BYCATCH OF SEABIRDS AND MARINE MAMMALS IN LUMPSUCKER GILLNETS 2014-2017

EXECUTIVE SUMMARY

In this report, bycatch of marine mammals and seabirds is estimated for the Icelandic lumpsucker gillnet fishery using data from 193 inspector trips carried out by the Directorate of Fisheries over a four-year period, 2014-2017. Four approaches were used for calculating bycatch; raising of a non-stratified dataset using all four years, the same dataset stratified by management area, same dataset stratified by month and finally the same dataset stratified by depth. Additionally, the effect of random sampling and annual variation in bycatch was investigated.

The most commonly bycaught marine mammal species were harbour seal, grey seal and harbour porpoise, while the most common seabird species were eider, black guillemot, common guillemot and cormorants/shags. The bycatch estimates from the three methods of stratification were relatively similar, although stratification for depth and stratification by month tended to give slightly higher estimates than the one stratified by management area. These three estimates were also broadly similar to the estimate from unstratified data. However, stratification of the data resulted in higher error around the estimates than the non-stratified dataset. The estimate for total number of marine mammals was lowest when stratified by management area (3100 ± 1086 animals), second lowest was the non-stratified estimate (3570 ± 607 animals), the estimate stratified by depth was slightly higher (3620 ± 2860 animals) but the highest estimate was the result of when the dataset was stratified by month (3850 ± 1577 animals). In comparison, there were 988 marine mammals registered in vessel logbooks in 2017. There was a similar result regarding the total numbers of seabirds, which were highest when stratified by month (9100 ± 3180 birds), second highest when stratified by depth (8800 ± 3962 birds), lowest when stratified by management area (7210 ± 3030 birds), with the non-stratified estimate being second lowest (8150 ± 1222 birds). A total of 2417 birds were reported in vessel logbooks in 2017.

When broken up by the most commonly bycaught species, the estimates for harbour porpoise differ little between estimates, with the depth stratified estimate (662) being 100 animals higher and the monthly stratified (428) being 100 animals lower than the other two estimates (~550). A total of 286 porpoises were reported in vessel logbooks in 2017. The depth stratified estimate for harbour seal is also higher (1663 seals) when compared to the non-stratified (1367 seals), stratified by month (1221 seals) and stratified by management area (1255 seals) estimates. The estimates stratified by depth and stratified by management area for grey seal were largely similar, while the non-stratified estimate was around 300 seals higher and the estimate stratified by depth being the highest at around 1900 animals. The four estimates for black guillemots were largely similar, or between 1500-2000 birds, and the same can be said for cormorants/shags were the three estimates were all between 800 and 1000 birds, with the highest estimates being the ones stratified by month. The eider bycatch estimates stratified by depth and stratified by month were around 1000-1400 birds higher than the other two estimates, while the common guillemot estimate stratified by depth was 400 birds higher than the non-stratified estimate and the estimate stratified by management area, while the estimate stratified by month was around 400 birds lower than those two estimates. A total of 442 eiders were reported in logbooks in 2017, while common guillemot was not reported separately, and therefore included in the "other seabird" category, but a total of 1198 "other" seabirds were reported in 2017.

Depth did not seem to have effect on bycatch rates, except for black guillemot, which had lower bycatch rates in deeper waters (40 m and deeper). Both grey seal and eider bycatch rates had decreasing trend with depth, but that effect was not statistically significant, perhaps due to low sample size.

Considerable annual variation was evident for some species, grey seals and eiders in particular. However, when the dataset was broken up by year, the most common bycatch species were the same in all four years. This suggests that the annual variation is mostly due to differences in sampling and the nature of the bycatch events, that tend to be rare but severe for these species, resulting in high variance.

Observed bycatch rates of both marine mammals and seabirds were higher in the inspection trips that were carried out at random when compared to targeted trips; trips were targeted to investigate anomalies in landings, allowable number of nets, bycatch of cod or other possible infractions.

Bycatch rates differed between months for grey seals, black guillemots and cormorants/shags that had higher bycatch rates in May-July than in other months. Caution should be advocated in interpreting these findings, as they are most likely confounded by management area and depth, since the areas have different fishing seasons, and operate in different depths depending on the month, and our sample size is inadequate to properly break up the data by management area and then month/depth. Depth and fishing months vary more between than within management areas, and therefore most of the variation due to depth and fishing months should be accounted for in the estimate stratified by area.

PREFACE

The fishery for lumpsucker (*Cyclopterus lumpus*) in Iceland primarily targets females for the roe. The males are targeted in a separate fishery with landings of males being approximately two orders of magnitude lower than that of the females. The male fishery is not considered in this report and all mentions of the lumpfish fishery refers to the female fishery. The lumpsucker fishery takes place from late March until August and uses large mesh (267-292 mm) gillnets. The main fishing areas are in coastal waters in Faxaflói, Breiðafjörður and all along the north coast. Very little fishing effort is in the east and south of the country (Figure 1). For management purposes, the country is divided up into 7 management areas, labelled A-G. The fishery is effort controlled, with limits placed on the total length of nets (lead lines), total number of fishing days per boat and total number of boats. Total catch is limited by altering the total number of fishing days allowed for each boat. The number of days set each year is controlled by the Minister of Fisheries and Agriculture, and is based on advised TAC from the MFRI

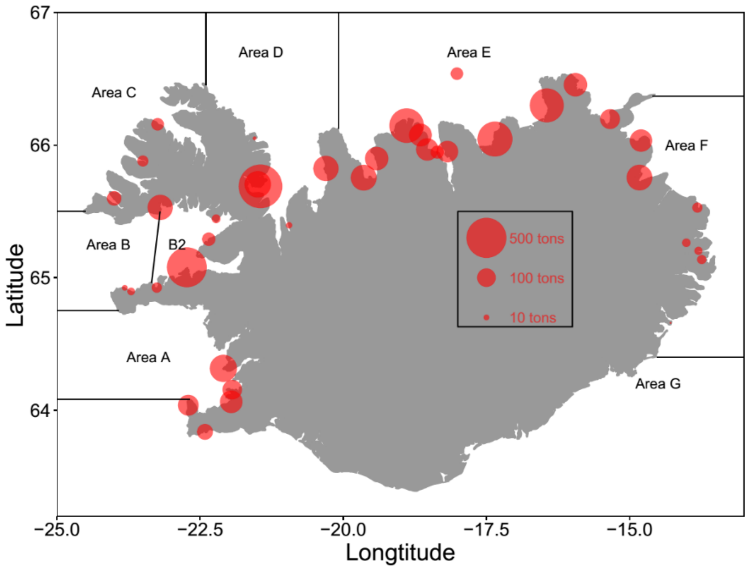

Figure 1. Landings of lumpsucker females by harbour in 2016. The lumpsucker management areas, A-G, are shown.

Marine mammal and seabird bycatch in the lumpsucker fishery was first estimated by Pálsson et al. 2015, that used paper-based logbooks supplemented by inspector checks to estimate the bycatch. They concluded, based on data from 2013, that around 400 porpoises, 700 harbour seals and 140 grey seals were caught annually in the lumpsucker fishery, in addition to around 2000 black guillemots, 1900 eiders and 900 cormorants. Seabird bycatch in the fishery was also estimated in 2016 by Birdlife International, using their own observers on 37 fishing trips (Bond et al. 2017). They estimated that around 9000 birds were bycaught in the fishery that year, thereof around 4000 black guillemots, 3000 eiders and 1500 great cormorants. It should be noted, however, that for the raising calculations Bond et al. (2017) used total allowable number of nets and fishing days as an effort metric, which may have resulted in an overestimation of bycatch by the fleet as not all boats use the total number of allowable nets (Bond et al. 2017), which might explain in part the difference of their estimate compared with Pálsson et al (2015).

METHODS

Before 2010, all bycatch of marine mammals and seabirds for the whole Icelandic fishing fleet was supposed to be reported by captains in paper-based logbooks. The data were subsequently entered manually into an electronic database at the Marine Research Institute in Reykjavik. These data paired with inspector checks was used in the report by Pálsson et al. 2015. An electronic logbook system was implemented in 2010, and since then logbook bycatch numbers for the lumpfish gillnet fishery have diminished due to unknown reasons, and there are indications that these numbers might be unrealistically low. Bycatch rates for this fishery were, for example, 5 times higher when an inspector was present in 2014-2016, when compared to the recorded bycatch rate of the fleet. Animals recorded by the inspectors were also rarely reported in logbooks, for example there were only 6 cases were harbour seals were reported both by the inspector and in the vessel logbook, out of 18 inspection trips were harbour seals were bycaught in 2017. Due to this apparent underreporting of bycatch in the logbooks, alternate data sources for bycatch were used for this study. The main source of data for this study are records of bycatch from onboard inspectors from the Directorate of Fisheries which were compared with logbook submissions.

Inspectors from the Directorate of Fisheries conduct dockside monitoring and deploy inspectors onboard fishing vessels all around the country. The main objective of the monitoring is to enforce rules concerning discards and gear regulations. The catch is also monitored and if it consists of a high proportion of under-sized fish, temporary area closures may be established. Since 2014, the inspectors also recorded any marine mammal or bird bycatch; before 2014, this was not always carried out. Inspector effort (observed trips vs total number of landings) in the lumpsucker fishery ranges from 0.7% in 2015 to 1.9% in 2017. Inspector effort over the four-years period considered for this study was therefore 1.4%. It is worth mentioning that the inspection trips are generally not selected randomly, as the process is often guided by anomalies in landings, or by the need to check for maximum number of nets, bycatch of cod or other possible infractions. To examine whether this potential bias impacts the estimated level of bycatch of marine mammals or birds, a separate study was made in 2017, where 40 out of the 71 inspection trips were selected at random in addition to those selected using the normal procedure. The bycatch rates in the randomly selected set of trips was compared with the non-randomly selected ones by a t-test for each of the more common bycatch species.

Total bycatch by species was estimated by four methods:

(1) No stratification, all years combined
(2) Stratifying by depth
(3) Stratifying by management area
(4) Stratifying by month

Bycatch was estimated in each strata using the formula:

$$Bycatch\ estimate = Bycatch\ recorded\ by\ inspectors\ \times \frac{total\ fishing\ effort}{observed\ fishing\ effort}$$

As an example, from the estimate stratified by management area, if 12 seals were bycaught in 17 inspection trips in management area A over the four years, and effort in that area was 1388 landings, then the estimated number of bycaught seals in that management area over the four years is $\frac{12}{17} \times 1388 = 980$ or 245 seals per year. The process is then repeated for the other management areas, and the results summed to get an annual estimate for the entire country.

Total number of landings by the fleet was used as the metric for effort rather than data on the number of nets and soak time from the fleet/logbooks, as the reporting of this data in the logbooks has been inadequate. For example, only 604 landings out of 3309 in 2016 had soak time and number of nets recorded, indicating that the logbook record is incomplete. The coefficient of variance of the calculated bycatch estimates was bootstrapped using the R package boot (Angelo and Ripley, 2017).

In regard to depth stratification, fishing depth was categorized into six 10-meter intervals, 0-10, 10-20, 20-30, 30-40, 40-50 and > 50 meters, where bycatch rates of the most common bycatch species were investigated using analysis of variance. Nets are laid perpendicular to the shore and for the purpose of this analysis, fishing depth was measured as the depth of the end of the net closest to shore. Depth was not recorded in 45 out of the 193 inspection trips, thus these trips were excluded from this analysis. For the purpose of raising the bycatch to the level of the entire fleet, the number of landings in each depth band was gathered when available from logbook data and the proportion at each depth interval multiplied by total landings to account for landings where depth was not recorded.

Influence of month on the bycatch rates of the most common bycatch species was investigated using analysis of variance, to investigate the effect of changes in behaviour of the bycaught species during the fishing season. The bycatch was then estimated by raising the observed monthly bycatch rates by number of landings in each month.

In regard to stratification by management area, bycatch was raised by the number of trips in each management area. The total bycatch of each species for the fleet is calculated by summing the total bycatch from each management area.

INSPECTOR COVERAGE AND FISHING EFFORT

In general, there was good correspondence between inspector effort and fishing effort by management area if all four years are lumped together (Tables 1 & 2). The main discrepancies were in management areas C that had higher inspector coverage than relative fishing effort, and management area E that had lower inspector effort than relative fishing effort. Other areas differed by 3% or less. Proportional coverage in each management area differs by year.

Table 1. Spatial coverage of inspections. Number of observed (ob.) trips by inspectors in the lumpsucker gillnet fishery by management area in 2014-2017. Percentage of the total number of trips is shown in brackets.

Area/Year	A	B	C	D	E	F	G	Total ob. trips
2014	5	14	8	6	5	0	0	38
2015	0	5	7	1	10	4	1	28
2016	3	8	6	7	21	8	4	57
2017	9	9	0	20	29	3	1	71
Total	17 (9%)	36 (18%)	21 (10%)	34 (18%)	65 (34%)	15 (8%)	6 (3%)	193

Table 2. Spatial distribution of the fishery. Number of landings in the lumpsucker gillnet fishery by management area in 2014-2017. Percentage of the total number of trips is shown in brackets.

Area/Year	A	B	C	D	E	F	G	Total trips
2014	333	544	164	371	1290	249	49	3000
2015	361	680	157	484	1536	426	125	3769
2016	315	515	101	523	1360	401	94	3309
2017	379	925	106	360	1286	460	116	3632
Total	1388 (10%)	2664 (19%)	528 (4%)	1738 (13%)	5472 (40%)	1536 (11%)	384 (3%)	13710

Temporal coverage of the inspector trips was not as good as the spatial coverage due to multiple trips in March in 2017, and relatively few inspector trips in May of the same year. There was good correspondence between inspector trips and number of landings by the fleet in April, June and July (Tables 3 and 4).

Table 3. Temporal coverage of inspections. Number of observed trips by inspectors in the lumpsucker gillnet fishery by month in 2014-2017. Percentage of the total number of trips is shown in brackets.

Area/Year	March	April	May	June	July	August	Total ob. trips
2014	0	8	19	12	0	0	38

2015	6	10	9	1	2	0	28
2016	1	42	5	7	0	0	57
2017	43	14	5	6	3	0	71
Total	50 (26%)	74 (38%)	38 (20%)	26 (13%)	5 (3%)	0 (0%)	193

Table 4. Temporal distribution of the fishery. Number of landings in the lumpsucker gillnet fishery by month in 2014-2017. Percentage of the total number of landings is shown in brackets.

Area/Year	March	April	May	June	July	August	Number of landings
2014	158	1395	1020	349	78	0	3000
2015	341	1563	1246	418	198	3	3769
2016	122	1937	762	334	150	4	3309
2017	390	1269	1122	469	285	97	3632
Total	1011 (7%)	6164 (45%)	4150 (30%)	1570 (12%)	711 (5%)	104 (1%)	13710

When stratified by depth, around 13% of the landings were from 0-10 m depth, while 28% of the inspector trips occurred at this depth range, while proportionally fewer inspector trips occurred at the two deepest intervals when compared to fishing effort at these depths (Table 5).

Table 5. Depth distribution of the fishery and inspector trips. Percentage of landings and inspector trips in the lumpsucker gillnet fishery by depth in 2014-2017.

Depth interval	Landings	Inspector trips
0-10 m	13%	28%
10-20 m	34%	30%
20-30 m	18%	19%
30-40 m	13%	10%
40-50 m	10%	5%
50 m +	13%	8%

RESULTS

NON-STRATIFIED BYCATCH ESTIMATE

Using data from all four years, the overall marine mammal bycatch rate was just above 1 animal per trip, while the overall seabird bycatch rate was around 2.4 birds per trip. The most common bycaught marine mammals were grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*), with a bycatch rate of 0.40 animals per trip, which, raised by effort, results in just below 1400 animals per year for both of these species. The coefficient of variation around the estimate was considerably higher for grey seals (36%) than it was for harbour seals (17%). Harbour porpoises (*Phocoena phocoena*) were the third most common bycaught marine mammal, with a bycatch rate of 0.16 animals per trip, which results in around 550 animals per year when raised by effort. Bycatch rates of the other three species of marine mammals observed, harp seals (*Pagophilus groenlandicus*), ringed seals (*Pusa hispida*) and bearded seals (*Erignathus barbatus*) were much lower. The most common bycaught seabird species, by far, were eiders (*Somateria mollissima*), with bycatch rate of 1.20 birds per trip, or around 4100 birds raised by effort. Black guillemots (*Cepphus grylle*) and common guillemots (*Uria aalge*) were the second and third most common seabirds observed, with bycatch rate of 0.47 and 0.39 birds per trip, or around 1600 and 1400 birds raised by effort. Cormorant/shag species (Great cormorant, *Phalacrocorax carbo*, and European shag, *Phalacrocorax aristotelis*) were the fourth most common seabirds, with 0.23 birds per trip or around 800 birds raised by effort. Other seabird species observed, Brünnich's guillemot (*Uria lomvia*), long tailed duck (*Clangula hyemalis*), common loon (*Gavia immer*), Atlantic puffin (*Fratercula arctica*), razorbill (*Alca torda*), black-legged kittiwake (*Rissa tridactyla*) and gannet (*Morus bassanus*), were much rarer (Table 6).

Table 6. Bycatch of marine mammals and seabirds in the lumpsucker in 2014-2017. Obs. numbers refer to amount of bycatch recorded by inspectors, while raised estimate are numbers raised by number of landings. Raised estimates have coefficient of variation (%) in brackets.

Species	Observed 2014-2017	Bycatch rate (n/trip)	Raised 2014-2017
Harbour porpoise	31	0.16	551 (21)
Harbour seal	77	0.40	1367 (17)
Grey seal	78	0.40	1385 (36)
Harp seal	10	0.05	177 (36)
Ringed seal	3	0.02	53 (75)
Bearded seal	2	0.01	36 (72)
Total marine mammals	**201**	**1.04**	**3570 (17)**
Common guillemot	76	0.39	1350 (37)
Brünnich's guillemot	4	0.02	71 (63)
Black guillemot	91	0.47	1616 (19)
Cormorant/Shag	45	0.23	799 (23)
Common eider	231	1.20	4102 (23)
Atlantic puffin	2	0.01	36 (69)
Long tailed duck	4	0.02	71 (48)
Black-legged Kittiwake	1	0.01	18 (100)
Razorbill	1	0.01	18 (100)
Gannet	1	0.01	18 (96)
Common loon	3	0.02	53 (57)
Total seabirds	**459**	**2.38**	**8151 (15)**

ANNUAL BYCATCH ESTIMATES

When the data is separated by year, it is evident that there is a considerable annual variation in bycatch. Undeniably, the same three species of marine mammals are most common all years but vary substantially between years. This is particular evident for the grey seal, which ranged from 4 observed bycaught animals in 2017, to 46 in 2016. Notably, the majority of those 46 seals in 2016 were caught in just three fishing trips. This results in very high coefficient of variation and therefore in a high estimate of bycatch for this species. As for seabirds, eiders are by far the most common bycaught species in all four years, but the numbers observed vary considerably between years, resulting in highly variable bycatch estimate. Black guillemots, common guillemots and cormorants/shags were also common in most years, while other species were rarer (Table 7).

Table 7. Bycatch of marine mammals and seabirds in the lumpsucker gillnet fishery by year in 2014-2017. Obs. Numbers refer to amount of bycatch recorded by inspectors, while raised estimates are observed values raised by number of landings. Raised estimates have coefficient of variation (%) in brackets.

Species	Obs. 2014	Raised 2014	Obs. 2015	Raised 2015	Obs. 2016	Raised 2016	Obs. 2017	Raised 2017
Harbour porpoise	6	486 (44)	3	404 (53)	6	374 (53)	16	819 (30)
Harbour seal	11	811 (30)	22	2961 (28)	10	624 (44)	34	1739 (29)
Grey seal	7	568 (65)	21	2827 (49)	46	2870 (56)	4	205 (47)
Harp seal	1	81 (97)	3	404 (74)	3	187 (56)	3	153 (70)
Ringed seal	2	162 (101)	0	0	0	0 (0)	1	51 (100)
Bearded seal	0	0 (0)	0	0	2	124 (73)	0	0 (0)
Total marine mammals	**26**	**2108 (33)**	**49**	**6596 (31)**	**67**	**4179 (39)**	**58**	**2967 (22)**
Common guillemot	10	811 (42)	7	942 (52)	12	749 (76)	47	2404 (57)
Brünnich's guillemot	2	162 (100)	0	0 (0)	1	62 (100)	1	51 (100)
Black guillemot	44	3568 (24)	11	1481 (39)	16	998 (52)	20	1023 (52)
Cormorant/Shag	21	1703 (24)	13	1749 (49)	1	62 (100)	10	512 (46)
Common eider	42	3316 (29)	95	12788 (44)	32	1997 (43)	62	3172 (38)
Atlantic puffin	0	0 (0)	1	135 (95)	1	62 (100)	0	0 (0)
Long tailed duck	1	81 (98)	0	0	1	62 (100)	2	102 (70)
Black-legged Kittiwake	1	81 (100)	0	0	0	0 (0)	0	0 (0)
Common loon	2	162 (68)	0	0	0	0 (0)	1	51 (100)
Razorbill	0	0 (0)	0	0	0	0 (0)	1	51 (98)
Gannet	0	0 (0)	0	0	0	0 (0)	1	51 (98)
Total seabirds	**122**	**9892 (17)**	**127**	**17095**	**64**	**3992 (33)**	**145**	**7468 (29)**

STRATIFICATION BY MANAGEMENT AREA

When the data is stratified by management area, it is evident that the bycatch rate of some species is uniform across management areas, while other species have higher rates in one or more areas. Out of the marine mammals bycaught, both harbour seals ($F_{6,185}$ = 1.25, p = 0.28) and harbour porpoises ($F_{6,185}$ = 0.45, p = 0.85) have relatively uniform bycatch rates across areas, while bycatch rates of grey seal are considerably higher in management areas B and C ($F_{6,185}$ = 2.67, p = 0.02) than in other areas. Bycatch rates of eiders was significantly higher in area C ($p < 0.05$), but uniform in other areas while bycatch rates of black guillemots were higher in areas A, B, C and F, than in areas D, E and G. Bycatch rates of cormorants/shags were significantly higher in areas A, B and G than in other areas ($p < 0.05$).

When total bycatch is estimated from unstratified data and when stratified by management area, the total annual marine mammal bycatch for the fleet during the period 2014-2017 differs by 500 animals; a total of 3600 animals for unstratified data and 3100 animals when stratified by management area. In regard to bird bycatch, unstratified data gave an estimate of 8200 birds while stratifying by area gave an estimate of 7200 birds. As for seabirds, almost all the difference observed can be explained by the bycatch of eiders, where the overall estimate from unstratified data is approximately 900 birds higher than the estimate from data stratified by management area, while the other species, black guillemots, common guillemots and cormorants/shags differ by around 100 birds or less (Tables 6 & 8).

Table 8. Bycatch of marine mammals and seabirds in the lumpsucker gillnet fishery in 2014-2017 by management area. Obs. numbers refer to amount of bycatch recorded by inspectors, while raised estimates are observed values raised by number of landings. Species were significant effect of area was observed are marked with an asterisk, and different letters above bycatch rates per area in those species indicate significant difference (p >0.05) from other months. Raised estimates have coefficient of variation (%) in brackets.

Species / Area	Observed 2014-2017								Bycatch rate (n/trip)							Raised 2014-2017 (CV %)							
	A	B	C	D	E	F	G	**Total**	A	B	C	D	E	F	G	A	B	C	D	E	F	G	**Total**
Harbour porpoise	4	8	3	6	7	3	0	**31**	0.24	0.22	0.14	0.18	0.11	0.2	0	82 (44)	148 (40)	19 (54)	76 (43)	147 (56)	77 (72)	0	**549 (52)**
Harbour seal	12	14	15	15	16	5	0	**77**	0.71	0.39	0.71	0.44	0.25	0.33	0	245 (77)	259 (39)	94 (31)	192 (29)	337 (27)	128 (47)	0	**1255 (42)**
Grey seal*	0	44	28	3	3	0	0	**78**	0[b]	1.22[a]	1.33[a]	0.09[b]	0.05[b]	0[b]	0	0	814 (47)	176 (59)	38 (56)	63 (53)	0	0	**1091 (54)**
Harp seal	2	0	5	1	1	1	0	**10**	0.12	0	0.24	0.03	0.02	0.07	0	41 (100)	0	31 (49)	13 (99)	21 (99)	26 (97)	0	**132 (89)**
Ringed seal	1	0	2	0	0	0	0	**3**	0.06	0	0.10	0	0	0	0	20 (100)	0	13 (95)	0	0	0	0	**33 (98)**
Bearded seal	0	0	0	0	2	0	0	**2**	0	0	0	0	0.03	0	0	0	0	0	0	42 (71)	0	0	**42 (71)**
Total marine mammals	**19**	**66**	**53**	**25**	**29**	**9**	**0**	**201**	**1.12**	**1.83**	**2.52**	**0.74**	**0.45**	**0.6**	**0**	**388 (54)**	**1221 (36)**	**333 (35)**	**319 (22)**	**610 (22)**	**231 (39)**	**0**	**3102 (35)**
Common guillemot	3	32	2	15	21	3	0	**76**	0.18	0.89	0.10	0.44	0.32	0.20	0	61 (94)	592 (68)	13 (70)	192 (60)	442 (79)	77 (68)	0	**1376 (73)**
Brünnich's guillemot	0	0	0	1	3	0	0	**4**	0	0	0	0.03	0.05	0	0	0	0	0	13 (98)	63 (74)	0	0	**76 (86)**
Black guillemot*	10	32	22	3	17	7	0	**91**	0.59[a]	0.89[a]	1.05[a]	0.09[b]	0.26[b]	0.47[a]	0[b]	204 (58)	592 (29)	138 (40)	38 (71)	358 (50)	179 (78)	0	**1510 (54)**
Cormorant/ Shag*	8	23	3	3	2	3	3	**45**	0.47[a]	0.64[a]	0.14[b]	0.09[b]	0.03[b]	0.20[b]	0.50[a]	163 (48)	426 (31)	19 (100)	38 (55)	42 (68)	77 (93)	48 (94)	**813 (70)**
Common eider*	22	27	98	16	61	7	0	**231**	1.29[b]	0.75[b]	4.67[a]	0.47[b]	0.94[b]	0.47[b]	0[b]	449 (57)	500 (44)	616 (42)	204 (61)	1284 (36)	179 (57)	0	**3232 (50)**
Atlantic puffin	0	1	0	0	1	0	0	**2**	0	0.02	0	0	0.02	0	0	0 (0)	19 (97)	0	0	21 (96)	0	0	**40 (97)**
Long tailed duck	1	0	1	1	1	0	0	**4**	0.06	0	0.05	0.03	0.02	0	0	20 (100)	0	6 (96)	13 (100)	21 (100)	0	0	**61 (99)**
Black-legged Kittiwake	0	0	1	0	0	0	0	**1**	0	0	0.05	0	0	0	0	0 (0)	0	6 (97)	0	0	0	0	**6 (97)**
Common loon	1	0	0	0	0	1	0	**2**	0.06	0	0	0	0	0.07	0	20 (99)	0	0	13 (100)	0	26 (100)	0	**59 (100)**
Razorbill	0	0	0	1	0	0	0	**1**	0	0	0	0.03	0	0	0	0	0	0	13 (100)	0	0	0	**13 (100)**
Gannet	0	0	0	0	1	0	0	**1**	0	0	0	0	0.02	0	0	0	0	0	0	21 (99)	0	0	**21**
Total seabirds	**46**	**115**	**127**	**41**	**107**	**21**	**0**	**459**	**2.65**	**3.19**	**6.05**	**1.38**	**1.75**	**1.60**	**0.50**	**919 (38)**	**2128 (21)**	**798 (33)**	**524 (32)**	**2252 (31)**	**538 (47)**	**48 (94)**	**7207 (42)**

STRATIFICATION BY MONTH

Total bycatch of marine mammals ($F_{4,186} = 1.79$, $p = 0.13$) and seabirds ($F_{4,186} = 1.56$, $p = 0.19$) did not vary significantly by month. However, if this was broken down to species level, catch rates of grey seal ($F_{4,186} = 2.74$, $p = 0.03$), black guillemot ($F_{4,186} = 8.20$, $p < 0.0001$) and cormorants/shags ($F_{4,186} = 12.96$, $p < 0.0001$) differed by month. Whereas, catch rates of harbour porpoise, harbour seal, guillemot and eider did not vary between months ($p > 0.2$).

Grey seal bycatch rates were significantly higher in May than in other months ($p < 0.05$). Similarly, bycatch rates of black guillemot were higher in May, June and July than in other months ($p < 0.05$). In regard to cormorants/shags, bycatch rates in May and July were significantly higher than in other months (Table 9).

When estimated bycatch stratified by month is compared to the unstratified estimate, the total marine mammal bycatch for the fleet differs by around 250 animals; a total of ~3600 animals for unstratified data and ~3850 animals when stratified by month, mostly due to higher grey seal bycatch in the stratified by month estimate. In regard to bird bycatch, the unstratified estimate was 8200 birds while the estimate stratified by month was 9100 birds. Bycatch of eiders, black guillemots and cormorants/shags was 300-1200 birds higher in the stratified by month estimate, while bycatch of common guillemots was 500 birds lower (Tables 6 & 9).

Table 9. Bycatch rates of marine mammals and seabirds in the lumpsucker gillnet fishery in 2014-2017 by month. Species were significant effect of month was observed are marked with an asterisk, and different letters above bycatch rates per month in those species indicate significant difference (p >0.05) from other months. Raised estimates are observed values raised by number of landings in each month. Raised estimates have coefficient of variation (%) in brackets.

Species /	Observed 2014-2017							Bycatch rate (n/trip)							Raised 2014-2017 (CV %)						
Month	3	4	5	6	7	8	Total	3	4	5	6	7	8	Average	3	4	5	6	7	8	Total
Harbour porpoise	14	9	4	4	0	0	**31**	0.28	0.12	0.11	0.15	0	0	0.13	71 (32)	187 (38)	109 (49)	60 (58)	0 (0)	0 (0)	**428 (44)**
Harbour seal	31	24	14	5	3	0	**77**	0.62	0.32	0.36	0.19	0.60	0	0.42	157 (33)	500 (25)	382 (43)	76 (40)	107 (81)	0 (0)	**1221 (44)**
Grey seal*	3	24	51	0	0	0	**78**	0.06^{b}	0.32^{a}	1.34^{a}	0^{b}	0^{b}	0	0.35	15 (54)	500 (71)	1392 (42)	0 (0)	0 (0)	0 (0)	**1907 (56)**
Harp seal	2	6	2	0	0	0	**10**	0.04	0.08	0.05	0	0	0	0.03	10 (99)	125 (46)	55 (69)	0 (0)	0 (0)	0 (0)	**190 (71)**
Ringed seal	1	0	2	0	0	0	**3**	0.02	0	0.05	0	0	0	0.02	5 (100)	0 (0)	55 (95)	0 (0)	0 (0)	0 (0)	**60 (97)**
Bearded seal	0	2	0	0	0	0	**2**	0	0.03	0	0	0	0	0.01	0 (0)	42 (68)	0 (0)	0 (0)	0 (0)	0 (0)	**42 (68)**
Total marine mammals	**51**	**65**	**73**	**9**	**3**	**0**	**201**	**1.02**	**0.88**	**1.92**	**0.35**	**0.60**	**0**	**0.96**	**258 (23)**	**1354 (32)**	**1993 (33)**	**136 (35)**	**107 (81)**	**0 (0)**	**3847 (41)**
Common guillemot	48	15	10	3	0	0	**76**	0.96	0.20	0.26	0.12	0	0	**0.31**	243 (55)	312 (65)	273 (42)	45 (94)	0 (0)	0 (0)	**873 (64)**
Brünnich's guillemot	1	2	1	0	0	0	**5**	0.02	0.03	0.03	0	0	0	**0.01**	5 (97)	42 (97)	27 (100)	0 (0)	0 (0)	0 (0)	**74 (98)**
Black guillemot*	1	14	41	29	6	0	**91**	0.02^{b}	0.19^{b}	1.08^{a}	1.15^{a}	1.20^{a}	0	**0.72**	5 (100)	292 (42)	1119 (27)	438 (34)	213 (79)	0 (0)	**2067 (56)**
Cormorant/shag*	3	1	25	10	6	0	**45**	0.06^{c}	0.01^{c}	0.66^{b}	0.38^{c}	1.20^{a}	0	**0.46**	15 (57)	21 (99)	683 (31)	151 (28)	213 (40)	0 (0)	**1083 (51)**
Common eider	12	119	52	44	4	0	**231**	0.24	1.61	1.37	1.12	1.20	0	**1.14**	61 (69)	2478 (38)	1420 (31)	664 (44)	142 (84)	0 (0)	**4765 (53)**
Atlantic puffin	0	0	1	1	0	0	**2**	0	0	0.02	0.04	0	0	**0.01**	0 (0)	0 (0)	27 (100)	15 (98)	0 (0)	0 (0)	**42 (99)**
Long tailed duck	2	1	1	0	0	0	**4**	0.04	0.01	0.03	0	0	0	**0.01**	10 (69)	21 (100)	27 (96)	0 (0)	0 (0)	0 (0)	**58 (88)**
Black legged Kittiwake	0	0	1	0	0	0	**1**	0	0	0.03	0	0	0	**0.01**	0 (0)	0 (0)	27 (98)	0 (0)	0 (0)	0 (0)	**27 (98)**
Common loon	0	0	2	1	0	0	**3**	0	0	0.05	0.04	0	0	**0.02**	0 (0)	0 (0)	55 (69)	15 (100)	0 (0)	0 (0)	**70 (85)**
Razorbill	1	0	0	0	0	0	**1**	0.02	0	0	0	0	0	**0.01**	5 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**5 (100)**
Gannet	0	1	0	0	0	0	**1**	0	0.01	0	0	0	0	**0.01**	0 (0)	21 (100)	0 (0)	0 (0)	0 (0)	0 (0)	**21 (100)**
Total seabirds	**68**	**153**	**134**	**88**	**16**	**0**	**459**	**1.36**	**2.06**	**3.53**	**3.38**	**3.2**	**0**	**2.71**	**344 (40)**	**3186 (31)**	**3659 (19)**	**1328 (31)**	**569 (53)**	**0 (0)**	**9086 (35)**

STRATIFICATION BY DEPTH

No significant effect of depth was observed on the total marine mammal bycatch rate ($F_{5,139}$ = 0.69, p = 0.63) (Figure 2). When broken up by species, there was no significant effect of depth observed on the bycatch rate for harbour seal ($F_{5,139}$ = 0.89, p = 0.49), grey seal ($F_{5,139}$ = 1.89, p = 0.10), harbour porpoise ($F_{5,139}$ = 1.05, p = 0.39), nor for harp seal ($F_{5,139}$ = 0.53, p = 0.75). Similarly, there was no significant effect of depth observed on total bird bycatch rate ($F_{5,139}$ = 1.449 p = 0.21) (Figure 3). When broken up by species, there was however a significant effect of depth on the bycatch rate for black guillemot ($F_{5,139}$ = 2.69, p = 0.02), where bycatch rates at 10 meters or less, 21-30 m and 31-40 m depth were higher than at 11-20 m or at deeper than 40-meters depth. No significant effect of depth was seen on the bycatch rate of other bird species (p > 0.4).

When bycatch stratified by depth is compared with the total bycatch estimated from unstratified data, the total marine mammal bycatch was very similar; or a total of 3570 animals for unstratified data and 3620 animals when stratified by depth (Table 10). This was expected, as no significant effect of depth was observed for marine mammals. In regard to bird bycatch, unstratified data gave an estimate of 8200 birds while stratifying by depth gave somewhat higher estimate of 8800 birds (Table 10).

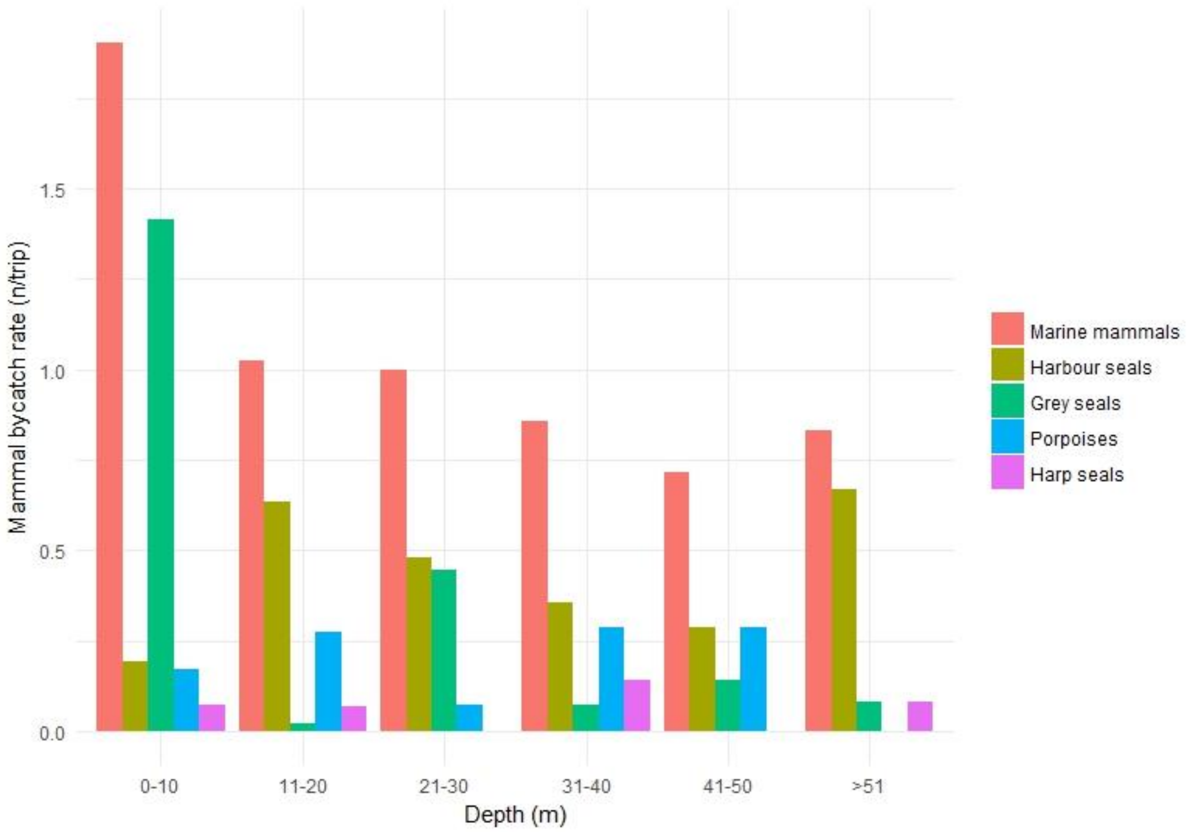

Figure 2. Bycatch rate of the four most common marine mammals, in addition to total bycatch rate of marine mammals by depth in the lumpsucker gillnet fishery in 2014-2017.

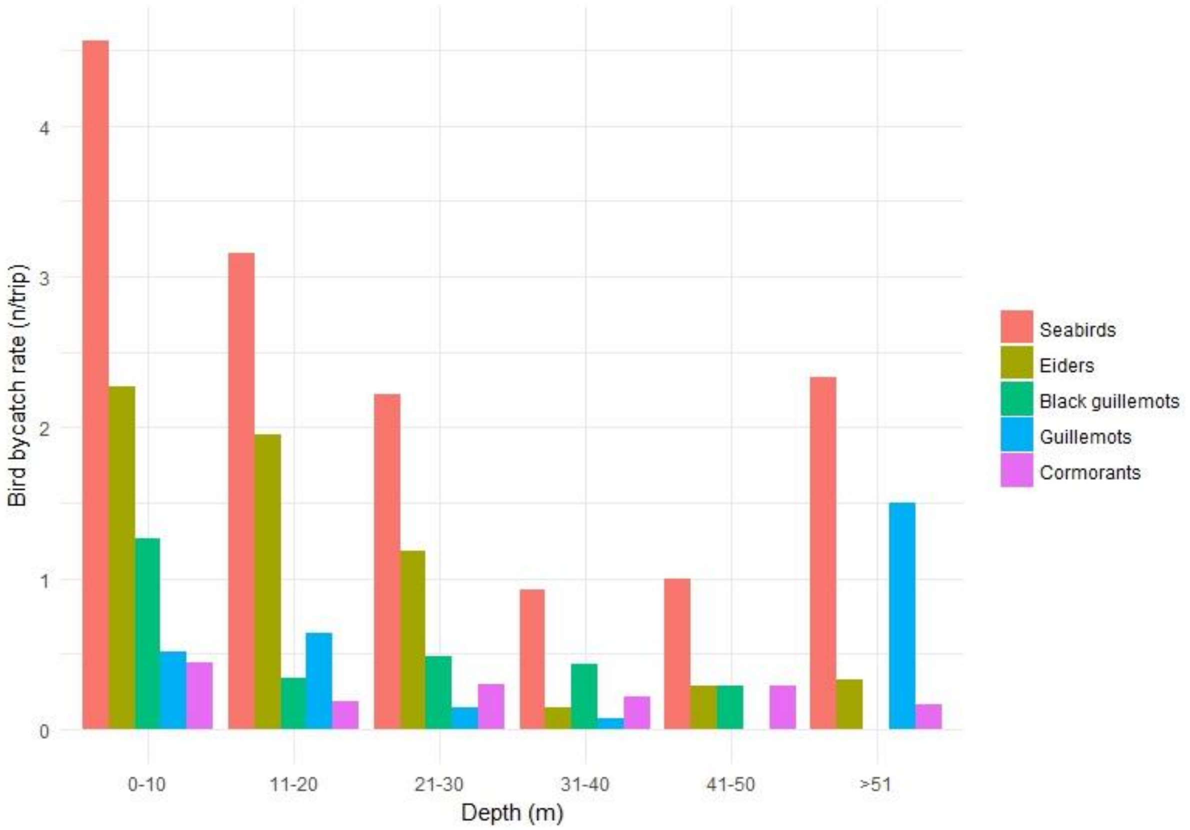

Figure 3. Bycatch rate of the four most common sea birds, in addition to total bycatch rate of seabirds by depth in the lumpsucker gillnet fishery in 2014-2017.

Table 10. Bycatch rates of marine mammals and seabirds in the lumpsucker gillnet fishery in 2014-2017 by depth. Raised estimates are observed values raised by number of landings. Species were significant effect of depth was observed are marked with an asterisk, and different letters above bycatch rates per depth interval in those species indicate significant difference (p >0.05) from other depth intervals. Raised estimates have coefficient of variation (%) in brackets.

Species /	Bycatch rate (n/trip)							Annual raised estimate 2014-2017						
Depth	0-10	10-20	20-30	30-40	40-50	50+	Average	0-10	10-20	20-30	30-40	40-50	50+	Total
Harbour porpoise	0.17	0.27	0.07	0.29	0.29	0.0	**0.18**	76 (35)	318 (38)	43 (70)	127 (54)	100 (59)	0	**662 (51)**
Harbour seal	0.20	0.64	0.48	0.36	0.29	0.67	**0.44**	87 (47)	742 (33)	281 (44)	159 (46)	100 (60)	297 (42)	**1663 (45)**
Grey seal	1.41	0.03	0.44	0.07	0.14	0.08	**0.36**	630 (44)	26 (100)	259 (75)	32 (96)	49 (89)	37 (98)	**1034 (84)**
Harp seal	0.07	0.07	0.00	0.14	0.00	0.08	**0.06**	33 (71)	79 (75)	0	64 (67)	0	37 (94)	**213 (77)**
Ringed seal	0.05	0.02	0.00	0.00	0.00	0.00	**0.01**	22 (95)	26 (100)	0	0	0	0	**48 (97)**
Bearded seal	NA	NA	NA	NA	NA	NA	**NA**	NA	NA	NA	NA	NA	NA	**NA**
Total marine mammals	**1.90**	**1.02**	**1.00**	**0.86**	**0.71**	**0.83**	**1.05**	**848 (35)**	**1192 (26)**	**583 (52)**	**382 (32)**	**245 (35)**	**371 (31)**	**3620 (79)**
Common guillemot	0.51	0.64	0.15	0.07	0.00	1.50	**0.48**	228 (98)	742 (44)	86 (73)	32 (95)	0	668 (84)	**1756 (79)**
Brünnich's guillemot	0.00	0.00	0.04	0.00	0.00	0.25	**0.05**	0	0	22 (98)	0	0	111 (71)	**133 (85)**
Black guillemot*	1.27[a]	0.34[b]	0.48[a]	0.43[a]	0.29[b]	0.00[b]	**0.47**	562 (25)	397 (43)	291 (42)	191 (92)	98 (61)	0	**1532 (53)**

Cormorant/shag	0.44	0.18	0.29	0.21	0.29	0.17	**0.26**	196 (33)	212 (48)	173 (53)	95 (92)	98 (62)	74 (65)	**848 (59)**
Common eider	2.27	1.95	1.19	0.14	0.29	0.33	**1.03**	1011 (34)	2278 (41)	691 (63)	64 (65)	98 (61)	149 (72)	**4289 (56)**
Atlantic puffin	0.02	0.00	0.00	0.00	0.00	0.00	**0.01**	11 (95)	0	0	0	0	0	**11 (95)**
Long tailed duck	0.02	0.02	0.00	0.00	0.14	0.00	**0.03**	11 (100)	26 (100)	0	0	49 (92)	0	**86 (97)**
Black legged Kittiwake	0.02	0.00	0.00	0.00	0.00	0.00	**0.01**	11 (95)	0	0	0	0	0	**11 (95)**
Common loon	0.00	0.02	0.03	0.07	0.00	0.00	**0.02**	0	26 (94)	22 (97)	32 (97)	0	0	**80 (96)**
Razorbill	0.00	0.00	0.00	0.00	0.00	0.08	**0.01**	0	0	0	0	0	37 (91)	**37 (91)**
Gannet	0.00	0.00	0.04	0.00	0.00	0.00	**0.01**	0	0	22 (100)	0	0	0	**22 (100)**
Total seabirds	**4.56**	**3.16**	**2.22**	**0.93**	**1.00**	**2.33**	**2.37**	**2032 (23)**	**3681 (26)**	**1295 (39)**	**414 (74)**	**343 (53)**	**1040 (53)**	**8805 (45)**

RANDOM OR TARGETED SAMPLING

Bycatch rate of both marine mammals and seabirds was considerably higher in inspection trips selected at random in 2017. The bycatch rate of marine mammals was almost 1 animal per trip in the randomly selected trips, while the targeted trips had a bycatch rate of 0.6 animals per trip. As for seabirds, the difference was higher, and bycatch rate in the randomly selected trips was 2.9 birds per trip while it was 0.9 birds per trip in the targeted trips. The difference in bycatch rate of marine mammals was not statistically significant (t_{67} = -1.09, p = 0.14), while the difference in seabirds was significantly higher in the randomly selected trips (t_{67} = -1.86, p = 0.03). Out of the most common bycaught marine mammals, no significant difference in bycatch rates between the two sampling schemes was observed ($p > 0.05$), as in the bycatch rates of common guillemot and cormorants/shags ($p > 0.1$). Bycatch rates of eiders (t_{46} = -1.86, p = 0.03) and black guillemots (t_{40} = -1.72, p = 0.05) were significantly higher in the randomly selected trips.

LOGBOOK DATA

The examination of logbook data shows that, as is the case of the data from inspectors, seal species were the most commonly reported bycatch by lumpsucker vessels in all four years. Some harbour porpoise bycatch was reported in the logbooks as well. The species composition of those bycaught seals is unknown due to the logbook entries only reporting them as “seals”. A similar problem exists regarding seabirds, as a substantial proportion of the birds are only reported as “seabirds”. However, black guillemots, eiders and cormorants/shags were sometimes reported as separate species/groups (Table 11). A marked increase in bycatch was observed in 2017, when the reported number of seals, eiders and black guillemots more than doubled from previous years and the number of porpoises and other seabirds recorded increased tenfold (Table 11). This increase in reporting could be attributed to a real increase in bycatch, to a better compliance in the reporting or both.

Table 11. Bycatch of marine mammals and seabirds in the lumpsucker gillnet fishery in 2014-2017 as reported by the fishing fleet.

Species	2014	2015	2016	2017	Average
Seal species	215	334	279	700	382
Harbour porpoise	65	20	22	286	98
White beaked dolphin	0	0	1	2	1

Unidentified dolphin	0	0	0	1	0
Total marine mammals	**280**	**354**	**301**	**989**	**481**
Cormorants/Shags	85	204	193	177	165
Black guillemot	97	252	288	600	309
Common eider	142	165	213	442	241
Other seabirds	219	299	182	1198	475
Total seabirds	**343**	**920**	**876**	**2417**	**1139**

RESULT SUMMARY

Overall, the four different bycatch estimates differed relatively little (Table 12). The estimates stratified by management area were generally lowest and the estimates stratified by depth or month highest. All three stratified estimates have considerably higher variation around the estimate than the non-stratified estimate. Although logbook reports in 2017 were considerably higher than in previous years, the reported bycatch was lower than the estimates using raised inspector data, although reported bycatch of harbour porpoises (286) and black guillemots (600) comes close to the lower end of the estimates stratified by management area (264-834 for harbour porpoise, 695-2325 for black guillemot) (Tables 11 & 12).

Table 12. Summary of the four different annual bycatch estimates (n/year) conducted in this study. The numbers reported in logbooks by the fleet in 2017 are also shown.

Species	Non-stratified bycatch estimate 2014-2017 (± CV*estimate)	Stratified by management area 2014-2017 (± CV*estimate)	Stratified by depth 2014-2017 (± CV*estimate)	Stratified by month 2014-2017 (± CV*estimate)	Logbooks 2017
Harbour porpoise	551 (412-630)	549 (264-834)	662 (324-998)	428 (240-616)	286
Harbour seal	1367 (1135-1599)	1255 (728-1782)	1663 (915-2411)	1221 (684-1758)	700 (all seal species)
Grey seal	1385 (886-1884)	1091 (502-1680)	1034 (165-1903)	1907 (840-2974)	
Harp seal	177 (113-241)	132 (15-249)	213 (49-377)	190 (55-325)	
Ringed seal	53 (13-93)	33 (1-65)	48 (1-95)	60 (1-118)	
Bearded seal	36 (9-63)	42 (12-72)	NA	42 (13-71)	
White beaked dolphin	0	0	0	0	2
Unidentified dolphin	0	0	0	0	1
Total marine mammals	**3570 (2963-4177)**	**3102 (2016-4188)**	**3620 (760-6480)**	**3847 (2270-5424)**	**988**
Common guillemot	1350 (850-1850)	1376 (372-2380)	1756 (369-3143)	873 (314-1432)	0
Brünnich's guillemot	71 (26-116)	76 (11-141)	133 (19-247)	74 (1-147)	0
Black guillemot	1616 (1309-1923)	1510 (695-2325)	1532 (720-2344)	2067 (910-3224)	600
Cormorant/Shag	799 (615-983)	813 (244-1382)	848 (348-1348)	1083 (531-1635)	177
Common eider	3316 (2354-4278)	3232 (1616-4848)	4289 (1887-6691)	4765 (2240-7290)	442
Atlantic puffin	36 (11-61)	40 (1-80)	11 (1-20)	42 (1-84)	0
Long tailed duck	71 (37-105)	61 (1-122)	86 (2-172)	58 (7-109)	0
Black-legged Kittiwake	18 (1-36)	6 (1-12)	11 (1-20)	27 (1-54)	0
Razorbill	18 (1-36)	59 (1-118)	80 (3-156)	70 (10-130)	0
Gannet	18 (1-35)	13 (1-26)	37 (3-71)	5 (1-10)	0
Common loon	53 (23-83)	21 (1-42)	22 (1-44)	21 (1-42)	0
Other seabirds	0	0	0	0	1198

Total seabirds	**8151 (6928-9374)**	**7207 (4180-10,234)**	**8805 (4843-12767)**	**9086 (5906-12266)**	**2417**

DISCUSSION

Although reported bycatch by the fleet has increased, which suggests better compliance, the overall bycatch rates are still much lower than observed in the trips by inspectors. Overall, the marine mammal and seabird bycatch rate in inspector trips was around four times higher than reported by the fleet in 2017, which shows the need to use other data in addition to the log books. This difference also warrants an investigation into why fishermen do no report bycatch, and how reporting can be made easier. A smartphone app is in development by the Directorate of Fisheries, which hopefully will make both reporting and identification of bycatch easier for operators in the fishery.

Bycatch rates in inspector trips vary considerably between years, which results in highly variable estimates of bycatch by year. The most likely factors explaining this difference are inadequate sampling, spatial/temporal mismatch in sampling, and the nature of bycatch events, but bycatch events of some species like eiders and grey seals seem to be characterized by few severe events. To counter this annual variation, and high coefficient of variation within years, lumping all four years of sampling together results both in better spatial match between inspector trips and fishery landings, and lower coefficient of variation for the estimates of bycatch due to higher explanatory power of the larger dataset.

Bycatch rates were different between management areas for some species, which highlights the importance of sampling across management areas in relation to fishing effort if the aim is to use non-stratified bycatch estimation. Out of the more common species, very little variation in bycatch rates between management areas was seen for harbour seals, harbour porpoises, and common guillemot. However, for grey seals, eiders, cormorants and shags, and black guillemots, one or more management areas where bycatch rates were higher. Grey seals were predominantly found in management areas B and C and raised by effort, area B accounts for 75% of the total estimate and area C for 16%. Raised by effort, around 40% the total estimate for eiders is estimated to be caught in area E, and around 15% in each of areas A, B and C. Bycatch rates of black guillemot were highest in areas B, E and A, and raised by effort, that accounts for around 14% in area A, 40% in area B and 24% in area E. Bycatch rates of cormorants and shags were highest in areas B, A and G, but areas B and A dominate when raised by effort, with more than 50% of the estimated bycatch occurring in area B and 20% in area A. This is unsurprising given that Areas A and B are the main breeding grounds for these species in Iceland (Skarphéðinsson et al. 2016). Factors influencing the differences of bycatch by management areas could be: (a) the relative concentration of the bycaught species among the areas (b) the variation of concentration of these animals during the season and the differences in the spatio-temporal distribution of the fishing effort or (c) a random effect. Stratification of the data by management area resulted in somewhat lower bycatch estimates for both marine mammals and seabirds when compared to the overall bycatch estimate, at the cost of higher variance. For individual species, stratification of area led to a decrease of 100 animals (7%) in comparison to unstratified data for harbour seals, whereas it resulted in no significant difference for harbour porpoises and most seabird species. The largest difference observed was in the case of grey seal, where stratification of the data by management area led to a decrease of 300 animals (22%) in the estimate of bycatch.

No significant effect of depth was observed on the bycatch rate of any of the marine mammals and all the seabird species except for the black guillemot that had higher bycatch rates at shallower depths. Stratification of the data by depth for harbour seals led to an increase of 300 seals (20%) in comparison to unstratified data, while it led to a decrease of 300 grey seals. The largest difference between these estimates in seabirds was for eiders and common guillemot, were the estimate stratified by depth was around 1000 eiders and 400 common guillemots higher than the total bycatch estimated from the unstratified data. Both eiders and grey seals showed decreasing trend with depth, and it is likely that a significant effect of depth would be observed if the sample size was larger. It could therefore be plausible to reduce bycatch of those three species (grey seal, black guillemot and eider) by reducing fishing effort at depths shallower than 20 meters. This would however, have the drawback that most of the fishery in area B would be shut down as most of the fishing grounds are in shallow water.

Comparison of the randomly and non-randomly selected inspection trip in 2017 show that the non-random trips are biased towards lower bycatch estimates compared to the random trips. The significantly higher bycatch rates of eiders and black guillemots observed in the randomly selected trips could be due to the inspectors focusing on possible infractions in the targeted trips and therefore overlooking some bycatch, although it is also possible that the difference is simply due to random chance.

Bycatch rates differed between months for several species; grey seals, black guillemots and cormorants/shags. The bycatch rates of these species were higher in May, June and July than in other months. This effect is likely confounded with both management area and depth, and caution should therefore be taken when interpreting these findings. The management areas have slightly different seasons, with areas D, E, F and G starting at the end of March, areas A and the outer part of B in early April, while the inner part of management area B starts in May. Depth is also confounded with month, as in most areas the fleet starts the fishing season in deeper water and move shallower as the season progresses, and area B is fished almost exclusively at depths <20m. Stratification of the data by month for grey seals led to an increase of 300 seals (20%) in comparison to unstratified data, while it led to a decrease of 100 animals in the estimate of harbour seals and harbour porpoise. The largest difference between these estimates in seabirds was for eiders, black guillemot, and cormorants/shags were the estimate stratified by depth was around 1200 eiders, 400 black guillemots and 300 cormorants/shags higher than the total bycatch estimated from the unstratified data while bycatch of common guillemots was 500 birds lower.

Inspector coverage was quite well distributed across areas, and therefore not surprising that the estimate stratified by area is not that different from the overall estimate, and similar can be said about the coverage across depths, although inspections were slightly biased towards 0-10 m. The nature of this bycatch dataset is very statistically challenging, and it is likely that all factors that were tested in the analysis here are confounded in some way. It is for example possible that bycatch rates differ by depth within areas, or by months within areas, but we lack the sample size to test for these effects. More sampling is therefore needed, either by increasing the number of inspections each year, or by other measures like onboard security camera systems.

The estimates in this survey are in many ways similar to the previous study by Pálsson et al (2015), were their estimates for harbour seal, harbour porpoise and black guillemot were similar to the estimates presented here although their estimated bycatch estimate for grey seal was considerably lower. Estimation of grey seal bycatch is problematic since the events are rare, but severe, and annual estimates therefore highly variable and have high variance. The seabird bycatch estimates of around 9300 birds presented by Bond et al. 2017 were 1000-2000 seabirds higher than the non-stratified estimate and the estimate stratified by area, but similar to the estimates stratified by month and depth. This study has higher estimated bycatch of eiders and common guillemot, while the study by Bond et al. (2017) reported considerably higher bycatch rates of black guillemot and cormorant/shag due to unknown reasons. The sample size in that study was 37 trips, and only conducted in one year, so it is possible that some random variance explains the difference in species composition between the studies.

Finally, it should be noted that the population estimates of the main bycatch species are highly uncertain/outdated in many cases. Monitoring the population trends of these species is important to estimate whether the bycatch in the lumpsucker gillnet fishery is having a negative effect on the populations. In cases where hunting is conducted, the combined effect of animal removal must be assessed to assure that the total number of removed animals is within biological limits of the species. Population trends of the harbour seal and grey seal are perhaps the best monitored out of the more common bycatch species. The population of harbour seal has declined by close to 80% since population surveys started around Iceland in 1980, with the last survey in 2016 estimated the population at 7700 seals (Þorbjörnsson et al. 2017). The grey seal population has also been declining, and there are 6 years since the last survey, conducted in 2012, that estimated the population at 4200 seals (Hauksson et al. 2012). A new grey seal census is underway in 2018. Further investigation is warranted into whether the decline in those two species is due to bycatch in fisheries, hunting, culling, environmental factors or a combination of two or more factors. Hunting and culling of seals is largely unregulated in Icelandic waters, and it is not required to report hunted/culled seals. Such mandatory reports are essential to properly asses whether the removal of seals is within biological limits. Only one population estimate is available for harbour porpoise, based on an incomplete aerial survey, that estimated the population at around 42.000 animals (Ólafsdóttir, 2010), which suggests that the bycatch amounts in the lumpsucker fishery are likely within biological limits, although population trends are unknown. The population estimates of eider and common guillemots suggest that the populations are large and stable (Skarphéðinsson et al. 2016), and bycatch is therefore unlikely to have any effect on the total populations. The populations of great cormorants and European shags are also stable at around 5000 birds of each species

(Skarphéðinsson et al. 2016) despite considerable hunting effort, indicating that the bycatch in lumpsucker gillnets is likely within biological limits of those species. The population of black guillemots has been declining since the 1980s, and the population is currently estimated at around 20-30.000 birds (Skarphéðinsson et al. 2016). Hunting of the species was banned in 2017 due to poor population status, which warrants further research into whether bycatch in the lumpsucker gillnets could be affecting the population.

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