caught is needed, including their species, age and sex distribution, as well as any parameters that can indicate the origin of their breeding populations. The practical and scientific challenges of gathering systematic and representative data to assess impacts of seabird bycatch include:

– The economic costs associated with gathering primary data of bycatch that are sufficiently randomized and representative.
– The nature of bycatch: evenly distributed or stochastic?
– The variations in time, space and fleet/gear characteristics, with additional costs when aiming to get an overview.
– The inconvenience and cost for fishermen in a hectic work day to report bycatch sufficiently detailed and accurate.
– The somewhat discomforting character of the theme, with potential problems associated with either lack of responses or with response bias in methods based on self-reporting.

To our knowledge, few studies have focused primarily on aspects related to sampling methods (but see Oliveira et al., 2015) and different estimators used for bycatch assessments. In this paper we aim to fill some of the knowledge gaps as presented above, exploring three identified fisheries outside Northern Norway; the coastal fishery for cod *Gadhus morhua*, the offshore fishery for Greenland halibut *Reinhardtius hippoglossoides* and the coastal fishery for lumpfish *Cyclopterus lumpus*. The purpose was to (1) quantify magnitude of seabird bycatch rates and estimate total bycatch from the entire fleet by different estimators (2) evaluate data from an access point survey (interviewing vessels as they arrive harbours for landing their catch) against monitoring data from a reference fleet as methods for collecting data on bycatch mortality of seabirds and (3) give advice on further bycatch studies. The study objectives should be regarded as essential first steps in solving problems of unintentional bycatch from fisheries (see framework suggested by Broadhurst et al., 2007).

2. Materials and methods

2.1. Fishery characteristics and study area

A pre-study (Christensen-Dalsgaard et al., 2008) identified specifically three target fisheries where it was judged most likely that unintentional bycatch could be significant. These fisheries were all conducted by small-vessels in the coastal fleet operating along the coast of Norway, basically within the 12 mile limit (opposite to the larger and ocean-going fleet that uses trawl, automatic long-lines, nets and different types of seines). In 2009, a total of 6510 fishing vessels were registered in Norway, of which 5417 were recognized as active (Aasjord, 2010). The small coastal fishing vessels are generally less than 15 m in overall length, constituting around 90% of the entire Norwegian fishing fleet. In Northern Norway, an overall total about 3200 vessels participated in the coastal cod-fisheries in 2009 of which about 2700 vessels were less than 15 m length over all (LOA). The range of operation for these vessels <15 m LOA is limited by the distance to the harbour since they have few facilities for on-board processing and storing of the catch, and for longer-term accommodation at sea. In general these vessels are multi-gear vessels, where the type, size and scale of gear is determined by the size of the vessel, number of crewmembers and the seasonal features of the fishery. These vessels have a somewhat similar behaviour in the fishery compared to vessels above 15 m LOA, which have fewer constraints concerning range of operation and length of time spent at sea on each trip.

The following three focus fisheries were selected:

1. *The coastal cod fishery*. The Norwegian fishery statistics describe this as a ''bottom fishery with conventional gears, except for seine and trawl'', i.e. it is mainly conducted with gillnets and some manual longlines. While the main target is cod, regular and legal bycatches of haddock, saithe *Pollachius virens*, and ling *Molva molva* are included in the catches. In the longline fishery, haddock *Melanogrammus aeglefinus* is also a target species, and we therefore refer to this as the cod-haddock longline fishery in Tables 1 and 2, whereas for gillnets the main target is cod. The fishery is conducted year

Table 1
Recorded bycatch (number of individuals) of different species and species groups of seabirds in 2009 in the Norwegian fisheries covered by this study, as recorded by the Survey ($n = 117$ vessels, 117 trips) and the Norwegian reference fleet ($n = 20$ vessels, 455 trips).

Fishery	Cod gillnet		CodHaddock_Longline	Greenl. halibut gillnet	Greenl. halibut longline	Lumpfish gillnet	Total	
Species	Data source							
	Survey	Fleet	Survey	Survey	Survey	Survey	Survey	Fleet
Northern fulmar	1	26	1	2	25		29	26
Auks	4	3	1			19[a]	24	3
Cormorants	1					6	7	
Seagulls		15	2		2	2	6	15
Ducks						1	1	
Northern gannet		1				2	2	1
Total	6	45	4	2	27	30	69	45

[a] Confirmed as black guillemot.

Table 2
Estimated bycatch of seabirds (individuals) per trip and in total for each fishery in 2009, based on the data in Table 1. Estimator 1 is mean bycatch per trip, whilst estimator 2 is stratified mean bycatch per trip. Total number of trips based on sales-note statistics from the Norwegian Directorate of Fisheries.

Data set	Estimator	Fishery	Mean bycatch/trip	SE	RSE	n	Total no. of trips	Estimated total bycatch	SE
Survey	1	CodHaddock_Longline	0.22	0.13	0.59	18	15 027	3 305	1954
	1	Greenl.Halibut_Gillnet	0.25	0.15	0.60	8	253	63	38
	1	Greenl.Halibut_Longline	1.93	1.08	0.56	14	801	1 546	865
	1	Lumpfish_Gillnet	1.58	0.37	0.23	19	2 053	3 244	760
	1	Cod_Gillnet	0.10	0.05	0.50	58	31 329	3 133	1566
Fleet	1	Cod_Gillnet	0.10	0.03	0.30	455	31 329	3 133	940
Fleet	2	Cod_Gillnet	0.11	0.03	0.31	455	31 329	3 446	940
Total, appr.								11 000	5000

round except for in summer, with a peak in late winter and spring. This is by far the largest commercial small-vessel fishery in coastal Norway. The vessels less than 15 m are responsible for around 10% of the total landings of fish and 30% of the cod landed in Norway. Gillnets are the most preferred and efficient type of gear among these vessels. About 2 500 vessels less than 15 m LOA participated in the fishery for cod in 2009 of with an average length about 10.3 m LOA.

2. *The coastal lumpfish fishery*. Lumpfish has been harvested in specific gillnet fisheries since the 1950s, and is a seasonal spring fishery conducted as the fish comes near the coast to spawn. Today it is only the roe that is utilized, salted and sold as caviar. The fishery is concentrated in rather shallow waters (5–40 m depth) of Northern Norway, mostly along exposed sections of the outer coast (Dahl et al., 2007). The fishery is dominated by vessels shorter than 13 m, often with only one person on board. Each vessel had a maximum quota of 2500 kg raw roe. The fishery starts in March and can go on until a set date, which in 2009 was June 20 west of 26 degrees east, and July 5 east of this longitude, dates which correspond with the beginning of the spawning period. Nearly the entire catch of lumpfish was taken with gillnets and approximately 310 vessels participated in this fishery in 2009 with an average length about 8, 9 m LOA, catching 415 tonnes raw roe, which corresponds to 2266 tonnes female lumpfish.
3. *The Greenland halibut fishery*. Greenland halibut is an Arctic species. Outside the Norwegian coast, most of the fishing is conducted along the edge of the continental shelf from west of Nordland county to the Svalbard archipelago and outside Finnmark. The fishery is strictly regulated with both total and vessel-wise quotas. In 2009, the quota for individual vessels less than 20 m fishing with long-lines and gillnets were 10 tonnes for vessels <14 m and 12 tonnes for vessels 14–19, 99 m. The total Norwegian catch of Greenland halibut in 2009 was 8400 tonnes, of which 27% was taken by demersal trawl, the rest by gillnets and longlines (Fiskeridirektoratet, 2010). Longlines totals about 75% of the total catch taken by vessels less than 15 m LOA. The participation amounted in 2009 to about 240 vessels with average length about 12.2 m LOA.

The lumpfish and Greenland halibut fisheries are only conducted in Northern Norway, whereas the coastal cod fishery is also practised further south, but concentrated in Northern Norway. To focus our effort accordingly, we therefore decided to limit our data collection to the four main fishing areas in this region; 00, 05, 04 and 03 (Fig. 1).

2.2. Data collection

The data used in this study were acquired from two different sample surveys: (1) An access-point survey and (2) the Coastal Norwegian Reference Fleet, both described more in detail below. The first included catch recordings from cod fisheries, lumpfish fisheries and Greenland halibut fisheries, whilst the second mostly covered the cod fisheries. Direct

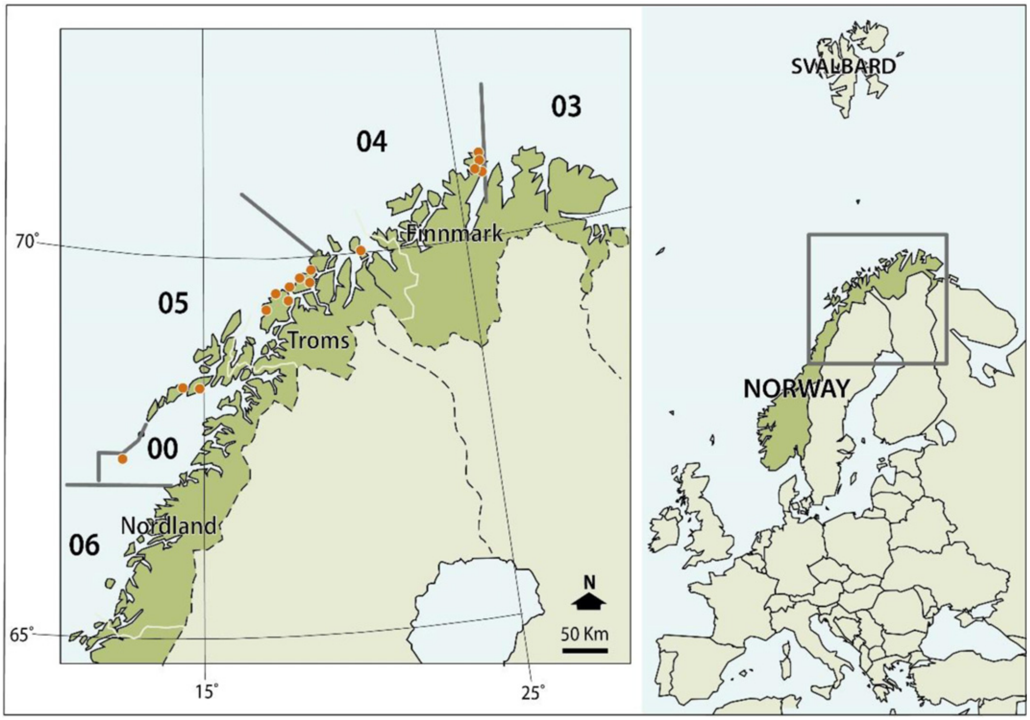

Fig. 1. Overview of the study area along the Northern Norwegian coast. The study is based on data from the four northernmost fishing-areas; 00, 05, 04 and 03 outside the counties of Nordland, Troms and Finnmark. The interviews were conducted at 22 access-points along the coast where fishermen landed their catch, market as 15 orange dots at the map.

comparisons of the two methods were feasible only for the cod gillnet fishery. This is nonetheless of high relevance, as this is by far the most important fishery in coastal Norway.

1: Access-point survey

Access-point surveys (Pollock et al., 1994; CRRFSM, 2006; ICES, 2014) are used to estimate catch of fishermen by intercepting a sample at access points (e.g., ports or harbours) on selected days over time, when they return from their fishing trips. On-site interviews as opposed to phone, mail or web surveys, is believed to be more accurate (Lien et al., 1994). We were advised that fishermen waiting to deliver their catch could have time for being interviewed about bycatch. We therefore considered a stratified design with representative samples of site-days combined with personal interviews (Hayne, 1990) of fishermen intercepted at the completion of their trips, as a suitable approach for data collection. In our sampling plan, site days were the primary sampling units, while the vessel trips targeted for interviews were secondary sampling units (ICES, 2014).

The sampling plan was based on two stages. First, we selected five areas (Fig. 1) and recruited interview personnel (six persons who received equal, in-depth training beforehand and who all had suitable backgrounds for interviewing) distributed in the study area aiming to cover the geographical study area as good as possible, however limited by lack of interviewers in some localities. Second, interviewers approached vessels which were present during selected interview time in a given area. We were restricted to make interviews with vessels that volunteered to take part in the survey, a common limitation in by-catch studies (Žydelis et al., 2009). The questionnaire (each completed representing one trip with one vessel) was filled out in cooperation between the interviewer and the skipper. The selected approach worked less well than expected. Vessels waiting in line were fewer than expected, resulting in busy crews with no time for interviews. As a result, time needed for each completed questionnaire increased because the interviewers had to spend more time travelling between harbours to find accessible vessels. This made the access-point survey less comprehensive and more expensive than planned for. The final sampling cannot be considered a formally random, stratified sample. Nevertheless, we believe the sample to be sufficiently large and well enough distributed in time and space to hold merit, at least to consider the potential of the method and to obtain data of sufficient quality to select specific fisheries for more in-depth studies.

In total, we conducted interviews from 22 access-points (Fig. 1), stretched over 50 interview days and 117 different vessels (for sample sizes within each fishery see Table 2, for sample size within each area see Appendix A). About two thirds of the trips represented cod fishing (mostly with gillnets), 16% were targeting lumpfish (gillnet only) and approximately the same share fished for Greenland halibut (most with longlines) (Table 1). The interviews were conducted from May 2009 to June 2010, with most (71%) of the interviews conducted in the months March, April, May and June. Emphasis on these months was intentional because they are important for all the selected fisheries and also represent a period where pelagic seabirds due to breeding, to a larger degree overlap spatially with coastal fisheries.

The fishermen were asked a range of questions about their last trip; including duration, location of area fished, type and amount of gear, catch, observations of seabirds, bycatch of seabirds that resulted in mortality and weather conditions. In terms of birds caught, we considered it not feasible to have them specify exact species for ducks, gulls, cormorants and auks, since this usually requires skills beyond common knowledge.

2: The Coastal Norwegian Reference fleet

The Coastal Reference fleet is organized by the Norwegian Institute of Marine Research (IMR) and consisted at the time of this study a total of 21 commercial vessels, mostly gillnet vessels between 9 and 15 m LOA. The vessels are selected based on gear (gillnet), target species and home port with the aim that the fleet at a general level should represent the Norwegian coastal fleet of small vessels fishing mostly with gillnets. Besides being representative in terms of gear and areas (cfr. Bjørge et al., 2013), the selected crews should be well reputed and supportive of sustainable management. The Reference fleet gathers a range of fisheries-specific data and takes samples according to a protocol developed by IMR. The fleet keeps a detailed logbook of the daily catches and reports of bycatch of seabirds were included in the sampling program from 2006. From the Reference fleet data set we used all data from 20 vessels that conducted cod gillnet fishery ($n = 455$ trips) within the study area in 2009, i.e. one vessel did not fish for cod within this area in 2009.

2.3. Analyses

The Directorate of Fisheries is in charge of the mandatory logging of landed catch. All sales-notes represent one fishing trip each and are reported via the Norwegian Fishermen's Sales Organization to the directorate, with information about catch specified on fish species, date of sale, vessel, fishing gear, and area and location of fishing. We therefore chose to focus our candidate estimators around these variables for feasible upscaling to the fishery as a whole. Statistics for vessels <15 m within each fishery were used to extrapolate the bycatch-rate to the entire fishing fleet in the study area to estimate the total bycatch of seabirds in Northern Norway in 2009.

All statistical analyses were run in the statistical software R, version 3.01 (R Development Core Team, 2008), using the package 'survey' (Lumley, 2011). Originally, we wanted to explore three types of estimators of bycatch: (1) the ordinary mean bycatch per trip (often referred to as the naïve estimator; Kish and Frankel, 1974), (2) the stratified (per area) mean bycatch per trip and, and (3) the ratio estimator, where mean bycatch rate in numbers of seabirds per kg of fish caught. However, preliminary data exploration showed no relationship between catch and seabird bycatch (Appendix B). We therefore excluded this estimator, and focused only on mean bycatch per trip in the reported analyses. Two types of estimators were developed for the fleet data, where estimator 1 was based on simple mean bycatch per trip and estimator 2 aimed to weight possible differences in bycatch associated with fishing areas (geographic strata). Further, we conducted a sensitivity analysis of sample size (i.e., trips sampled) on the mean bycatch estimates. Specifically, various sample sizes were re-sampled by random with 500 iterations from the reference fleet containing data from the cod fishery. We thus obtained random variations in mean bycatch estimates and confidence intervals as a consequence of sample size. Based on the results from the sensitivity analysis, we choose to only include bycatch estimates from estimator 1 for the questionnaire data due to the relatively low sample size per area. Mean bycatch per unit effort is estimated for each fishery.

Estimator 1

Estimator 1 is mean bycatch per trip and its variance (the naïve estimator), under the assumption of a simple random sample of trips from the entire fleet (i.e., ignoring possible variation between areas). The total bycatch is then calculated by scaling the simple mean up to all trips in the fishery as a whole.

Estimator 2

Estimator 2 is a stratified mean bycatch per trip extrapolated to the total number of trips by all vessels. For fishing operation j within trip k by vessel i in stratum h let $x_{i,j,k,h}$ be the bycatch of seabirds in numbers. An estimator for the mean and total bycatch for trip k for vessel i in area h is then

$$\bar{x}_{i,k,h} = \frac{\sum_j x_{i,j,k,h}}{m'_{i,k,h}} \tag{2.1}$$

and

$$\hat{x}_{i,k,h} = m_{i,k,h}\bar{x}_{i,k,h} \tag{2.2}$$

respectively, where $m'_{i,k,h}$ is the number of fishing operations sampled for trip k, and $m_{i,k,h}$ is the total number of fishing operations. An estimator for mean bycatch per trip across all vessels in area h is then

$$\bar{x}_h = \frac{\sum_i \sum_k \hat{x}_{i,k,h}}{n_h} \tag{2.3}$$

Table 3
Mean bycatch of seabirds (no. of individuals) incidentally killed per unit fishing effort, sample size, and mean fishing effort per trip in the cod gillnet, cod-haddock longline, Greenland halibut and lumpfish fisheries in Northern Norway in 2009, based on the survey data.

Fishery	Mean bycatch/net/day	Mean bycatch/1000 hooks	SE	RSE	n	Mean no. of nets/trip	Mean no. of hooks/trip	SE	RSE
Cod gillnet	0.002		0.001	0.536	58	55.5		3.006	0.054
CodHaddock longline		0.064	0.040	0.624	19		4505	835.2	0.185
Greenl. halibut gillnet	0.002		0.002	0.662	8	126.4		13.76	0.109
Greenl. halibut longline		0.294	0.186	0.632	14		6621	704.8	0.106
Lumpfish gillnet	0.038		0.012	0.303	19	51.4		6.607	0.128

where n_h is the total number of trips in area h. An estimator for the total bycatch in h is

$$\hat{X}_h = N_h \bar{x}_h \tag{2.4}$$

with variance

$$\text{var}(\hat{X}_h) = N_h^2 \text{var}(\bar{x}_h) \tag{2.5}$$

where N_h is the total number of trips in h by all vessels.

3. Results

3.1. Incidental seabird bycatch

In terms of bird species and species groups, the unintentional bycatch from the access-point survey and the Reference fleet paint the same picture—bycatch was dominated by northern fulmar and several auk species, most frequently black guillemot *Cepphus grylle* (Table 1). Cormorants and gull species were also quite frequent caught. Occasionally, ducks and gannets were registered as bycatch. Fulmars dominated strongly the bycatch in longline fisheries (some gulls also included in the longline bycatch), while, generally, a wider mix of birds were caught in gillnet fisheries. In the lumpfish fishery, auks, especially black guillemot seemed most vulnerable.

The bycatch rates observed (estimator 1) varied between the different fisheries in the access-point survey (Table 2). The bycatch rate was highest in the Greenland halibut longline fishery, with a mean bycatch rate of 1.9 seabirds per trip whilst the bycatch rate for cod-haddock longline fishery was much lower with a mean of 0.22 seabirds per trip. The bycatch rate of the lumpfish gillnet fishery was nearly 1.6 seabirds per trip. In comparison, the cod gillnet fishery had a much lower average of around 0.1 seabirds per trip. From the fleet observations, the bycatch rate (estimator 1) for this fishery was calculated to be the same as that for the survey (Table 2). For the fleet data set, the estimated stratified bycatch rate (estimator 2) in the cod gillnet fishery differed only by ten percent of that calculated by the non-stratified estimator (Table 2). The spatial variation in sampling effort between areas thus had little influence on the mean bycatch estimate for the cod gillnet fishery in 2009 (estimated at about 3100–3400 birds, Table 2). The much smaller lumpfish fishery had an estimated total bycatch of 3200 seabirds of which most would be auks (Tables 1 and 2). Also, the small Greenland halibut longline fishery could induce a total mortality of around 1500 seabirds, mostly northern fulmars (Tables 1 and 2). For the larger cod-haddock fishery the mortality was estimated to be 3300 seabirds in 2009 (Table 2).

Based on the access-point survey, mean bycatch per unit effort (BPUE) in the gillnet fisheries was highest for the lumpfish fishery with 0.038 seabirds per net per day, and only 0.002 for the gillnet fisheries of cod and Greenland halibut (Table 3). In comparison, the bycatch per net for the Reference fleet cod gillnet fishery was approximately half of that from the survey (0.0009, Nedreaas, pers. info). For the longline fisheries, BPUE was as high as 0.294 seabirds per 1000 hooks for the Greenland halibut fishery and 0.064 for the cod-haddock fishery (Table 3).

3.2. Sensitivity analysis

The sensitivity analysis of mean bycatch per trip estimates in relation to sample size indicated the estimates to be rather sensitive to low sample sizes (Fig. 2). This is, however, to be expected due to the high number of zero-bycatch-observations in the data. Low sample sizes would thus with a high probability underestimate the bycatch estimates, but could by chance result in greatly overestimated bycatch rate as well. However, the sensitivity of the estimates seems to even out at a sample size of approximately 60 and upwards (Fig. 2). The probability to estimate close to "true" bycatch rate (i.e., within the standard error of the bycatch rate estimated from the total Reference fleet), was estimated to be approximately 20% at a sample size of 60 trips. Further, the same probability reaches 50% at a sample size of approximately 150 trips, and naturally increases as the sensitivity decreases with sample size.

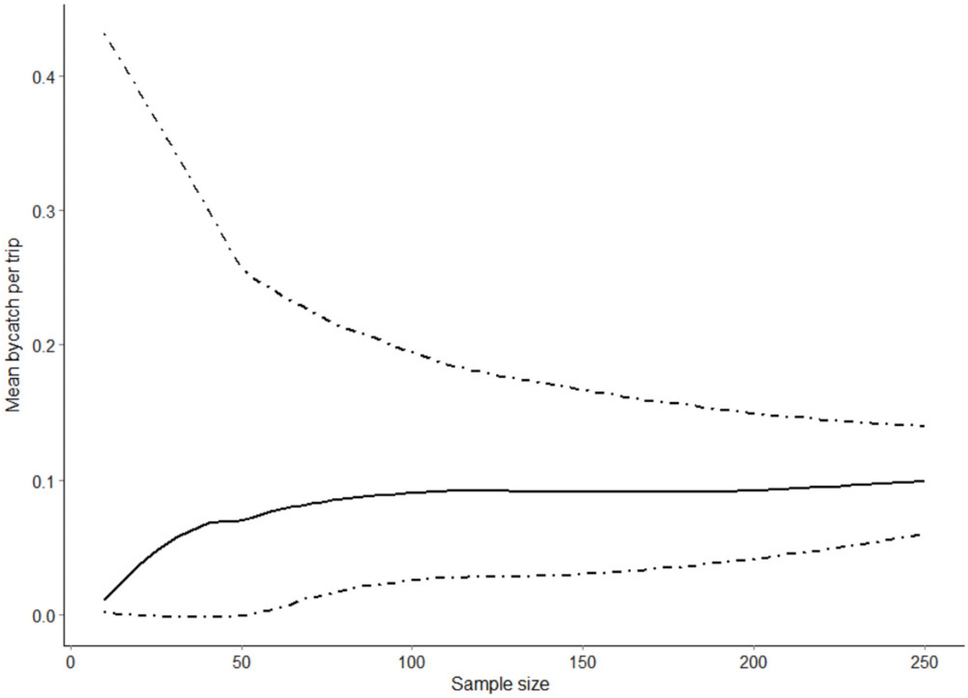

Fig. 2. Trend lines representing the sensitivity of mean bycatch-per-trip estimates (y-axis), as a function of sample size, i.e., number of trips sampled (x-axis). Solid line represent the median bycatch rate, upper dotdashed line represent the 95% percentile and lower dotdashed line the 5% percentile of the estimated bycatch rate. Each sample size was randomly drawn with 500 iterations from a data set representing bycatch data from the cod gillnet fishery of the Reference fleet in 2009 ($n = 455$).

4. Discussions

4.1. Seabird bycatch rates

Our results indicate that both the bycatch rates and species at risk vary substantially between fisheries and are highly dependent on fishing method and targeted fish in the Norwegian small-vessel fisheries. Fulmars dominated heavily the bycatch of the Greenland halibut longline fishery, whereas the three more coastal gillnet fisheries harvested a wider array of seabird species, with auks being most vulnerable.

The highest bycatch rate was observed in the Greenland halibut fishery, followed by the lumpfish gillnet fishery. However, for both of these fisheries our sets of observations were relatively limited and the results are characterized by high standard errors. Nonetheless, given our sensitivity results from the cod fishery, it is interesting to observe these high bycatch estimates as one should expect them to be underestimated rather than overestimated if the probability of bycatch was low. These fisheries should therefore be subjected to further surveys. The predominant cod fisheries had lower bycatch rates per unit effort, yet the extent of these fisheries resulted in a significant bycatch. The two different data-sampling approaches applied for the cod gillnet fishery produced similar bycatch estimates, suggesting both were valid. However, the mean catch per gillnet was about twice as high in the survey data compared to the fleet. This should be subject to further studies but we believe that a reason for this might be that while the fleet data are year-round data, the survey data for the most part come from spring and early summer.

To adjust for possible differences in bycatch rates between fishing areas, the cod gillnet fishery data was also analysed by using stratified mean. As this approach only changed the estimate by ten percent, the relative variation in sampling effort per area had little influence on the mean estimate. Thus, each area was almost equally represented in sampling effort according to the total fishing effort per area in the 2009 cod fishery data. Consequently, there were little in favour of have confidence in estimator 2 over estimator 1 for our data.

Our estimates of BPUE for the longline fishery (0.294 for the Greenland halibut fishery and 0.064 for the cod/haddock fishery) is well within the range of 0.00–1.008 birds per 1000 hooks reported in a global review of 68 studies of seabird bycatch in other longline fisheries (Anderson et al., 2011), yet definitively a high BPUE-estimate. Dunn and Steel (2001) estimated the summer bycatch for the Norwegian autoline fleet in 2006 to be 0.023 birds per 1000 hooks. In a former Norwegian study of the Atlantic auto-longline fishery for cod, ling and haddock (Løkkeborg, 2003), the corresponding rate ranged from 0.55 to 1.75 for lines without mitigation measures employed and from 0.00 to 0.49 for lines when testing the use of bird-scaring line, setting funnel or line shooter to avoid bycatch of birds. Taken together, this suggests that our results are in the lower range compared to Løkkeborg's study, but higher than in Dunn and Steel (2001) study. These findings do however need to be corroborated with more data to reduce measurement error due to low sample size. Our estimate of BPUE for the cod gillnet fishery was approximately twice as high for the survey data compared to similar estimates for the Reference fleet cod gillnet fishery. The variance between these estimates may have various causalities, and is beyond the scope of this study to pin-point. However, as the Reference fleet used on average twice as many gillnets per boat compared to the boats included survey (Nedreaas, pers. info), this might indicate that there is a non-linear relationship in BPUE for the gillnet fishery. It is also important to emphasize that our study only covered one year, and that substantial inter-annual variability in bycatch rates can be expected because of inter-annual variations documented for bird numbers and distribution at sea (e.g. Fauchald and Erikstad, 2002).

4.2. Estimates of total seabird bycatch

For upscaling bycatch rates to estimates of total bycatch for longline fisheries, effort measured as number of hooks set (either actual or estimated) is most frequently used (Anderson et al., 2011). Žydelis et al. (2009) state that the metrics used to record bycatch rates in gillnet fisheries vary, the most common being the number of birds caught per 1000 m of net length per day and, in the absence of true fishing effort, the bycatch rate per fishing vessel or per season. The Norwegian fisheries authorities do not request a specific measure of fishing effort as a parameter in the mandatory reporting system, giving no option to estimate total annual bycatch for a whole fishery based on BPUE. As we found no correlation between bycatch of seabirds and fish catch using the latter, this upscaling factor was judged inadequate. We therefore estimated bycatch rates by using the number of fishing trips as a proxy for effort, and extrapolated by the total number of fishing trips reported by sales-notes for the fleet in Northern Norway in 2009, but also estimated rates per 1000 hooks and per net ($\sim$length per net 27 m) making comparisons with other studies more feasible.

When upscaling the bycatch rates, the total bycatch-estimate ranged between 3100 and 3400 seabirds for each of the cod-haddock longline, cod gillnet and lumpfish gillnet fisheries in 2009. In the much smaller Greenland halibut longline fishery, about 1500 northern fulmars were estimated killed this year. Overall, the total bycatch from the screened fisheries total to around $11\,000 \pm 5000$ (SE) birds. However, the total bycatch rate for all the fisheries are rather hypothetical as the sample size for some of the fisheries are rather low, except for the estimates for the cod fishery from the reference fleet. The cod fishery makes up a large proportion of the North Norwegian coastal fishery with boats <15 m LOA, so except for a few other fisheries our study comprise the most important coastal fisheries. Our sensitivity analysis indicates that the variance of the mean bycatch rate estimates starts to stabilize when sample size reaches about 60 trips out of the total of 455 trips of the reference fleet. This represent a sampling effort of around 13% of the total. Although the variance naturally continues to decrease with further increase in sample size, this could then be considered as an absolute minimum sample size for the survey data set to be comparable to the reference fleet data set considering the 2009 cod fishery. This should however not be considered as an absolute limit, and will likely vary with e.g. fishery, and area. Simulation results from a Portuguese study (Oliveira et al., 2015) indicated that estimated seabird bycatch and associated 95% confidence limit began to stabilize after around 80 interviews and 200 vessel-trips per stratum.

4.3. Access-point survey as a method for collecting bycatch data

We have gained experience from the collection and analysis of two types of data; from a well-administered Reference fleet and from an adapted randomized survey of vessels as they approach a harbour to deliver their catch. The Reference fleet data for 2009 provided a statistically robust data set of high value, but it should be noted that the fleet samples only approximately 1% of the total coastal cod fleet (IMR, 2011). Therefore, the fleet is also too small to provide data for small niche fisheries such as the Greenland halibut and lumpfish fisheries. The training and reimbursement of the Reference fleet suggests that there will be less bias related to these data, however there is reason to question if the participating vessels are representative for the whole fleet as they are not recruited on a random basis. However, the accordance between the different bycatch estimates for cod gillnet fishery gives merit to both approaches. The access-point method proved to be less efficient and more costly than expected, yet the approach is useful, especially in smaller fisheries which limits the applicability of other methods (e.g. too costly to establish a reference fleet or lack of space on-board for independent observers). Therefore, interviews can be a feasible way to estimate bycatch especially from fisheries well defined in terms of vessels involved, season length and fishing area.

4.4. Research needs

The rate of seabird bycatch was found to be especially high in two of the fisheries studied; the lumpfish gillnet fishery and the Greenland halibut longline fishery, but the results are rather uncertain due to small sample sizes. Further research on incidental bycatch from these two fisheries is therefore needed.

A key question remaining un-explored is to what extent the mortality figures have a significant effect on the seabird populations involved. Especially, the high number of fulmars in the long-line fisheries and the vulnerability of black guillemot especially in the lumpfish gillnet fishery needs further attention. It is difficult to assess the origin of fulmars, but even if the decreasing population breeding on the Norwegian mainland does not count many more birds (e.g. Barrett et al., 2006), the fulmar is one of the most numerous seabird species encountered offshore in this area at all times of the year due to its large floating population of non-breeding individuals from other populations (Barrett et al., 2002; Fauchald, 2011). Considering that the black guillemot is among the most resident seabird species in the region and that the Norwegian population only counts about 35 000 breeding pairs (Barrett et al., 2006), this mortality may well have measurable effects at the population level. To more reliably assess effects at the bird population-level, both for northern fulmar and auks, more information is needed about the birds subjected to the bycatch; their age, gender and reproductive status breeders vs. non-breeders and population affiliation.

Finally, potential inaccuracies and biases of the methods applied need to be assessed, especially if self-reporting from fishermen produce lower estimates than those of independent observers. Also, potential biases in the selection procedure for participants in the reference fleet should be considered. Distribution of bycatch of seabirds is 0-inflated, and this needs to be considered both in the sampling plan and in choice of statistical approaches.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.gecco.2015.06.001.

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