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Reducing Seabird Strikes with Trawl Cables in the Pollock Catcher-Processor Fleet in the Eastern Bering Sea.

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ABSTRACT
Mitigation measures have been used to reduce seabird mortalities due to cable strikes in southern hemisphere trawl fisheries. However, little is known about threats posed to seabirds by cable strikes in northern hemisphere trawl fisheries or what mitigation measures might reduce those threats. We conducted experiments comparing the rate of heavy seabird strikes with third-wire (scanning trawl sonar) cables and warps, using three mitigation measures compared to a control of no mitigation. Experiments were conducted aboard two catcher-processor vessels targeting pollock (*Theragra chalcogramma*) in the eastern Bering Sea, one that rendered offal into fish meal and fish oil and one that minced offal prior to discharge into the sea. More birds attended the mincing-vessel, but the rate of seabird cable strikes was higher on the rendering-vessel due to the greater aerial extent of its cables. Streamer lines significantly reduced heavy seabird strikes with both cable types by at least an order of magnitude regardless of discharge characteristics. Reducing the aerial extent of third-wires also reduced third-wire strike rates, but this method was less effective than streamer lines. Warp booms designed to divert seabirds from warps failed to reduce seabird warp strikes, but this technique can be improved. These results show for the first time that seabird strikes with modern third-wire trawl sonar cable systems can be reduced through mitigation or gear modification and that warp strikes can be mitigated with techniques similar to those found successful in southern hemisphere fisheries. Regardless of these results, the need for seabird mitigation in this fishery is unclear.

INTRODUCTION
Seabird mortality is recognized as a major conservation problem in a variety of fishing gears used throughout the world (Brothers et al. 1999, FAO 2008). Food in the form of discharges of fishes and fish processing waste, baits on or from hooks, and dislodged fish from nets attract seabirds to fishing vessels, drawing them into proximity of fishing equipment and associated dangers. In trawl fisheries, seabird mortality can occur from net entanglement and from cable strikes (Bartle 1991, Weimerskirch et al. 2000). These cables include trawl warps (warps), the two cables that pull the net, and data transmission cables. Data transmission cables include third-wires (also referred to as netsonde cables), which connect a transducer mounted on the net to the stern of the vessel and paravane cables, which suspend a receiver for wireless signals transmitted from a net monitoring transducer (see Sullivan et al. 2006b and Bull 2009).

Cable strikes occur with birds on the water or in flight, but water cable strikes are most lethal (Sullivan et al. 2006b, Watkins et al. 2008). Large-winged birds such as albatrosses and giant petrels are most susceptible to cable strike mortality (CCAMLR 2006). When alarmed, seabirds on the water typically extend their wings and when hit by a trawl cable the extended wing can wrap around it. Unable to extract the wing against the force of the moving cable, the bird is driven down the cable and drowns. Unless jagged cable splices or other equipment impale and retain the carcass, the mortality is hidden and as such difficult to detect or quantify (Sullivan et al. 2006b).

In the early 1990's, third-wires were prohibited in several southern hemisphere trawl fisheries due to substantial albatross mortality from third-wire strikes (Bartle 1991, Weimerskirch et al. 2000). In the early 2000s, warps, initially thought to be non-lethal to seabirds, were shown to have caused the mortality of thousands of albatrosses (Sullivan et al. 2006b). Since then, research on reducing warp strikes has been vigorously pursued, but research on reducing third-wire strikes has not. The inaugural effort to mitigate warp strikes in the Falkland Island finfish trawl fisheries found that streamer lines and a warp "scarer" (a device attached to the warps) reduced warp strikes by 98.3% and 94.6%, respectively (Sullivan et al. 2006a). Since then variations on these mitigation concepts have also proven successful at reducing warp interactions in other fisheries (Gonzalez-Zevallos et al. 2007, Watkins et al. 2008).

The frequency and severity of seabird cable strikes are a function of a number of factors. Several authors have linked the rate of cable strikes to periods when fish or fish waste (offal) is discharged (Sullivan et al. 2006a), suggesting that managing this discharge could prevent cable strikes. Mincing offal or minimizing offal by further processing it into meal, retaining it, or discharging it in batches, are options being considered in some fisheries (Abraham et al. 2009). The frequency and severity of cable strikes could also be a function of a variety of operational and physical factors (Sullivan et al. 2006a, Sullivan et al. 2006b).

The level of seabird mortality in northern hemisphere trawl fisheries is poorly documented. In Alaska, bird takes in trawl codends have been documented since 1993 through systematic fishery observer sampling (Fitzgerald et al. 2008), but data on seabird mortalities from cable strikes are few and not routinely collected. Third-wire related mortalities of Laysan albatross (*Phoebastria immutabilis*), northern fulmars *(Fulmarus glacialis*) and short-tailed shearwaters (*Puffinus tenuirostris)* have been documented, but how representative these events are of Alaska's diverse trawl fisheries is unknown (Labunski and Kuletz 2004). Because Laysan albatross share a common distribution with short-tailed albatross (*P. albatrus*), a congener listed as endangered under the U.S. Endangered Species Act (ESA), the possibility of short-tailed albatross mortality emerged as a serious fishery management issue for Alaska. The Laysan albatross fatalities, spatial overlap of short-tailed albatross distribution and trawl fishery effort, and reports of extensive albatross mortality in southern hemisphere trawl fisheries, led to the inclusion of Alaska trawl fisheries under the short-tailed albatross biological opinion for Alaska groundfish fisheries required under the ESA. The incidental take statement under the biological opinion limits the expected take of short-tailed albatross in Alaska trawl fisheries to a total of two birds for this fleet of 194 vessels working in fisheries valued at over US$ 1 billion (USFWS 2003).

Although neither the use nor development of mitigation measures for seabird cable strikes is required under the biological opinion, the catcher-processor sector of the Alaska pollock fishery requested a pilot study designed to identify mitigation options for this fleet should they prove necessary (Melvin et al. 2004). This paper reports the results of more extensive trials based on results of the pilot study that were conducted aboard two catcher processors targeting pollock in the eastern Bering Sea (EBS). We compared the effectiveness of one technology specifically designed to reduce third-wire strikes (snatch block), one technology specifically designed to reduce warp strikes (warp booms), and a third technology to mitigate both (streamer lines). All were compared to a control of no mitigation, or in this case the status quo.

METHODS

Vessels

In 2005, the Alaska catcher-processor fleet targeting pollock in the EBS included 19 vessels. All had net sonar third-wires and all processed pollock primarily into fillets and surimi with recovery rates of approximately 30% of unprocessed weight. The larger vessels (14) operated fish meal plants that rendered fish offal (fish heads, frames, and viscera) and non-prohibited bycatch into fish meal and in some cases fish oil, yielding higher recovery rates and lower discharge volumes of rendered solids and solubles. Five of the smaller vessels lacked meal plants. These vessels discharged offal and non-prohibited bycatch ground (minced) to a maximum of 12.7 mm as per legal requirements to protect water quality. To account for any discharge differences, we tested several mitigation measures designed to protect seabirds from trawl cables on two catcher-processors: one with a meal plant (rendering-vessel) and one without (mincing-vessel; Table 1). Both vessels discharged their processing waste from multiple outlets along their sides and both discharged wash water from their surimi plants. Prohibited species (not including seabirds or marine mammals) such as salmon, crab and Pacific halibut (*Hippoglossus stenolepis*) were exceedingly rare and discarded whole as required by law. Third-wires were stored on hydraulic drums on the deck above the fish deck and run through a block near the centerline at the stern.

Mitigation

The three mitigation measures tested in this study were selected based on the input of fishing captains and the pilot study (Melvin et al. 2004). The sequence of deployment for each mitigation measure was randomized within each day and across each week to minimize the possible effects of time-of-day or prevailing physical conditions. Data were collected on both vessels from July 14 to August 19, 2005, as they fished in the same area.

<u>Third</u>-<u>Wire</u> <u>Snatch</u> <u>Block</u>: The snatch block functioned to draw the third-wire close to the water at the stern to reduce its aerial extent – the length of a cable from the stern to the water interface – (referred to hereafter as extent) to within the extent of the warps. This technique is sometimes used in the fishery in heavy ice conditions to minimize third-wire damage. Snatch block design varied between vessels. On the rendering-vessel the snatch block was applied with a dedicated crane mounted to the deck just above the forward edge of the stern ramp which pulled the third-wire down from 8.7 m to 3 m above the water in the stern ramp. On the mincing-vessel the snatch block lowered the third-wire from 7.6 m to 2.6 m above the surface via a line winched through a block on the safety bar above the stern ramp.

<u>Warp</u> <u>Booms</u>: Booms with streamers were installed outboard and forward of the warps to divert birds foraging on processing waste as it was discharged from the vessel outboard and away from the warps. Streamers extended to the water spanning the discharge plumes. The warp boom specifications varied between vessels. On the mincing-vessel, 7.6 m steel booms were affixed with a hinge to the outboard face of the gantry both port and starboard, at 7.6 m from the stern and were angled slightly astern. Streamers were five 50 mm yellow, polypropylene lines suspended at 1.5 m intervals along each boom such that 2 m of the lines dragged in the water aft of the boom. Bright orange chaffing gear was affixed to the end of the suspended lines approximately 2 m from the surface to enhance their visibility. On the rendering-vessel 6.3-m

steel booms were affixed to the forward face of the gantry on the port and starboard sides 18 m forward of the stern and were maintained perpendicular to the long axis of the vessel. Streamers were seven 50 mm, greenish-blue polypropylene lines suspended along each boom such that 2 m of the lines dragged in the water. The distance of the boom to the stern was reduced to 7 m by moving the port boom to the aft face of the gantry for the second of two fishing trips after we determined that the original placement of the warp boom was too far forward to divert birds around the warps.

Streamer Lines: Streamer lines, also known as bird or tori lines, were used to scare birds away from both the third-wire and from warps. Streamer lines were deployed from both the port and starboard sides of the vessel and maintained with a minimum extent of 60 m. Streamer lines were stored and hauled by hydraulic drums via a block suspended from the gantry at the each side of the stern. Each streamer line consisted of 90-m of 7.9 mm blue steel poly line with streamers of branched, brightly colored, Kraton® UV protected, orange tubing spaced every 5 meters (Melvin et al. 2001). Buoys with chain fixed at the terminal end created drag to maximize their extent. Streamer lines were maintained at minimum 1 m above the third-wire along its extent starting at the stern block in an effort to divert birds in flight above the third-wire. Individual streamers extended to the surface of the water outside the warps to afford protection to seabirds from warp strikes.

Data Collection

Two seabird observers aboard each vessel collected data on seabird interactions during the long daylight hours (~17 hours) of the high latitude summer. Each worked an overlapping 12-hour shift, which was used to standardize observations, maximize data collection and share information. Data were collected by trawl stage: the period in which the trawl net leaves the deck and reaches fishing depth (set), the period that the net is at fishing depth (tow), the period when the net is retrieved from fishing depth to the deck (haul). When fish catch exceeded storage capacity, the net was hauled from fishing depth to a point where the trawl doors were maintained at the surface near the stern, thus closing the mouth of the net and temporarily storing the catch subsurface in the codend. This sub-stage of the haul is referred to as short-wiring the net. At this point warps were retrieved, the third-wire and the trawl door bridles remained in the water with the bridles inboard of where the warp cable had been.

With the exception of the snatch block on the rendering-vessel, all mitigation measures were deployed as the net approached fishing depth and were retrieved prior to net hauling. The snatch block on the rendering-vessel was deployed as the net sonar was deployed during the set and removed as the sonar was recovered during the haul.

Data collection sessions involved a sequence of cable observations preceded or followed by an estimate of seabird abundance around the vessel by species. Counts were made of birds in the air and on the water within a 100-m hemisphere radiating from the center of the stern. To facilitate counting, the 100-m hemisphere was divided into three areas: the wake zone, which included birds bounded by the width of the vessel and birds associated with the discharge plume, the port flank, and the starboard flank (Figure 1). During the tow, observation sessions included monitoring the third-wire and the warps for 30 minutes each. Warp observations were conditioned on discharge. If discharge occurred from both sides of the vessel, each warp was monitored for 15 minutes, and if only one side, the warp on the discharge side was observed for 30 minutes. The sequence in which cables were monitored within each cable observation session during a tow was alternated from session to session. For trawl stages other than the tow, cable observations were limited to the third-wire. When the net was short-wired, the third-wire was monitored for 30 minutes with a bird count immediately following. For sets and hauls, the third-wire was monitored from the time the third-wire transducer was deployed to when the net reached fishing depth and from the time the net left fishing depth to the time the third-wire transducer came aboard. Seabird counts followed the set and preceded the haul. Interactions with the net were monitored during the set from the time the net left the deck until the third-wire transducer was deployed, and during the haul from the time the third-wire transducer was recovered until the time the net was on deck. Tow and short-wire sessions were repeated one hour after the beginning of the first session for the duration of the tow. Each data collection session within a trawl was assumed to be independent for the purposes of statistical analysis.

Cable strikes were recorded by species and classified as heavy or light and as occurring in the air, on the water or both (Table 2). Heavy strikes were those that had the potential to cause injury. During the haul the terminus of all cables – warps at the trawl doors and the third-wire at the transducer – were observed for bird carcasses. Neither vessel spliced warps as the captains found this practice unsafe, consequently warp entangled birds could only accumulate at termini.

Several operational and physical variables were monitored either per trawl or per cable observation. The variables recorded per trawl were: barometric pressure, latitude and longitude, bottom depth, fishing depth, vessel speed, swell height, wind speed and direction, weather, visibility, mitigation measure deployed, and the number and types of vessels within 12 nmi (nautical miles). The variables recorded per individual cable observation were: the extent of the cable, wind direction, location and duration (intermittent or continuous) of waste discharge, percent time the cable was within the offal plume, and the frequency and duration of turns.

Data Analyses
Because of the cryptic nature of seabird mortality from cable strikes, like Sullivan et al. (2006a) we assumed that mortality could not be reliably quantified and that heavy cable strikes were a proxy for mortality. We used simple two and three-factor generalized linear models (GLMs) to evaluate the effect of mitigation on seabird numbers in the wake zone (where most birds congregate around discharges) and the rate of heavy cable strikes. We also used more complex, multifactor models to evaluate the contribution of other variables for the subset of cable observations where data was were complete (Table 3). In general, we used GLMs with quasi-likelihood estimators with a log-link and variance of the same form as the Poisson distribution, except for a constant of proportionality ($Var(y_i) = \phi E(y_i)$). Quasi-likelihood methods allow for the estimation of the dispersion parameter, ϕ, and inclusion of the dispersion estimate in F-tests for model comparisons.

Given two models, M_0 and M_1, where $M_0 \subset M_1$, an F-statistic can be constructed to test whether the smaller model, M_0, is sufficient to describe the data relative to the larger model M_1. The F statistic used to compare two nested models is

$$F = \frac{D(y,\mu_0) - D(y,\mu_1)}{(p - q)\hat{\phi}_1} \sim F_{p-q,n-p}$$

where D is model deviance ($2[l\ M\ ]$, where $l\ M$ is the corresponding quasi log-likelihood function for model M), p is the number of parameters in the larger model, q is the number of parameters in the smaller model, and $\hat{\phi}_1$ is the estimated dispersion parameter for the larger model (Agretsi 2002, Hojsgaard and Halekoh 2006, Thompson 2007).

Separate GLMs were constructed for the rate of heavy strikes with third-wires and with warps. Third-wire analyses included the snatch block and streamer lines as mitigation for the tow and short-wire stages of the trawls. The simple third-wire model included mitigation, vessel and trawl stage, and consisted of 248 observations (Table 5). Warp analyses included streamer lines and warp booms as mitigation measures for the tow stage only. The simple, two-factor warp model included mitigation and vessel as factors, and consisted of 219 observations. Post-hoc tests were performed using Bonferroni techniques. The complex models included as many of the variables as possible, as explained below (Tables 3 and 4). Excluding records with missing values, the complex models yielded 196 and 171 observations for the third-wire and warp models, respectively.

Model selection for the complex GLMs was based on a step-wise process, starting with main effects. Single-variable main effects models were compared with a null model that only included a grand mean (i.e., no variables included). All variables that showed significant ($p<0.10$) main effects were then combined into all possible combinations of two-variable main effects models and compared with the most significant corresponding single-variable main effect model. Depending on the number of significant individual and two-term main effect models, this process was continued in a forward and backward stepping process. The best main effects model was selected and a similar process was used to evaluate all potential significant two-way interactions (based on variables having significant main effects). For each analysis a best model, composed of main effects and two-way interactions, was selected. Higher level interactions were not considered due to the lack of degrees of freedom and the inability to interpret the biological significance of higher order effects. The final "best" model containing significant main effects and two-way interactions was compared with a "global" model. The "global" model was a surrogate for a saturated model—in this case the "global" model consisted of all main effects and all two-way interactions, for which there were sufficient degrees of freedom, for the original 13 variables that were being considered (Table 3). S-PLUS Professional 2000 Release 3 was used to generate all models.

RESULTS

General

A total of 170 experimental trawls (of 200 total) were made and observed during daylight hours. The rendering-vessel made 86 experimental trawls with 91 warp observations and 204 third-wire observations. The mincing-vessel made 84 experimental trawls with 86 warp observations and 226 third-wire observations. The number of trawls per mitigation scenario varied yielding 59 trawls with no-mitigation, 41 with streamer lines, 37 with the snatch block on the third-wire and 33 with a warp boom. Weather conditions were relatively mild with swell height rarely exceeding 2 m and winds rarely exceeding 25 knots.

Nine seabird species or species groups attended trawl vessels although northern fulmars and short-tailed shearwaters were by far the predominate species, accounting for 83% and 15% of numbers, respectively, during third-wire observations. Other species sighted included blacklegged kittiwakes (*Rissa tridactyla*) and red-legged kittiwakes (*R. brevirostris)*, fork-tailed storm petrels (*Oceanodroma furcata*), thick-billed murres (*Uria lomvia*), jaeger species (*Stercorarius* spp.), and gulls (*Larus* species). One albatross was sighted in the course of observations – a Laysan albatross during a haulback.

No Mitigation
In general, when no mitigation was used the mincing-vessel had 2.5 to 3 times more birds attending, but the rendering-vessel, despite fewer birds, had higher cable strike rates (Table 4 and Figure 2). Counter to logic, strikes rates for the rendering-vessel were higher than those of the mincing-vessel for both the warps (by 36%) and for third-wires (by 26 to 54% across trawl stages). Though warp strike rates were lower (>70%) than third-wire rates, warps struck a higher percentage of birds on the water. Third-wire strike rates were similar during tows and sets and lowest during hauls. As the net was short-wired and the extent and scope of third wires increased as the net approached the surface, the rate of third wire strikes increased, sharply in the case of the rendering-vessel, and the percentage of water strikes increased while the percentage of heavy to total strikes was largely unchanged (Table 4 and Figure 3).

Cable aerial extent overrode bird abundance as a determinant of heavy cable contact rates. The extent of the rendering-vessel's third-wire was 13 m longer and the warps 12 m (two times) longer than that of the mincing-vessel (Table 1). The reason for these differences is probably a function of several factors: fishing depth, height of third-wire blocks from the water, vessel speed during tows (not recorded), vessel horse power and net configuration including the distance of the net from the vessel (see Table 1). Functionally, longer extents provided more cable for birds to interact with and increased cable scope. As scope increased approaching horizontal, more of the cable cut through the water with each swell and longer extents pushed cable strikes further from the vessel making them more difficult to mitigate.

Mitigation/Seabird Abundance
Seabird abundance in the wake zone varied significantly among treatments during third-wire ($p<0.001$) and warp observations ($p<0.001$; Figure 2) with treatment explaining 16% and 13% of model deviance (respectively, Figure 2). Only streamer lines significantly reduced bird numbers relative to controls.

Mitigation/Third-wire Strikes
In the simpler model using all data and "mitigation", "vessel" and "trawl stage" as factors, the third-wire model explained 41% of model deviance. Third-wire strikes varied significantly among treatments ($p<0.001$) with mitigation measure explaining 32% of model deviance (Table 5). Significantly fewer third-wire strikes occurred when mitigation measures were used. The strike rates were statistically similar ($p<0.05$) for the snatch block (rendering = 12.2 strikes/hr; mincing = 1.6 strikes/hr) and streamer line (rendering = 0.7 strikes/hr; mincing = 0.1 strikes/hour) mitigation measures in post hoc comparisons (Figure 2). Third-wire strike rates varied significantly by vessel and trawl stage (tow vs. short-wire) explaining 5% and 2% of model deviance, respectively (Table 5).

The more complex model exploring the contribution of other factors to heavy third-wire strikes yielded a model that explained 75% of the deviance. Mitigation treatment explained the most deviance (37%). Unlike the simple model, third-wire interaction rates were statistically different for all mitigation treatments in post hoc comparisons. Strike rates were highest for the control of no mitigation and lowest with streamer lines deployed. Eight other factors were also significant: date, Beaufort sea state, bird numbers in the wake zone, wind direction, and the interaction between wake abundance and date, trawl stage, vessel and the interaction between vessel and fishing depth (Table 5).

Mitigation/Warp Strikes
In the simpler model using all data and "mitigation" and "vessel" as factors, the rate of heavy warp strikes varied significantly among the two mitigation treatments ($p<0.001$) with treatment explaining 19% of model deviance (Table 5). Mean warp strike rates were similar when no mitigation was used and when the warp boom was used (rendering = 15.1 strikes/hour; mincing = 4.5 strikes/hour) and both were significantly higher than when streamer lines were used (rendering = 0.9 strikes/hr; mincing = 0.1 strikes/hr; Figure 2). "Vessel" was marginally significant explaining only 3% of model deviance.

More complex models exploring the contribution of other factors to the rates at which heavy warp strikes occurred yielded a model that explained 54% of model deviance. As with the simpler model, warp strikes were significantly reduced relative to controls only when streamer lines were used. Treatment explained the most deviance (23%) while Beaufort sea state, the presence of discharge, date, and the number of vessels within a 12-mile radius explained 18% to 3% of model deviance. "Vessel" was not a significant factor when these other variables were accounted for in the model.

Mortalities
Twenty confirmed seabird mortalities occurred due to interactions with trawl gear: 17 were caught in the net (8 fulmars, 5 short-tailed shearwaters and 4 unidentified birds), one fulmar was recovered at the third-wire transducer during a warp boom deployment, one fulmar was wrapped around the third-wire when no mitigation was used, and one fulmar was entangled in the chafing gear of the warp boom itself. Most confirmed mortalities (60%) occurred during trawls with no mitigation.

DISCUSSION

No Mitigation
In addition to providing a reference by which to monitor the relative success of mitigation measures, the control of no mitigation in this study provides the first quantification of seabird cable strikes in a northern hemisphere pelagic trawl fishery. As expected, the vessel discharging minced offal consistently had two to three times more birds associated with it than did the rendering-vessel presumably because it provided more food in a form more useable by birds. This result is consistent with the findings of a study in the New Zealand hoki (*Macruronus novaezealandiae*) fishery comparing the effect of mincing and rendering offal on bird abundance around the vessel (Abraham et al. 2009). Compared to unprocessed waste, mincing offal had no effect on the number of individuals of most species attending the vessel with the exception of large albatrosses (*Diomediea* spp.), while rendering reduced the number of individuals of all seabird species including the small albatrosses (*Thalassarche* spp.), which are similar in size to the North Pacific albatrosses. The New Zealand study assumed that the rate of seabird interactions with trawl fishing gear was a function of bird abundance and that seabird abundance was a valid proxy for the rate of trawl warp strikes. In this study the opposite was true – heavy cable strikes (warp and third-wire) occurred 1.5 times more frequently with the vessel rendering waste than with the vessel mincing waste, even though the latter vessel had more birds attending.

Short-wiring the net confirmed the influence of cable (third-wire and warp) extent on bird strikes. When the rendering-vessel's trawl net was short-wired, third-wire extent increased by 20 to 30 m (Table 1), increasing third wire strikes by up to 60%. Because cable extent was relatively constant from tow to tow it became an inherent attribute of each vessel and was comingled with a host of attributes in the factor "vessel" in our GLM models. For this reason, the effect of extent could not be isolated and statistically proven. If the extent of third-wires and warps were the same across vessels in a given fleet then seabird abundance could in fact be a legitimate proxy for cable strikes, but the variability of cable extent can undermine this assumption. Similarly, if the cable extents of the vessels in this study were reversed – the mincing-vessel had the longer extents – the influence of extent could have gone undetected. We could expect that a rendering-vessel with short, extent cables would have dramatically fewer cable strikes than a rendering-vessel with longer extent cables.

Third-Wire Mitigation

This study demonstrates for the first time that seabird strikes with third-wires can be reduced in at least two ways: using streamer lines deployed at least a meter above the third-wire block, and by minimizing its extent. Streamer lines proved superior during tows as well as during net short-wires when third-wires were at their maximum extents. Streamer lines were the only mitigation measure tested that also significantly reduced seabird numbers astern of the vessel. Essentially, they excluded virtually all birds from the area within their 90 m total extent from the stern. Streamer lines, however, can prove difficult to manage in high winds and in some cases individual streamers can wrap around the third-wire. This study took place in summer when conditions in the Bering Sea are comparatively mild and few mishaps occurred. As with streamer line requirements in place for Alaska demersal longline fisheries (NOAA 2007) wind speed thresholds could be established beyond which requirements for streamer lines would be suspended.

Although reducing the extent with the snatch block reduced seabird strikes with third-wires, performance varied by vessel. For the rendering-vessel, strike rates were reduced four-fold during tows when extents were reduced to 25 m; strike rates increased to only half that of the control during short-wires when extents increased to 35 m. The combination of increased cable extent and scope (approaching horizontal) exacerbated risk to seabirds as the wire cut through 10s of meters of water on each swell. The mincing-vessel's snatch block, on the other hand, consistently reduced seabird contacts in both trawl stages by at least an order of magnitude due to the relatively shorter extent of the third wire during the tow (14 m) and the short-wire (20 m). Although reducing the extent of the third-wire via a snatch-block was less effective at reducing heavy strikes than using streamer lines, we are confident that third-wires can be pulled closer to the water or submerged at the stern to make this measure highly effective. In that third-wires are fragile and expensive data transmission cables, any snatch block-like system must aim to minimize cable wear.

Available evidence suggests that considerable confusion exists on net monitoring technology and the value of modern wired trawl net sonars to some fishing operations. Bartle (1991) in his argument to ban third-wires described the wired net sounder monitoring systems used by the Russian fleet in the early 1990s as "obsolete" and inferior to newer and more popular wireless acoustic systems. The early-generation, wired net sounders and the wireless net sounders available today use a stationary transducer positioned on the headrope of a trawl net that repeatedly interrogates the area immediately below the unit producing a one dimensional view of fish below the transducer (see Parish 1959). The wireless net sounders communicate that information to the vessel via an acoustic signal that can be unreliable in heavy weather conditions and when a vessel turns (Scharfe 1971). In contrast, the current generation of wired scanning trawl sonars use a rotating transducer that yields a two dimensional, cross sectional image of the net, that includes the location and density of fish both outside and inside the net in all directions (see Ona and Eger 1987). Scanning trawl sonar systems also gather information from other sensors on the trawl and relay that information together with information from the sonar itself to the vessel, thus they transmit much more information than wireless systems at faster rates. Virtually all of the pollock trawl vessels fishing in Alaska consider wired trawl sonar net monitoring systems essential despite their considerably higher purchase and maintenance costs. While there is no question that wireless net monitoring systems with receivers mounted in the hull reduce threats to large winged seabirds, there is also no question that eliminating wired scanning net sonars would reduce the amount and quality of information available to the fishing operations, and make fishing less efficient, which could in turn increase the bycatch of other taxa and lower fuel efficiency. The results of this study demonstrate that third-wire strikes can be reduced using either gear modification or mitigation, or both. As modern wired net monitoring systems provide significant advantages over wireless systems, decisions to ban wired systems should be evaluated carefully and reevaluated where appropriate. Research programs such as this one conducted in collaboration with industry could help determine whether these mitigation measures can protect large-winged seabirds of the southern oceans from lethal strikes with trawl sonar cables.

Warp Cable Mitigation
Streamer lines significantly reduced seabird strikes with warps by over an order of magnitude to near zero, similar to streamer line results for warps in Falkland Islands trawl fisheries (Sullivan et al. 2006a). The warps of the mincing-vessel were better protected with streamer lines owing to their shorter extent. As with the third-wire, streamer lines were the only mitigation technique we tested that reduced the number of seabirds attending the vessel and also reduced the rate of heavy warp strikes. However, care must be taken to avoid tangles with the warps or third wire when the streamer lines are deployed.

The warp boom, designed to divert birds that are feeding from the discharge plume forward of the stern away from the vessel and warps, failed to significantly reduce seabird strikes with warps in either model, but this result was primarily driven by differences in warp boom performance between the vessels. Despite this result, we are confident that the warp boom approach has considerable merit and should be further explored, perhaps in combination with streamer lines. In this study, the mincing-vessel used a longer boom with bright yellow streamers to protect a warp cable with a relatively short extent. Although the bright orange chaffing gear on each line may have enhanced its effectiveness as a visual deterrent, it entangled and killed one bird when it became worn. The rendering-vessel had difficulty applying the warp boom, which led to relatively fewer deployments, resulting in lower sample sizes and greater error around the mean. Our observations strongly suggest that performance standards are critical to the success of mitigation measures in general and this is especially true in the case of warp booms. Future attempts should use booms that are as long and as far aft as practicable and should use brightly colored ropes or hose as streamers, which not only extend to the water but drag back at least one to two meters.

The warp boom was an idea suggested by an Alaska fishing captain but has attributes in common with the Brady Baffler, a warp mitigation structure that includes booms aft as well as outboard on each side of the stern (Sullivan et al. 2006a). In the Falkland Islands demersal trawl fishery, researchers found that the Brady Baffler was the least effective mitigation method evaluated and that it was subject to operational and structural problems. Specifications, such as boom lengths, distance from the stern and length and spacing of streamers, are not described for the Baffler precluding comparisons with the warp boom used in this study.

Other effects

Our pilot study identified the frequency and extent of turns as a critical factor influencing the rate of heavy strikes with both the warp and third-wires (Melvin et al. 2004). However, our attempt to quantify this effect in this study was frustrated by our failure to define "turns" in a consistent way and by the difficulty of estimating the duration of turns while timing observations and quantifying strikes. However qualitative evidence from this study strongly suggests that turns can dramatically increase heavy contacts with birds on the water. When the vessels maintained a steady course, their warps maintained position at or near the inside edge of the discharge plume while birds aggregated on the outside edge. The third-wire remained inside both plumes forward of where port and starboard discharge plumes converge, depending on extent. When the vessel turned, the cables cut across the plume and through the most dense bird aggregations to a point well outside the wake and plumes. In more extreme turns, the cable-water contact was perpendicular to the long axis of the vessel. As the cable traveled through the bird aggregation and back again, cable strike rates increased. The definition of a turn was problematic because vessel captains at times maintained a slight swerve to the path of the vessel to align the net with fish aggregations observed on the net sonar in an attempt to maximize catch. This swerving could last for seconds, in which case the cable would only approach the bird aggregation associated with the discharge plume, or persist for longer and cut well into the aggregation. An adjustment to course on the other hand, could draw trawl cables through the aggregation into contact with birds not associated with the discharge plume and then back through the aggregation a second time as the vessel assumed a new course. Turns also exacerbated the effect of extent: the greater the extent of a cable the wider the swath that was cut while turning and the more birds it encountered. In some cases when a vessel turned sharply – up to 180º – the captain would bring the doors to the stern and short-wire the net to prevent the net and doors from fouling. This maneuver would clear birds from the stern, further complicating the effect of turns on cable strikes. It is also very likely that high swell is an important determinant of cable strike rates (Sullivan et al. 2006b and Sullivan 2006a), but swell height rarely exceeded 2 m during this study, consequently we were unable to detect a significant swell effect.

Mortality

It is important to note that this study has not established a clear link between cable strike rates and seabird mortality rates. Two confirmed northern fulmar mortalities when no third-wire mitigation was in place were clearly associated with third-wire strikes in 170 experimental trawls, and these are probably an underestimate (Weimerskirch et al. 2000). No mortalities were documented from interactions with warps, but given that trawl cables are spliced only at the trawl doors, had mortalities occurred they would have been difficult to detect. However, we did detect 17 net mortalities, but whether these net mortalities were associated with cable strikes is unknown. At the same time, fisheries observers carrying out routine catch sampling not connected with this research detected only three bird mortalities in 200 trawls – two northern fulmars and one short-tailed shearwater. Clearly the existing catch sampling in the fishery designed to measure fish catch by species is inadequate to quantify seabird mortalities in the net forward of the cod-end or from cable strikes.

Sullivan et al. (2006b) established a link between heavy warp contact rates and seabird mortality with primarily large winged birds typical of the Southwest Atlantic shelf – black-browed albatross (*Thalassarche melanophrys*) and giant petrels (*Marcronectes spp*.) – but also cautioned that the relationships between contact rates and mortality are fishery-specific. In this study, the primary species interacting with cables were small birds with relatively short wingspans. Evidence from hundreds of observation hours revealed that these species were little affected by even heavy cable contacts. Anecdotal observations suggested that after heavy on-water contacts, birds that did not extend their wings would bob like corks and resume feeding immediately. Birds with wings extended would typically rotate part-way around a cable, come free and resume activities as if the contact had not occurred. In many cases, birds striking the third-wire while in flight and crashing to the water appeared unaffected. There were cases after heavy contact where a bird's fate could not be determined or it was suspected to have drowned, but these events were rare and injury or mortality could not be verified. Further, the small seabirds did not attempt to consume whole fish dislodged during net haulbacks as seen in other studies involving large southern hemisphere birds (Weimerskirch et al. 2000; Sullivan et al. 2006b; Watkins et al. 2008), perhaps due to smaller gape size, consequently interactions with the full net at the surface were minimal. Given the absence of large-winged birds in this study and the high likelihood they are more susceptible to cable strike mortalities and possibly net mortalities than the small winged birds, a need exists for dedicated Alaskan seabird monitoring programs in areas where large-winged birds (albatrosses) are most abundant to better correlate heavy cable strikes with seabird mortality. Future studies should give serious consideration to developing and using methods to reliably intercept seabird carcasses from cables so that cable related mortality can be quantified and separated from net mortality.

The Need for Conservation

The extent to which seabird mortality in the EBS trawl fisheries is a conservation problem requiring mitigation is unclear. Conservation concern in Alaska fisheries focuses on the endangered short-tailed albatross. Although the distribution of short-tailed albatross overlaps the EBS pollock trawl fishery during summer and early fall (Suryan et al. 2006, Dietrich and Melvin 2007, Slater et al. 2008 and Zador et al. 2008a), evidence of short-tailed albatross interactions with EBS trawl fisheries is lacking. None was seen in this study, nor in our pilot study (Melvin et al. 2004), nor in a related study of third-wires in the EBS trawl fisheries (McElderry et al. 2004). Nor have short-tailed albatross been killed in any Alaska trawl fishery (Fitzgerald et al. 2008), although routine observer program sampling in these fisheries is unlikely to detect rare short-tailed albatross mortalities should they occur. Risk analysis of possible increased short-tailed albatross mortality in Alaska trawl fisheries beyond the current two-bird take limit established under ESA (which is based on expected take as opposed to population biology), suggested that the take could be exceeded by as much as a factor of 10 with little impact on the recovery goals due to high current survival rates for the species (Zador et al. 2008b). The distributions of two other North Pacific albatross species, the Laysan and black-footed albatross, also overlap with the EBS trawl fisheries. No documented takes or reports of gear interactions have been reported between Alaska trawl fisheries and black-footed albatross, a species under consideration for ESA listing since 2007. A single Laysan albatross, a species not listed or considered for listing under the ESA, but listed as vulnerable by IUCN, was observed taken in EBS trawl fisheries from 2002 to 2006 (Fitzgerald et al. 2008). However, an estimated 45 Laysan albatross were killed annually in the much less intensive Aleutian Island trawl fisheries in the same time period. Both of the predominant species interacting with trawl cables in this study (northern fulmars and short-tailed shearwaters) are characterized as species of least concern by the IUCN. Where trawl cable strikes do pose serious threats to seabird populations, mitigation measures and concepts identified in this study provide tools to address those threats.

In conclusion, this study demonstrates several important factors about seabird interactions with trawl cables:

1. The frequency of seabird cable strikes, and with it the likelihood of seabird mortality resulting from cable strikes, is more complex than the magnitude and nature of factory discharge or the number of birds attending a vessel;
2. Cable aerial extent can be an overriding factor determining the frequency of seabird strikes. Future efforts should attempt to reduce cable aerial extent to reduce seabird strikes;
3. The species, in particular the wing size, of birds interacting with cables is important, as small-winged birds appear to be at less risk from trawl cable mortality than large-winged birds. It follows, therefore, that the threat of trawl fisheries to seabirds due to cable strikes could be very different in northern hemisphere fisheries dominated by small seabirds than in southern hemisphere fisheries dominated by large seabirds;
4. Third-wire net monitoring systems are widely used and have advantages over wireless systems to maximize fishing efficiency in some fisheries. Seabird mortality from third-wire strikes can be reduced through mitigation, in this case with properly deployed streamer lines and by reducing or eliminating the aerial extent of the third-wire;
5. Seabird warp strikes can be reduced with streamer lines, and with more effort, warp booms; and
6. Future studies quantifying seabird cable strikes and their mitigation should be carried out on vessels that capture the diversity of a specific fleet.

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Table 1 Vessel specifications. sw = when net is short-wired.

Attribute	Minced Discharge	Rendered Discharge
Length	84.1 m	102.4 m
Breath	13.4 m	15.5 m
Horse Power (to thrust)	3300	4500
Gross Tonnage	2241	3800
Hold Capacity	910-920 t	1,400 t
Products	fillets, surimi, roe, mince*	fillets, surimi, roe, meal,
Factory Discharge	72,000 gal/hr	89,817 gal/hr
3rd Wire Diameter	11.5 mm	12 mm
3rd Wire Aerial Extent (tow/sw)	32 m/39 m	45 m/69 m
3rd wire block to water	7.6 m	8.7 m
Snatch Block to Water	2.6 m	3.0 m
Trawl Block to Water	5.0 m	5.9 m
Trawl Warp Aerial Extent	25 m	13 m
Fishing Depth	100 m	112 m
Net Sonar Manufacturer	Simrad	Simrad
Vessel Width at the stern	11.5 m	14.8 m
Diameter Warp Cable	36 mm	36 mm

*mince is a product and in this application does not refer to discharge

Table 2 Seabird-cable strike definitions adapted from Sullivan et al. 2006a.

Location	Light Strike	Heavy Strike
Air	Bird glances off or touches cable and flies away in a controlled manner.	Bird significantly changes course and/or falls to water after hitting a cable.
Water	Bird sitting on water is touched by cable, but swims or flies away with no apparent effect.	Bird sitting on water is struck by cable and is at least partially dragged under water.
Air + Water	na	Bird flies into the cable and falls to water, then is at least partially dragged under by the cable.

Table 3 Variable definitions and types used in modeling seabird interaction rates.

Explanatory Variable	Definition	Type
Abund-Offal[b]	Offal presence during abundance observation. 4 levels: None, Port, Starboard or Both	Factor
Beaufort	Beaufort sea state	Factor
Distance	Estimated distance astern cable entered water.	Continuous
Depth	Fishing depth (fathoms)	Continuous
Offal	Estimated percent of time cable was in offal stream: 5 levels: 0, 25, 50, 75 & 100	Factor
Treatment	Mitigation treatment – none (control), paired streamers, snatch block, warp boom	Factor
Date	Julian date gear was deployed	Continuous
Trawl Stage[a]	Stage of haul: Tow or Shortwire	Factor
Vessel	Meal or No meal	Factor
Vessel Total	Total number of vessels within 12 nmi (from radar)	Continuous
Wake Total	Total birds in wake zone	Continuous
Weather	5 options: Full sun, partly cloudy, Overcast, Thick fog, Rain	Factor
Wind Direction[c]	Wind direction during observations - categorized as Cross, Bow, Stern, None, Variable	Factor

[a] Third wire analyses only.
[b] Mitigation analyses only.
[c] Warp mitigation analyses only

Table 4. Seabird abundance and cable strike rates for catcher-processors with minced and rendered factory discharge.

Variable	Minced Discharge	Rendered Discharge
Mean Seabird Abundance (per observation)		
third-wire observations	1,010	389
warp observation	932	268
Third-Wire Strikes (per hr)		
while towing	36.9	54.7
while short-wired	40.6	88
while setting	41.9	56.7
while hauling	3.9	7.2
Warp Strikes (per hr)	8.4	13.2
Birds Struck On-Water (%)		
third-wire (while towing)	16	23
third-wire (short-wired)	24	42
warps	94	63
Heavy Strikes (%)		
third-wire while towing	32	41
third-wire while short-wired	34	41
warps	18	36

Table 5. Significance of factors in 'best' models of heavy seabird strikes with trawl third-wire cables (left) and warp cables (right). Samples sizes differ between simple and multiple variable models due to missing values in one or more covariates. Percent deviance was calculated using the change in deviance as each variable was removed individually (*not additive to total explained deviance). na=not included in the model; ns=not significant.

	Third Wire				Warp			
	Treatment, vessel, stage only *(n=248)*		Multiple variables *(n=196)*		Treatment & vessel only *(n=219)*		Multiple variables *(n=171)*	
Factors	p-value	%dev	p-value	%dev	p-value	%dev	p-value	%dev
Treatment	0.000	32%	0.000	37%	0.000	19%	0.000	23%
Vessel	0.023	5%	0.027	1%	0.083	3%	ns	
Stage	0.023	2%	0.002	2%	na		na	
Vessel -Total	na		ns		na		0.046	3%
Beaufort	na		0.004	5%	na		0.000	18%
Abund-Offal	na		ns		na		0.003	9%
Date	na		0.000	11%	na		0.010	4%
Depth	na		0.000	6%	na		ns	
Wind Direction	na		0.008	3%	na		ns	
Wake Total	na		0.001	3%	na		ns	
Vessel:Depth	na		0.007	2%	na		ns	
Date:Wake Total	na		0.001	3%	na		ns	
Total Deviance*		41%		75%		20%		54%

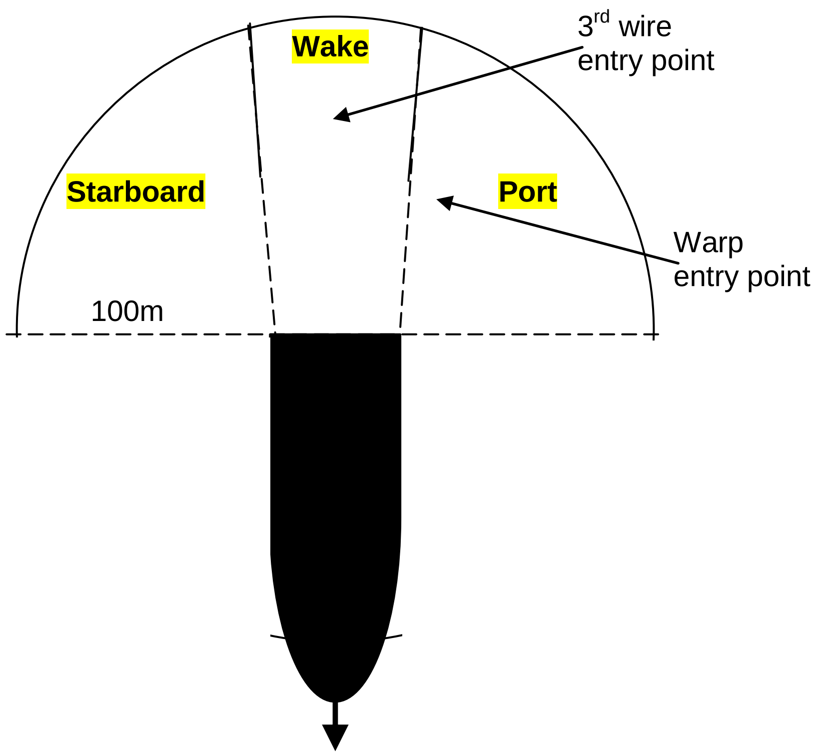

Figure 1 Seabird counts were collected within 100-m hemisphere from the stern. Wake zone is defined by vessel width, birds associated with the discharge plume, and the wake itself.

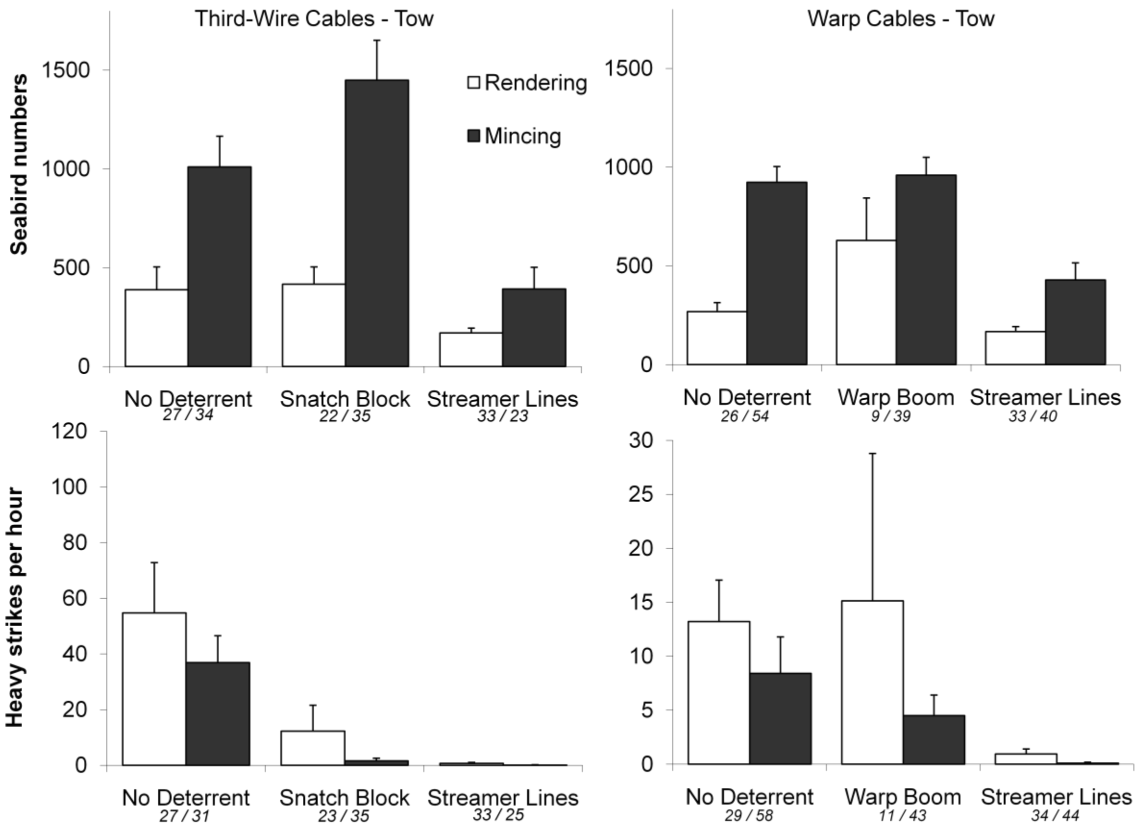

Figure 2 Mean numbers of seabirds in the wake zone and heavy seabird strike rates with third wire (left) and warp cables (right) by vessel (rendered discharge or minced discharge) and mitigation measure. Number of observations (n) is in italics under each bar. Error bars are standard errors

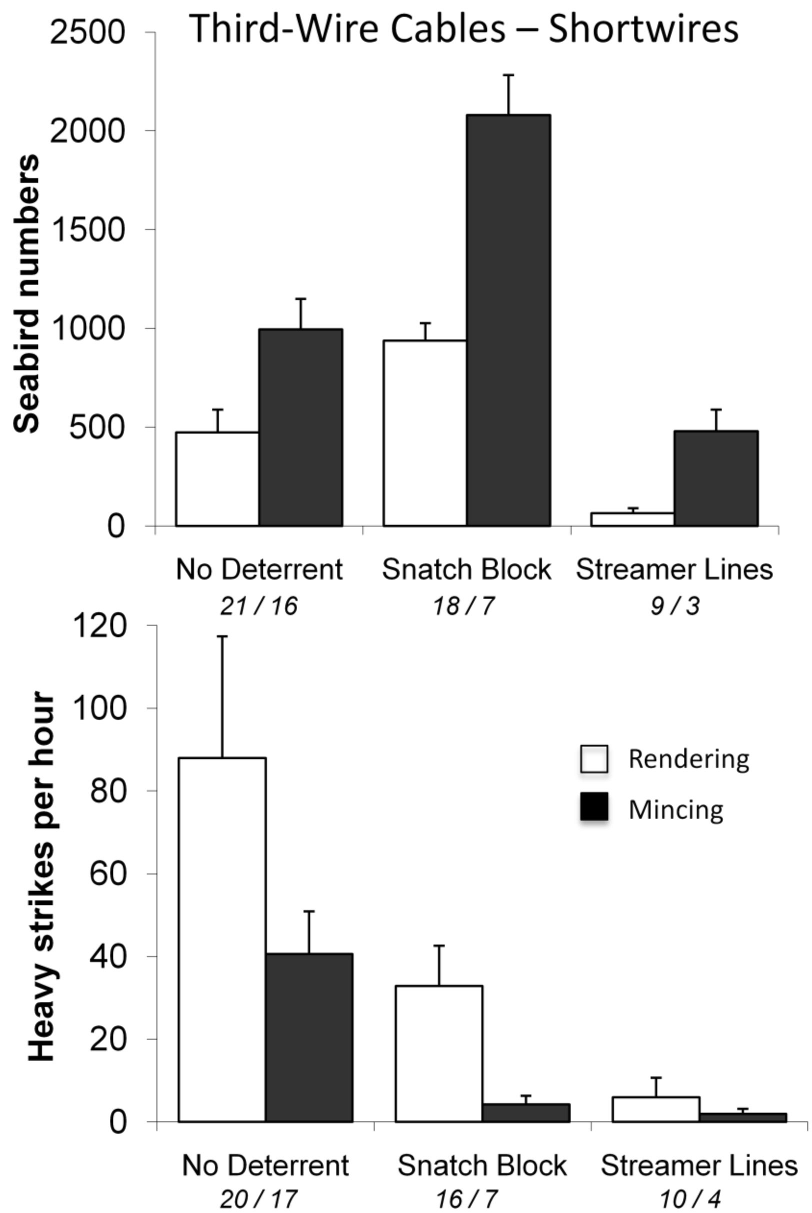

Figure 3. Mean numbers of seabirds in the wake zone and third wire strike rates by vessel type (rendered discharge or minced discharge) and by mitigation measure when nets were short-wired. Number of observations (n) is in italics under each bar. Error bars are standard errors.