HIGH-CONTRAST BANNERS DESIGNED TO DETER SEABIRDS FROM GILLNETS REDUCE TARGET FISH CATCH

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ABSTRACT

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The incidental catch of non-target species in fishing gear (i.e., bycatch) is a global threat to sustainability and conservation in marine systems. Seabirds experience substantial bycatch mortality, with gillnets having the greatest impacts of any fishing gear. Widespread mitigation to reduce seabird bycatch in gillnet fisheries is tenuous, and information on bycatch in inshore surface-set gillnets remains a major knowledge gap. To help address these issues, we collaborated with commercial fishers to test the efficacy of high-contrast banners designed to alert seabirds. In waters of Newfoundland, Canada, banners were attached to surface-set gillnets for Atlantic Herring *Clupea harengus* and were compared with simultaneously unmodified control nets within the foraging ranges of major seabird colonies. The banners reduced target catch, creating a non-viable option for fishers. Seabird bycatch was low, although it may have been more substantial than indicated by local information sources. Bycatch included fish species of concern (Atlantic Salmon *Salmo salar* and Porbeagle Shark *Lamna nasus*). Owing to the episodic nature of seabird and other non-target catch, collaboration with fishers is needed to continue long-term monitoring of inshore gillnet bycatch.

Key words: bycatch, incidental catch, gillnets, mitigation, high-contrast banners, target catch, seabirds, Newfoundland

INTRODUCTION

Incidental take of non-target marine fishes, reptiles, birds, and mammals in fishing gear, referred to as bycatch, is a major fishing threat to resource sustainability and conservation throughout the world's oceans (Lewison *et al*. 2014). Bycatch can cause substantial mortality, often reflected at population levels and, in some cases, with negative effects on endangered species (Croxall *et al*. 2012, Gray & Kennelly 2019). Seabirds are a highly threatened group, with about one-third of all species impacted by fishing gear mortality (Tasker *et al*. 2000, Dias *et al*. 2019, Melvin *et al*. 2023).

Considerable research on mitigating seabird bycatch has been directed at long-line fisheries, with a major focus on surface-feeding seabirds (e.g., albatrosses, shearwaters, petrels; Anderson *et al*. 2011, Sullivan *et al*. 2018). Many effective mitigation procedures are being used to reduce seabird bycatch in long-line fisheries (Melvin *et al*. 2023). These techniques and tactics include Tori lines (Domingo *et al*. 2017), weighted hooks (Jiménez *et al*. 2018), night-setting (Jiménez *et al*. 2020), underwater baiting (Robertson *et al*. 2018), and emerging technologies such as hook-pods (Sullivan *et al*. 2018).

Although gillnets kill more seabirds than other types of fishing gear, efforts to mitigate seabird bycatch in gillnets have been extremely challenging (O'Keefe *et al*. 2021). Owing to high catch rates, gillnets are a ubiquitous gear of choice among inshore commercial fishers (Žydelis *et al*. 2013, Rouxel & Montevecchi 2017, Bærum *et al*. 2019, Montevecchi 2023). Auditory techniques (pingers) have deterred seabirds from diving near gillnets, but they attract seals (Melvin *et al*. 2001), an association referred to as the "dinner bell" effect. Seabird bycatch was reduced in gillnets when target fish abundance was highest and when fishing occurred during the day (precluding dawn and dusk; Melvin *et al*. 2001).

The demographic influence of gillnet mortality on seabirds was well documented following the closure of the Atlantic Salmon *Salmo salar* and Northern Cod *Gadus morhua* fisheries in the Northwest Atlantic during the early 1990s. The closures removed thousands of inshore gillnets, which corresponded with predicted positive population responses by diving seabird species vulnerable to gillnet entanglement (Regular *et al*. 2014). Similar influences have been observed following gillnet closures in the North Pacific (Ainley *et al*. 2021.).

In the Newfoundland and Labrador inshore fisheries, both demersal/bottom-set cod/ground-fish gillnets (Hutchings & Myers 1994, Rose 2007) and surface-set gillnets targeting Atlantic Herring *Clupea harengus* are used (Redden *et al*. 2002). The former takes the bulk of the inshore cod catch, while the latter is primarily a bait fishery.

The demersal cod/ground-fish gillnets have been estimated to entangle and drown up to 7000 seabirds in a year, though no seabirds were detected as bycatch in the inshore herring fishery between 2001 and 2003 (Benjamins *et al*. 2008). In contrast, a province-wide telephone survey of fishers during 2001 reported considerable seabird bycatch in surface-set herring gillnets,

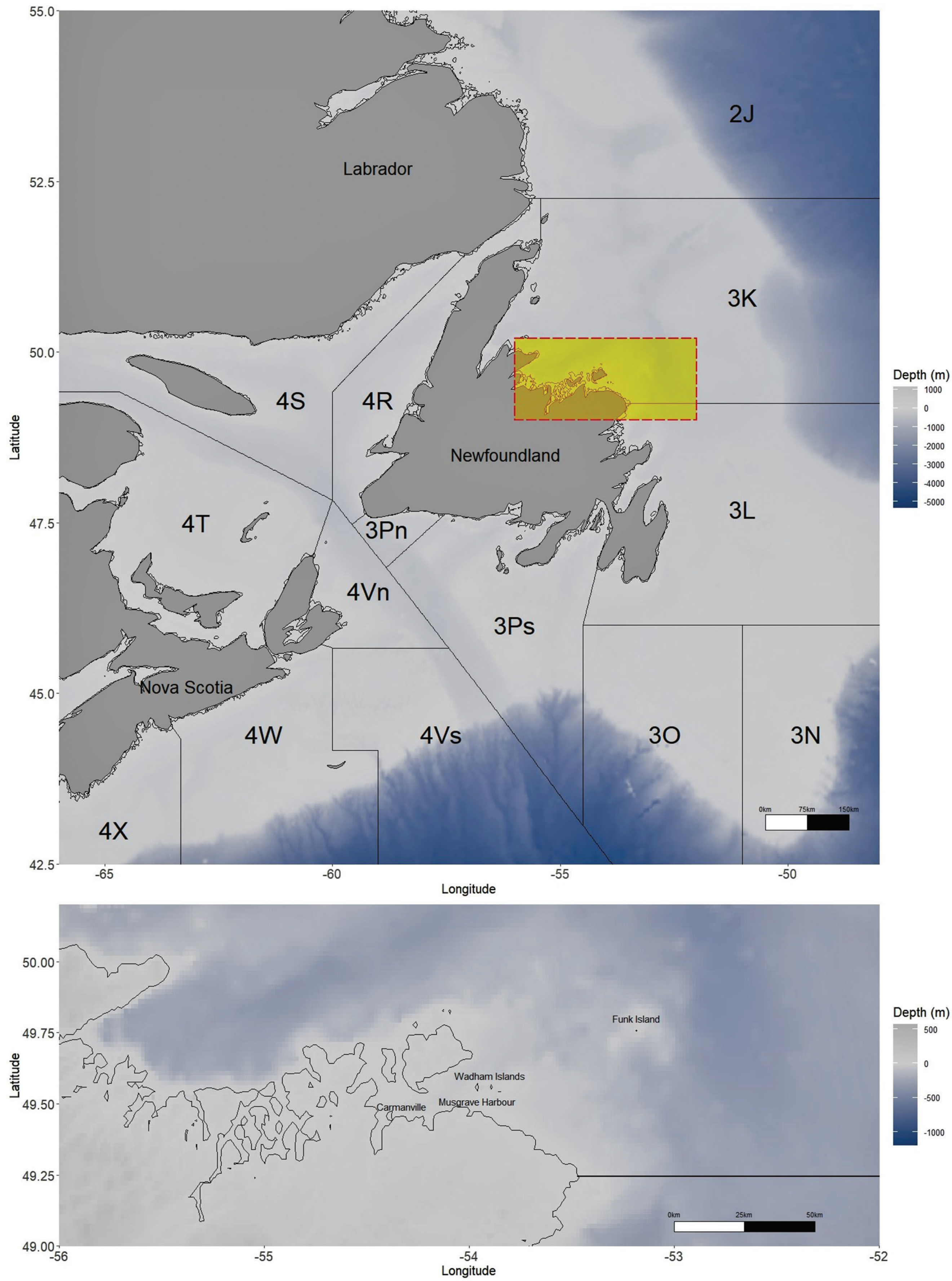

Fig. 1. Study area on the northeastern Newfoundland coast. Inset shows larger scale with North Atlantic Fisheries Organization (NAFO) Fishery areas.

representing 1.7% of all reported bycatch (Redden *et al*. 2002). Since 2016, the Department of Fisheries and Oceans Canada has collected bycatch observations from a subset of herring gillnet fishers during an annual telephone survey. Seabird bycatch was reported in 2016, 2017, and 2018 in relatively low numbers (Bourne *et al*. 2018, 2023). Current data on seabird bycatch in the herring gillnet fishery are needed.

Translucent monofilament gillnets are essentially invisible to seabirds foraging in the water column (Melvin *et al*. 2001), so the use of visual cues is considered to be the most promising way for seabirds to detect fishing gear (Martin & Crawford 2015). Under a wide range of light levels, diving seabirds use acute achromatic lateral vision with low forward resolution. Gillnets are therefore often not detected by diving birds until they are at very close range (2–20 m), depending on light level and species (Martin & Crawford 2015). Melvin *et al*. (2001) showed that seabird bycatch in salmon driftnets was reduced by 37% when the upper 20 meshes of the nets were refitted with high-contrast white line.

With the expectation that increasing gillnet visibility will facilitate avoidance, Martin & Crawford (2015) designed high-contrast black and white banners specifically for attachment to gillnets to alert seabirds. We worked with commercial fishers to assess the hypothesis that visually foraging diving seabirds are repelled by high-contrast banners attached to gillnets. We compared the bycatch and catch of experimental gillnets with three different high-contrast banner attachments in simultaneously and adjacently set unmodified control gillnets. We predicted that the high-contrast banners would reduce seabird bycatch without affecting target fish catch. Other bycatch species were also evaluated. To assess the influence of seabird bycatch in the inshore herring gillnet fishery, we compared our findings with other local information sources.

MATERIALS AND METHODS

Study sites

Working with a crew of commercial fishers on a single inshore fishing boat, we deployed herring gillnets as part of their normal bait-fishing operation in coastal waters. Nets were set just off Musgrave Harbour (49.2733°N, 53.5748°W) and Carmanville (49.4033°N, 54.2867°W), along the northeastern Newfoundland coast between Notre Dame Bay (NDB) and Bonavista Bay (BB); North Atlantic Fisheries Organization (NAFO) Division 3K (Fig. 1). Gillnets were always set at the same fisher-selected sites, though the gillnets were, at times, moved slightly (hundreds of meters) for subsequent setting if the catch was low or in relation to changing tides and currents. The gillnets were set within the foraging ranges of major seabird communities on Funk Island Ecological Seabird Reserve (49.7569°N, 53.1811°W) and of other significant colonies of diving seabirds (Montevecchi *et al.* 2019).

Procedures

During each fishing trip, standard green translucent fixed subsurface-set herring gillnets (27.43 × 5.5 m with 6.35-cm stretched mesh) were deployed. Gillnets were set at a depth of 3.66 m (2 fathoms) below the surface, parallel to the shoreline as per Fisheries and Oceans Canada policy (DFO, 2018). We deployed 107 gillnet sets, including 39 in 2017 (control = 13, banner = 26) and 68 in 2018 (control = 34, banner = 34). As is common in the herring gillnet fishery, the nets were hauled and cleared after an approximate 24-hr soak time, although the intervals between settings and hauls varied with weather and fishers' other activities. All gillnets were redeployed as soon as they were cleared of fish. Fishing was conducted during the lobster and crab fishing seasons (April–June) from 30 May to 26 June 2017 (13 trips; 13 gillnet sets) and from 07 May to 24 June 2018 (17 trips; 34 gillnet sets). In 2017, a single set of three adjacent gillnets was deployed, and in 2018, two sets with two adjacent gillnets were deployed 100 m apart. In 2017, each set included an unmodified control gillnet and two experimental gillnets with high-contrast banners: (a) 60 × 60 cm square canvas banners with 15 × 15 cm "checkered" black and white squares, and (b) 45 × 90 cm rectangular canvas warning banners with three

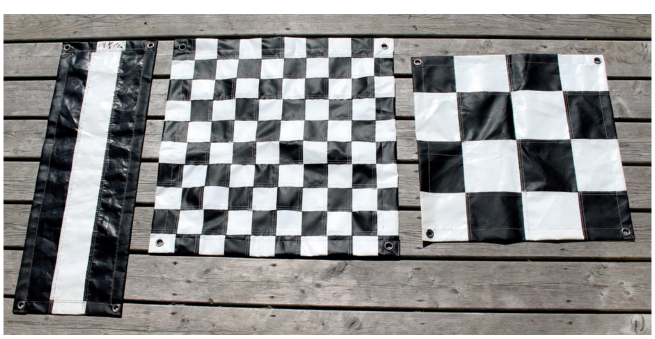

Fig. 2. Three warning banners deployed (left to right): striped, small checkered, large checkered. (Photo: W. Montevecchi)

Fig. 3. Northern Gannet *Morus bassanus* entangled in a surface-set herring gillnet. (Photo: Marina Montevecchi)

15 × 90 cm alternating black and white stripes. In 2018, each set included an unmodified control gillnet and an experimental gillnet with 60 × 60 cm square canvas warning banners with 6 × 6 cm "checkered" black and white squares (Fig. 2; Appendix 1, available on the website). At the fishers' suggestion, the banners were attached 3 m apart along the top-line of the gillnet. Thus, they could move freely in the water, thereby preventing gillnet movement in a tidal change or current, as well as making the banners more visible to birds on and above the water. In 2017, we deployed 960 m of gillnets with 320 m per treatment fished for 11.67 d (soak time). In 2018, 4 296 m of gillnets with 2 148 m per treatment were fished for 39.15 d (soak time).

Seabirds and all other non-target organisms caught were identified to species and counted per gillnet treatment for each gear haul in each year. Because seabirds can also entangle in gillnets during hauling and setting (Trippel *et al.* 2003), we counted and identified all seabirds on the water and flying within 200 m of the boat during net hauls and redeployments.

On return to the wharf, a sub-sample of 15 herring in 2017 and 10 herring in 2018 (though sometimes fewer fish were available on poor fishing days) from each treatment were weighed (Pesola spring scales) and measured (fork-lengths; Wildco fish-board 118-E40). We recorded the total number of herring caught and the total catch weight (estimated from the weight of sampled fish) for each experimental treatment on each trip. Herring catch rates were determined for catch weight and for total fish caught by dividing each value by the soak times/gillnet of their respective treatments and were compared within and across years.

Statistical analysis

Statistical analyses were run in R (version 1.4.1717, R Core Team, 2021). All models were validated using diagnostic plots of residuals versus fitted values and qqplots to ensure that they met the assumptions of normality and homoscedasticity. The models' responses were also validated by plotting the simulated data versus the raw data as semi-transparent histograms to ensure that they overlapped appropriately. We set $P < 0.05$ as the significant threshold.

The catch data were not normally distributed and were highly right-skewed, with many zeroes and an extensive left tail. To cope with this, the response variable catch rate (kg/net/min) was square-root-transformed, normalizing the data and meeting the assumptions of parametric statistics as necessitated by residual analysis. Because our experimental treatments consisted of three banner types, we partitioned the banners two ways to best explore our response variable by: (a) lumping banners together and investigating the effect of banner or no banner on the gillnets; and (b) examining each banner type separately, forming a four-level variable (control, striped, checkered large, checkered small). We accounted for the year of deployment by adding it as a fixed effect to each model. We investigated the possibility of an interaction between the banner treatment and year, but the interaction term

TABLE 1
Non-target incidental bycatch caught in herring gillnets with high-contrast banners and in simultaneously-set unmodified control herring gillnets during 2017 and 2018[a]

Incidental Catch	High-contrast Banner 2017	High-contrast Banner 2018	Control 2017	Control 2018	Total Bycatch
Invertebrates					
Rock Crab *Cancer irroratus*			14[b]		14
Finfish					
Atlantic Salmon *Salmo salar*			2		2
Sea Trout *Salmo trutta*	1				
Capelin *Mallotus villosus*		1			1
Rock Cod *Gadus macrocephalus ogac*	1				1
Sculpin *Myoxocephalus* spp.	7	1	14[b]	3	25
Lumpfish *Cyclopterus lumpus*	1	3	1	1	6
Seabirds					
Northern Gannet *Morus bassanus*			2		2
Total Finfish	9	5	31	4	49
Total Seabirds	0	0	2	0	2
Grand Total	9	5	33	4	51

[a] Total of 107 gillnets were deployed, including 39 in 2017 (control = 13, banner = 26) and 68 in 2018 (control = 34, banner = 34)
[b] Caught during a single haul

TABLE 2
Birds observed within a 200 m radius of surface-set gillnets (listed in order of abundance)

Species	2017	2018	Total
Herring Gull[a] *Larus argentatus*	160	299	459
Northern Gannet[b] *Morus bassanus*	112	318	431
Cormorant[b] *Phalacrocorax* spp.	114	166	280
Great Black-backed Gull[a] *Larus marinus*	67	130	197
Common Murre[b] *Uria aalge*	7	41	48
Razorbill[b] *Alca torda*	36	0	36
Black Guillemot[b] *Cepphus grylle*	0	36	36
Arctic Tern[a] *Sterna paradisaea*	17	0	17
Ring-billed Gull[a] *Larus delawarensis*	9	4	13
Merganser[b] *Mergus* sp.	9	0	9
Long-tailed Duck[b] *Clangula hyemalis*	0	6	6
Canada Goose[a] *Branta canadensis*	0	4	4
Bald Eagle[a] *Haliaeetus leucocephalus*	3	0	3
Common Tern[a] *Sterna hirundo*	0	3	3
Iceland Gull[a] *Larus glaucoides*	0	2	2
Total Surface-Feeders	256	442	698
Total Diving Species	278	567	845
Grand Total	534	1009	1543

[a] Surface-feeder
[b] Diving species

was never significant and was therefore excluded from the models. We used two linear models (LMs), each including the predictor's year and banner treatment, the latter either as a two-level factor (banner types combined vs. no banner control) or as a four-level factor (each banner type, including the no banner control). Because each deployment included paired gillnets with and without high-contrast banners, the timing, location, and soak time of each deployment was controlled within settings. It was therefore not necessary to factor spatial and within-season temporal controls into our model, nor did we need to control for non-independence of bycatch for each retrieval (see also Field *et al.* 2019). *Post hoc* Tukey HSD (honestly significant difference) tests assessed comparative differences between and among treatment groups.

Fig. 4. Wounded Atlantic Herring *Clupea harengus* removed from an Atlantic herring surface gillnet. (Photo: Yann Rouxel)

We tested the effects of year and banner treatments on the bycatch count using general linear models (GLMs) with a negative binomial distribution to account for over-dispersion. The negative binomial regression also gives more weight to small differences between counts, making it appropriate to distinguish between the low counts of bycatch (Ver Hoef & Boveng 2007).

RESULTS

All non-target organisms caught incidentally in herring gillnets with high-contrast banners and in simultaneously set unmodified control herring gillnets during 2017 and 2018 are in Table 1. Although more than twice as much bycatch was entangled in control nets compared to bannered nets, the difference did not attain statistical significance. Inter-annual variation revealed significantly less bycatch in 2018 (Appendix 2, Table A1, available on the website).

Two Northern Gannets *Morus bassanus* were entangled and drowned on the same day (07 June 2017) in a control gillnet (Fig. 3). No other seabirds were caught in either control or experimental gillnets. Seabirds comprised 3.9% (2/51) of all bycaught animals (Table 1).

Most seabirds observed within 200 m of gillnets were diving species, predominantly Northern Gannets and cormorants *Phalacrocorax* spp. (Table 2). Surface-feeders were common, primarily Herring Gulls *Larus argentatus* and Great Black-backed Gulls *L. marinus*. Diving seabirds often foraged in flocks near the gillnet sites, though they were at greater distances and not attracted to the nets during either deployment or hauling compared to gulls that frequently plunged at the gillnets, trying to obtain fish (Appendix 1). A number of herring that had wounds apparently inflicted by avian predators were also found in the gillnets (Fig. 4).

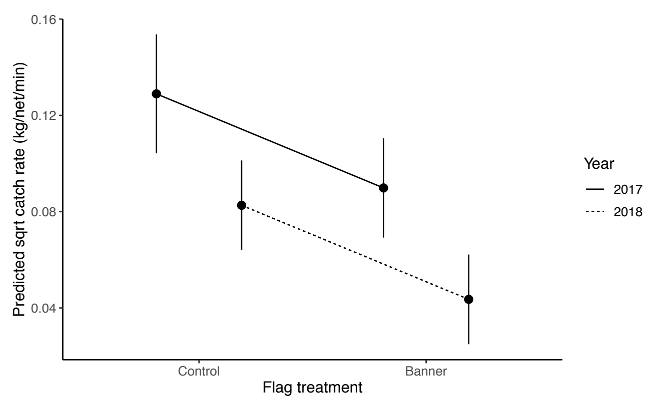

Fig. 5. Difference in the estimated marginal mean catch rate (weight (kg)/net/soak time (min)) of herring in gillnets with high-contrast banners compared to simultaneously set unmodified control gillnets in 2017 and 2018 on the northeast Newfoundland coast, Canada. The vertical lines represent 95% confidence intervals.

TABLE 3
Comparison of herring catch rates in surface-set gillnets with and without high-contrast banners[a]

Treatment	Gillnets (*n*)	Soak time (min)		Catch (kg)		Catch rate[b] (kg/min)	Catch (no.)		Catch rate (no./min)
		Total	Mean ± SD	Total	Mean ± SD	Mean ± SD	Total	Mean ± SD	Mean ± SD
Checkered 2018	34	56 382	1 658.29 ± 672.88	183.65	5.40 ± 7.39	0.004 ± 0.006	796	23.41 ± 32.44	0.0165 ± 0.025
Control 2018	34	56 382	1 658.29 ± 672.88	502.66	14.78 ± 21.53	0.012 ± 0.021	2175	63.97 ± 91.60	0.05 ± 0.089
Checkered 2017	13	16 811	1 293.15 ± 132.12	149.6	11.51 ± 12.89	0.009 ± 0.011	607	46.69 ± 54.28	0.037 ± 0.045
Control 2017	13	16 776	1 290.46 ± 133.56	421	32.38 ± 29.30	0.025 ± 0.022	1692	130.15 ± 116.10	0.10 ± 0.087

[a] Totals represent one set per trip in 2017 and two sets per trip in 2018; the means and standard deviations (SD) represent the value adjusted for a single gillnet.

[b] Owing to variation in catch rates, *post hoc* Tukey tests revealed that gillnets with small checkers banners caught significantly less herring (kg/net/min) than did simultaneously set unmodified control gillnets ($P = 0.004$; Table 4). In contrast, herring catch rates in gillnets with large checkered and striped banners did not differ from that of controls and also did not differ from the catch in gillnets with small-checkered banners (Fig. 6).

TABLE 4
Linear regression of the herring catch rate based on the type of banner treatment (control, striped, checkered large, checkered small) and the year of deployment (2017, 2018)

Response	Predictors	*df*	*F*-value	*P*
Catch rate[a] (kg/net/min)	Banner treatment	3 102	3.84	0.012
	Year	1 102	9.03	0.003

Residual standard error = 0.06 on 102 *df*

[a] Catch rate was square-root transformed to meet the assumption of normality and homoscedasticity

When high-contrast banners were attached to herring gillnets, they significantly reduced target fish catch rates (kg/net/min) compared to unmodified control gillnets (LM: $F_{1,104} = 10.60$; $P = 0.002$). Applying high-contrast banners to gillnets resulted in about a 50% reduction in target fish catch rate compared to unmodified control gillnets (Fig. 5, Table 3). While there was a marked year effect with significantly lower herring catch rates during 2018 compared to 2017 (LM: $F_{1,104} = 13.99$, $P < 0.001$), there was no interaction between the banner treatment and year (Fig. 5; Tables 3, 4).

Owing to variation in catch rates, *post hoc* Tukey tests revealed that gillnets with small checkered banners caught significantly less

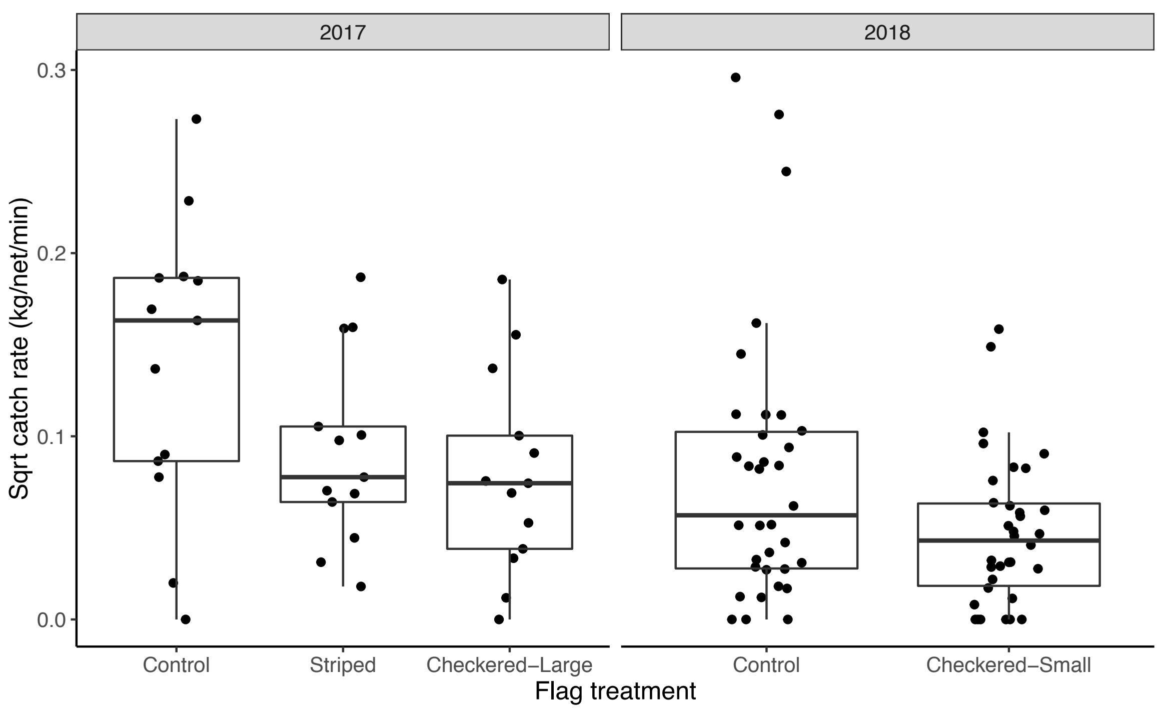

Fig. 6. Differences in target fish catch rate (kg/net/min; square-root transformed) in gillnets with different types of high-contrast banners compared to simultaneously-set unmodified control herring gillnets. Raw data are represented by the points, grouped by banner treatment groups: no banner control ($n = 13$ in 2017 and $n = 34$ in 2018), striped banner ($n = 13$), large-checkered banner ($n = 13$), small-checkered banner ($n = 34$).

herring (kg/net/min) than simultaneously set unmodified control gillnets ($P = 0.004$; Table 4). In contrast, herring catch rates in gillnets with large checkered and striped banners did not differ from that of controls and nor from catch rates in gillnets with small checkered banners (Fig. 6).

Fish weight did not differ among treatments, and fork-lengths differed very slightly between experimental and control gillnets; significantly larger herring were caught in 2018 (Appendix A2, Tables A2, A3, and A4).

DISCUSSION

The primary finding of this study is that the attachment of high-contrast banners designed to mitigate bird bycatch substantially decreased target fish catch. Using pliable visual cues on gillnets to alert birds appeared to stimulate avoidance by herring and reduced catch rates. Many herring caught in the experimental nets were in the lower portions of the nets below the banners, unlike the wider distribution of fish in control nets (WAM pers. obs.). Melvin *et al*. (2001) also reported reductions in target catch (Sockeye Salmon *Oncorhynchus nerk*) in gillnets with high-contrast mesh along the top. Under-reporting of negative findings may have precluded documentation of other ineffective mitigation techniques. Regardless, the use of high-contrast banners to mitigate seabird bycatch in gillnets is not a viable option for fishers.

Two Northern Gannets were drowned in a control gillnet, but such a number is too low to infer anything about the influence of the high-contrast banners on reducing seabird bycatch. Field *et al*. (2019) used vertical striped checkered banners on bottom-set gillnets and found no difference in marine bird bycatch when compared to control gillnets set at the same locations and times. It is notable that a number of herring that remained in the gillnets were wounded by birds (Fig. 4). It appears that predatory seabirds often interact with and presumably remove fish in surface gillnets without becoming entangled.

Birds are often entangled in fishing gear during hauling and setting (Trippel *et al*. 2003). During gillnet deployment and hauls, diving seabirds were the predominant species near (< 200 m) fishing boats, although none were observed diving near the nets while the crew was on site. Surface-feeding gulls were the only birds seen on the nets and pecking into them (Appendix 1). Though surface-feeding seabirds are less prone to gillnet entanglement than diving birds, gulls occasionally drown in gillnets (Benjamins *et al*. 2006, Žydelis *et al*. 2013).

While Benjamins *et al*. (2008) reported no seabird bycatch in the Newfoundland herring fishery, a previous province-wide telephone survey of fishers to assess bycatch indicated that seabirds made up 1.7% (136/7986) of all bycatch (Reddin *et al*. 2002). Bycatch of seabirds was also reported in three of the last six years during the annual Department of Fisheries and Oceans Canada herring bait fisher telephone survey at relatively low levels (ranging from an estimated eight to 34 birds total annual and representing 1% or less of the total bycatch; Bourne *et al*. 2018, 2023). In our study, seabirds represented 3.9% (2/51) of all non-target animal bycatch. Including data from a 2016 pilot study in which a Common Murre *Uria aalge* and 20 other animals were bycaught in herring gillnets (Table A5), seabirds represent 4.2% (3/72) of the total bycatch of non-target animals. The greater proportionate representation of seabirds in our bycatch data compared to the phone survey reports could reflect local vs. regional patterns. However, the limitations of survey data (Brown *et al*. 2018) and the tendency of fishers to under-report bycatch (Brown *et al*. 2021) could have dampened survey bycatch estimates.

Non-seabird bycatch, including species of concern, were entangled primarily in the control gillnets. During 2001 (Redden *et al*. 2002), 2016, and 2017, Atlantic Salmon were bycaught, and in 2016, an endangered Porbeagle Shark *Lamna nasus* (COSEWIC, 2014) was bycaught. Sculpins *Myoxocephalus* spp., Lumpfish *Cyclopterus lumpus* and cod were also frequent bycatch in all years (Redden *et al.* 2002, Bourne *et al.* 2023; Table 1 and Appendix 2, Table A5).

Owing to long-standing concerns about seabird bycatch in gillnets, considerable research effort has gone into mitigating this mortality (Melvin *et al*. 2001, 2023). However, a lack of viable, wide-spread technical methods to address the problem is spurning growing interest in minimizing the time gillnets are in the water (Melvin *et al*. 2001) and in gear-switching to hand- and long-lining, which impose less bycatch, have effective mitigation, and capture high value live fish (e.g., Rouxel & Montevecchi 2017). Mitigation research is ongoing (Mangel *et al*. 2018, Field *et al*. 2019, Rouxel *et al.* 2021), and visual modifications to hand-line gear are being assessed in efforts to enhance catch rates, though to date, the results have been equivocal (Blackmore *et al*. 2021, 2023).

As the episodic nature of seabird and other bycatch is difficult to document during short-term assessments, continued collaboration with fishers is needed to monitor the bycatch of inshore Atlantic Herring gillnets.

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