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Effectiveness of fish waste management strategies in reducing seabird attendance at a trawl vessel

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ABSTRACT

The risk of seabird bycatch in trawl fisheries is increased by high numbers of seabirds attending vessels to feed on fish waste discharged. We conducted an experimental test of whether mincing fish waste prior to its discharge from a factory trawler reduced the number of seabirds attending the vessel. The trial was conducted on a mid-water trawler targeting hoki (*Macruronus novaezelandiae*) in New Zealand waters, and the experiment compared three treatments (1) discharging 'unprocessed' waste (fish offal and whole discards), (2) mincing all waste to a small particle size before discharge, or, (3) converting all waste to fishmeal and reducing discharge to sump water. The response to the experimental treatments was determined using seabird abundance within a 40 m-radius semi-circular area centred on the vessel stern. Mincing reduced the numbers of large albatrosses (*Diomedea* spp.) feeding astern of the vessel, but had no significant effect on other groups of seabirds. In contrast, reducing discharge to sump water resulted in a significant reduction in numbers of all groups of seabirds. In particular, the abundance of the small albatross group (principally *Thalassarche* spp.), and some smaller procellarids (e.g. sooty shearwater, *Puffinus griseus*, and white-chinned petrel, *Procellaria aequinoctialis*), was reduced to less than five percent of the number that were within the sweep area when unprocessed discharge was released. While mincing significantly reduced the abundance of large albatrosses at the vessel stern, relatively small numbers of these birds attend trawl vessels in New Zealand waters and associated bycatch rates are low. In contrast, reducing the quantity of fish waste discharge by mealing resulted in reduced abundances of a wide range of seabirds at the vessel. Therefore, compared to mincing, we recommend fish waste retention as a more effective management strategy for reducing seabird bycatch.

1. Introduction

Seabird bycatch has been reported from a variety of fisheries globally, and has been linked to the declines of some seabird populations (e.g. Kock, 2001; Tuck et al., 2001; Lewison and Crowder, 2003). In trawl fisheries, waste resulting from fishing and fish processing (e.g. fish offal and whole discards) is attractive to foraging seabirds (Bertellotti and Yorio, 2000; Weimerskirch et al., 2000). Discharged fish waste can alter ecosystem dynamics by providing unnatural feeding opportunities for seabirds. These indirect effects of discharge on seabird populations may be positive or negative, e.g. including dispersal of breeding-age adults (Oro et al., 2004), seabirds switching prey (Votier et al., 2004), and chick deaths when fed low quality prey sourced from fishery waste (Grémillet et al., 2008). However, seabirds that are feeding behind vessels can be injured and killed when they collide with net-sonde monitor cables, are captured in the meshes of nets, or strike the thick cables (trawl warps) that run between nets and vessels (Weimerskirch et al., 2000; Wienecke and Robertson, 2002; Munro, 2005; Sullivan et al., 2006a).

Here our primary focus is on one of the direct effects of trawl fishing on seabirds: mortalities from warp strikes that occur during

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fishing. This source of mortality has only been recognized relatively recently (Wienecke and Robertson, 2002), but has now been reported from several locations globally. These mortalities can be high. During 750 h of observations while trawl fishing in waters around the Falkland Islands, 70 birds were killed by interactions with the trawl warps and came aboard on warp retrieval (Sullivan et al., 2006b). These observations were extrapolated to an estimate of more than 1500 birds being killed in Falkland Islands' waters annually. This estimate does not include birds which may have been killed by warps but not brought on board the vessel. During 190 h of observations in the South African deep water hake (*Merluccius paradoxus*) fishery, Watkins et al. (2006) observed 30 birds being killed on the trawl warps, despite only two dead birds being landed on the vessel. From this data, they estimated that a total of between 7000 and 26,000 birds are killed annually in the South African deep water hake fishery.

The number of seabird warp strikes, and the associated mortality, is greatly reduced when no waste is discharged (Sullivan et al., 2003, 2006a,b; Watkins et al., 2006; Abraham et al., in preparation; Abraham and Kennedy, 2008). For example, during a recent experiment in New Zealand waters (Abraham et al., in preparation), the mean strike rate without discharge was less than one percent of the strike rate when discharge was released. Although discharge was not controlled as part of the design of that experiment, the results suggest that reducing the discharge of waste or discards should be a focus of strategies that aim to reduce seabird mortality.

Globally, the New Zealand region has the highest seabird diversity, with the co-occurrence of over 50 seabird species (Karpouzi et al., 2007). In this region, there is substantial overlap between seabird distribution and commercial fishing effort (Karpouzi et al., 2007). Within the New Zealand Exclusive Economic Zone, 25 different seabirds have recently been confirmed killed in trawl fisheries (Robertson et al., 2004; Baird, 2004a,b, 2005), with white-capped albatross (*Thalassarche steadi*), sooty shearwater (*Puffinus griseus*), and white-chinned petrel (*Procellaria aequinoctialis*) being the most frequently caught taxa. The IUCN (2007) classifies the white-capped albatross and sooty shearwater as near threatened, and the white-chinned petrel as vulnerable. Mitigation devices (such as tori lines) are now widely used in New Zealand trawl fisheries, and have been shown to reduce seabird strikes on trawl warps (Abraham et al., in preparation). Based on a global review of seabird bycatch reduction measures, Bull (2007) suggests that the use of offal management to reduce the numbers of birds around the vessel, together with other mitigation techniques, would provide the best protection against incidental mortality. However, Sullivan et al. (2006b) consider that the use of mitigation devices is primarily a short term measure until fish waste discharges can be managed to avoid attracting seabirds to fishing vessels.

For trawl vessels globally, the intentional retention of fish waste is not a traditional part of standard operating practice. On many trawl vessels active in New Zealand fisheries, it is impossible to retain all processing waste on board even for the duration of a trawl, due to the space constraints onboard vessels and the volume of waste produced from current fishing and processing practices. So, for seabird bycatch reduction in the current operational context, waste management solutions are needed that allow for some discharge while fishing. Anecdotal observations of seabird feeding preferences have led to the suggestion that mincing fish waste may reduce its attractiveness to seabirds (e.g. Munro, 2005). If effective, mincing offal would provide a practical solution to seabird bycatch, as most vessels could be retro-fitted with mincing machines.

We sought to determine whether reducing the particle size of discharged fish waste affected its attractiveness to seabirds, especially albatrosses. We considered that if the waste was minced so finely that albatrosses did not feed on it, there should be a reduction in the numbers of albatrosses in the area immediately behind the vessel. This should then result in fewer albatrosses being struck by the trawl warps. Due to differences in gape size, we considered that albatrosses were less likely to target very small food items, compared to smaller seabirds (petrels, shearwaters). While mincing or mealing fish waste may change the availability of this food source to seabirds, with potential flow-on demographic effects, we focus on methods for mitigating the direct risk to seabirds from interactions with fishing vessels. Indirect effects are not considered further. Thus, our study compared the numbers of seabirds attending a trawl vessel under three experimentally controlled fish waste management regimes. The experimental treatments were (1) a control, with all waste (i.e. skins, guts, frames, fish trimmings, and whole fish discards) discharged without further processing, (2) discharging minced fish waste with a nominal maximum particle size of 25 mm diameter, and (3) minimal discharge, in which all waste was sent to the fishmeal plant and the only remaining discharge was liquid from the meal plant and vessel sumps.

2. Methods

2.1. Location and vessel set-up

The trial was carried out between September 18 and October 10, 2006, on a trip targeting hoki (*Macruronus novaezelandiae*). Fishing was carried out in two areas in the New Zealand Exclusive Economic Zone, one to the east and the other to the south of New Zealand (Fig. 1). The vessel was a 70 m long Norwegian-built stern trawler set-up for fillet processing. The vessel had a meal plant capable of processing all factory waste and bycatch to fishmeal (Atlas Stord model T5WH, with a capacity of 5–8 tonnes pack weight per day). A mincer (Napier engineering, model PB3-GC) was installed in the vessel's factory. This mincer was originally designed for use in meat processing plants. The same machines have been used on other fishing vessels to reduce the size of the offal before it goes into the meal plant. The mincer used an auger to chop the waste and move it towards the outlet, forcing it through a final mincing plate with

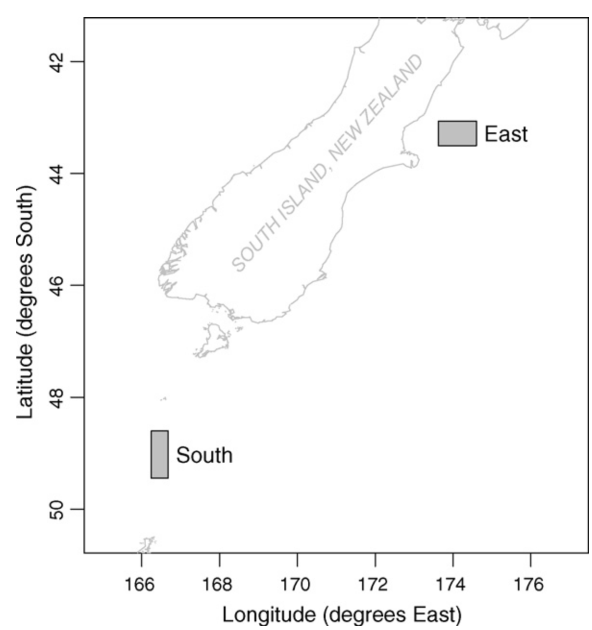

Fig. 1. Experiment location showing the two fishing grounds (shaded). During the first part of the experiment (September 18 to October 1, 2006) all fishing was within the East fishing ground. The vessel then moved to the South fishing ground for the remainder of the experiment (October 3 to October 10, 2006).

25 mm holes. The mincer was capable of handling both offal (fish guts, frames, skins, etc.), as well as whole bycatch (such as sharks) and reduced the waste to a paste which was mixed with water before being pumped overboard. The vessel used tori lines to reduce seabird interactions with the warps. Mince was discharged at the stern, while unprocessed waste was discharged from the side of the vessel. The tori lines met the legal specifications required for large trawlers in the New Zealand Exclusive Economic Zone (Department of Internal Affairs, 2006).

2.2. Sampling protocol

The key measure used to compare the treatments was the abundance of birds, by species group, behind the vessel. The rate of seabird interactions with fishing gear is related to seabird abundance in the vicinity of vessels (e.g. warp strikes Abraham et al., in preparation), and so the counts were made as a proxy for interactions between the birds and the warps. We recognize that numbers of bycaught seabirds, and counts of warp strikes, would be more direct measures of injurious seabird interactions. However, given sensitivities around conducting lethal experiments, and the large number of such interactions that would be required to resolve treatment effects (Abraham et al., in preparation), we opted not to use these measures.

Observations were carried out by an experienced New Zealand government fisheries observer, who made conducting seabird observations a priority during the trip. Birds were counted within a semi-circular zone of 40 m radius extending from the stern of the vessel. The observer recorded the numbers of birds in each of 15 different categories. Counts were made of five species groups:

(1) Large albatrosses (royal and wandering albatrosses; *Diomedea* spp.).
(2) Small albatrosses (other albatrosses; *Thalassarche* spp. and *Phoebetria* spp.).
(3) Giant petrels (*Macronectes* spp.).
(4) Cape petrels (*Daption* spp.).
(5) Shearwaters and other petrels (other *Procellariidae*).

The birds were also grouped by their behaviour into three categories:

(1) Flying (flying or gliding).
(2) Sitting (sitting on the water, but not feeding).
(3) Feeding (feeding or engaged in feeding related activity including diving, surfacing, or aggressive interactions with other birds).

Each count was made in a separate visual sweep of the 40 m-radius semi-circle. The observer spent no more than 1 min on each individual sweep, and a maximum of 15 min on each set of 15 sweeps. Because each species-behaviour category was counted separately, some individual birds may have been counted more than once, or not at all, if they changed behaviour between sweeps.

Three fish waste treatments were used:

(1) Unprocessed (the discharge of all offal and whole discards).
(2) Minced (the discharge of offal and discards after passing through the mincer).
(3) Mealed (all offal and discards were converted to fish meal, so the only discharge was of water and any scraps through the factory sump pump, and liquid from the meal plant).

Treatments were implemented daily from 06:00 h until 18:00 h, following a schedule that was determined before the experiment started. A randomised block design was used, with each treatment being used once within each group of 3 days. Observations were made on 21 days (seven repeats of each of the three treatments). The observer also recorded the rate at which discharge entered the 40 m-radius observation area, using four discharge categories:

(1) Sump water.
(2) Minced material (material that had gone through the mincer).
(3) Offal (heads, guts and frames of processed product).
(4) Discards (whole fish, squid or other bycatch).

The rate at which each discharge type appeared was categorised as none, negligible, intermittent or continuous. In previous observations of warp strikes, a similar qualitative categorisation of discharge has been found to have significant explanatory power for both bird counts and warp strikes (Abraham et al., in preparation; Abraham and Kennedy, 2008). These observations also provided a check on the implementation of the discharge management treatments.

When the vessel was trawling, the observer recorded heavy strikes on the trawl warps or tori lines. These observations followed the protocol outlined in Abraham et al. (in preparation), which was based on the methods developed by Sullivan et al. (2003, 2006a). A heavy strike was defined as one where the bird was deflected from its path and the contact was on the head or body, or above the carpal joint (the wrist) on the wing. The protocol required the observer to watch both the warp and the tori line on the side of the vessel where most offal was discharged for 15 min each, recording the number of heavy contacts made by each of two species groups:

(1) Albatrosses and giant petrels (all albatrosses: *Diomedea*, *Thalassarche* and *Phoebetria* spp., and giant petrels, *Macronectes* spp.).
(2) All other seabirds.

Seabird counts were also made in the 40 m-radius observation area when the vessel was not fishing, in order to increase the set of observations. This allowed data to be collected when the birds were close to the stern, as the mitigation used during fishing normally reduced bird numbers in this area.

Finally, auxiliary daily bird counts were made as part of the observer's other duties. These provided an estimate of the total number of seabirds within 50 m of the vessel stern during the first daylight trawl haul. These counts give a more detailed taxonomic breakdown than was recorded in the experimental observations.

2.3. Statistical analysis

A statistical model was built for each of the 15 species-behaviour groupings to determine whether the treatments were having a significant effect. The count data was assumed to be appropriately represented by the negative-binomial distribution (e.g. Venables and Ripley, 2002), with the means varying according to the treatments and other covariates.

To select potential covariates, negative-binomial generalised linear models were built using the lmer function in the lme4 package (Bates and Sarkar, 2006) of the statistical software R (version 2.4.0, R Development Core Team, 2006), and an automated step procedure used to select the significant covariates. In addition to the experimental treatments, the potential covariates included wind speed (Beaufort scale), time of day (hours), whether or not the vessel was fishing, the tonnage of offal discharged during each day, vessel speed (knots), the day of the experiment, and a factor indicating the location of the vessel (East or South fishing ground, see Fig. 1). Wind speed was not always available at the time of the observation, as it was only recorded during warp-strike observations, and the closest available wind speed estimate was then used. The factors relating to treatment were included in each model. The step procedure then chose between the remaining covariates, using Akaike's Information Criterion (AIC) to select between alternate models. Having found a parsimonious model for each series of species-behaviour data an additional selection step was carried out. For each species grouping, covariates were retained that were significant ($p < 0.05$) in two or more of the three behavioural categories. This meant that, within each species group, the three models had the same structure.

After this initial exploration, the selected covariates were used to build final generalised linear models using Bayesian methods (e.g. Gelman et al., 2003; Congdon, 2003). Markov-chain Monte-Carlo simulations were used to estimate the model parameters from the data, with the software OpenBugs being used (version 2.2.0 beta, Thomas et al., 2006) from within R. The bird-count observations, y_{ij} (where the indices represent an individual observation i from experimental block j), were assumed to be drawn from negative-binomial distributions with mean μ_{ij} and variance $\mu_{ij} + \mu_{ij}^2/\theta$, where θ describes the overdispersion. The mean value was assumed to be a function of the fixed effects, x_k, with

$$\log(\mu_{ij}) = \alpha_j + \sum_k \beta_k x_{ik}.$$

Block-level random effects, α_j, were included in the final model, with a different value for each of the experimental blocks of 3 days. The values were drawn from a normal distribution, with the standard deviation varying between the different blocks, and with the mean being the intercept of the linear predictor

$$\alpha_j \sim \text{Normal}(\beta_0, \sigma^2).$$

The inclusion of the intercept (β_0) within the random effects distribution improved convergence in the model. If the intercept was included as a fixed effect, there was a correlation between the intercept and the random effects, and the estimated intercept was liable to wander. Covariates which had the same value throughout an experimental block, such as the fishing ground, were not included in the model, as they could be accounted for by the random effect.

Given the mean and the overdispersion, the observations are compared with samples from a Poisson with a Gamma-distributed mean, which generates the appropriate negative-binomial distribution,

$$y_{ij} \sim \text{Poisson}(\delta_{ij}),$$
$$\delta_{ij} = \text{Gamma}\left(\theta,\ \frac{\theta}{\mu_{ij}}\right).$$

To complete the model specification, priors are required for the parameters β_k, and hyperpriors for the hyperparameters β_0, θ and σ. We chose the vague bounded uniform (hyper)priors below for all these (hyper)parameters.

$$\beta_k \sim \text{Uniform}(-10, 10)$$
$$\beta_0 \sim \text{Uniform}(-10, 10)$$
$$\log(\theta) \sim \text{Uniform}(-3, 5)$$
$$\sigma \sim \text{Uniform}(0, 10)$$

The bounds were selected on the assumption that higher or lower values of these parameters would be unreasonable. Parameters that approached these bounds might suggest problems with model misspecification. On some treatments there were no birds observed in some behavioural categories, and the lower bound prevents the corresponding treatment effects from drifting towards negative infinity. The choice of a uniform prior for the standard deviation of the random effects follows the recommendations of Gelman (2006).

For each model fitted, two chains were run. The chains were initialised with values derived from a similar generalised linear model that was fitted in R. For all the final model fits reported here, the simulations were run for an initial burn-in period of 100,000 iterations. After discarding the burn-in, 5000 samples were retained from each chain, with a thinning interval of 500 updates. The large thinning interval was needed as some covariates were highly autocorrelated. The median of the posterior of each parameter was used as the best estimate, and credible intervals were determined from the 2.5% and 97.5% percentiles of the posterior distributions. Convergence was determined from inspection of the posterior densities, and of traces of the chains. More formally, a diagnostic based on a Cramer–von-Mises test of whether the sampled values come from a stationary distribution (Heidelberger and Welch, 1983) was used to determine whether the chains of parameters associated with the treatment effects had converged.

To ascertain whether the experimental discharge treatments had a statistically significant effect on tori-line strikes, two generalised linear models of the strikes were built, following the methodology given above. In the first, the only factors that were included were the treatment effects, and in the second the bird counts were also included. Because of the low numbers of observations, we were unable to explore whether other covariates have a confounding effect. As with the models of the count data, block-level random effects were used.

3. Results

3.1. Experimental summary

During the trial the mincer functioned well. Waste production ranged between seven and 24 tonnes per day, and the mincer was able to process the entire discharge stream. The mince had initially been set to discharge at the side of the vessel, however the mince bound into clumps that attracted birds. On the second day of the mincing treatment, the outlet from the mincer was diverted so that it was pumped through the wave gate channel and discharged into the propeller wash at the vessel stern. With the thrust used when the vessel was fishing, the turbulence from the wash was sufficient to break any clumps and disperse the mince. The meal plant also functioned well through most of the experiment. On one observation during a mealed treatment, the plant became blocked and there was discharge of offal. This observation was removed. Otherwise, during the mealed treatments all waste was retained with the only discharge being sump water.

There were 161 complete bird-count observations made through the experiment. The production of waste, including sump water, was almost continuous, and there were only 14 observations that had either negligible or no discharge. These were excluded from the analysis. Observations were made both when the vessel was fishing, and when it was processing catch but not fishing. Typical fishing speeds were between 3.8 and 5.7 knots. When the vessel was not fishing, there were nine observations made when the vessel was travelling at more than six knots and 28 observations made when it was travelling at less than 3.5 knots. These observations were excluded from the analysis to prevent data collected at atypical speeds from influencing the results. This left 40 observations made during the unprocessed treatment, 36 made during the minced treatment and 45 made during the mealed treatment. After excluding the observations collected under unsuitable conditions, there were no observations remaining from the final experimental day.

Table 1
Median number of birds around the vessel, with range given in brackets, for days during the experiment when the vessel was at the Eastern fishing ground, and when it was at the Southern fishing ground

Group	Common name	Scientific name	Median bird count (range)	
			East	South
Large albatross	Southern royal, Antipodean, and wandering albatross	*Diomedea epomophora, D. antipodensis, D. exulans*	11 (3–19)	4 (3–11)
Small albatross	White-capped albatross	*Thalassarche steadi*	20 (0–30)	200 (150–300)
	Black-browed albatross	*Thalassarche melanophrys*	1 (0–1)	50 (20–70)
	Salvin's albatross	*Thalassarche salvini*	300 (100–320)	5 (3–6)
	Buller's albatross	*Thalassarche bulleri*	0 (0–1)	10 (5–20)
Giant petrel	Giant petrel	*Macronectes halli, M. giganteus*	13 (7–22)	30 (20–70)
Cape petrel	Cape petrel	*Daption capense*	600 (400–800)	600 (300–600)
Other petrel	White-chinned petrel	*Procellaria aequinoctialis*	10 (0–60)	200 (150–200)
	Sooty shearwater	*Puffinus griseus*	30 (0–300)	300 (200–300)

Birds were identified to species level where possible. No other species, apart from those listed, were recorded by the observer.

A total of 109 warp or tori-line strike observations were made during 36 tows. There were some observation forms that were incomplete, and where the missing information could not be inferred. When these were removed from the analysis, a total of 96 individual observations remained, from 31 different tows. When broken down into the different treatments and between the warps and the tori lines, the number of observations in each category is small (20 or less).

3.2. Bird counts

Data from the daily bird counts are shown in Table 1. The assemblages of birds around the vessel were dominated by the cape petrels, small albatrosses and the other petrel groups. Giant petrels and large albatrosses are present in relatively low numbers. In the eastern region, Salvin's albatross (*Thalassarche salvini*) was the most frequent smaller albatross, whereas in the southern region white-capped albatrosses were more common. The 'other petrel' category was a mix of both sooty shearwaters and white-chinned petrels, and both of these species were largely absent from the eastern region. (Because of low numbers of other petrels early in the experiment, only data from the southern fishing ground were used when modelling this category.)

A summary of the count data from all the observations that were used in the modelling is shown in Fig. 2. During the unprocessed treatment the mean numbers of birds within the sweep area were nine large albatrosses, 143 small albatrosses, seven giant petrels, 124 other petrels (southern ground only) and 371 cape petrels. The numbers of sitting birds tended to be higher than the other two behavioural categories.

In all models of the count data, the random block effects, treatment effects and a factor indicating whether the vessel was fishing were included. The only other covariates that were carried through from the initial analysis to the Bayesian modelling were wind speed (for all groups apart from large albatross) and time of day (for small albatross). All model chains passed the stationarity test for both treatment effects, although the diagnostic suggested that three chains had not achieved convergence after the initial burn-in. Given that 60 different chains were tested, we were not concerned by this failure.

The suitability of the negative-binomial model was checked by inspecting the quantile residuals (Dunn and Smyth, 1996) shown in Fig. 3. Most models had the expected distribution of residuals, although some differences were seen. The poorest model was of feeding cape petrels. In this case there were more observations with low numbers of cape petrels than would be expected from the fitted distribution. These deviations may have affected the estimation of the credible intervals.

The only treatment effect which approached the bounds of the prior was the mealed treatment for feeding large albatross. This was not well constrained as no large albatrosses were observed feeding during the mealed treatment.

The results of the statistical modelling are summarised in Fig. 4. The mealed treatment showed significant reductions in abundance (relative to the unprocessed treatment) in all behavioural categories for both large and small albatrosses and for the other petrels, with the biggest reductions being in the numbers of feeding birds. When all discharge was mealed, the numbers of feeding small albatrosses and of other petrels were reduced to less than five percent of the numbers counted during the unprocessed treatment. No large albatrosses were observed feeding when the waste was mealed. The numbers of feeding giant petrels and cape petrels also showed significant reductions under the mealing treatment. During the minced treatment there were significant reductions in the numbers of large albatrosses, across all behavioural categories. When the waste was minced, there was less than five percent of the number of feeding large albatrosses present, compared to when unprocessed waste was discharged.

3.3. Tori-line strikes

There were 47 large seabird contacts on the tori lines across the trial (a mean rate of 1.07 birds per 15 min observation), and a total of 77 other bird contacts (a mean rate of 1.75 birds per 15 min observation). As giant petrels were uncommon during the trial (Table 1 and Fig. 2), large bird strikes were likely to be of albatrosses. The overall rates of other bird tori-line contacts are similar between the East and South fishing grounds (1.81 and 1.69 strikes per observation, respectively). At the time of the experiment, sooty shearwaters and white-chinned petrels were largely absent from the eastern region, suggesting that most of these strikes were associated with cape petrels, the only other species in this category that was present in large numbers (Table 1).

There were few strikes on the trawl warps (one large bird and four other birds, a rate of 0.02 and 0.08 birds per observation, respectively). Because of the low number of strikes on the warps, we did not look for treatment effects in this dataset. The variation in the numbers of strikes on the tori lines is shown in Table 2. The raw data suggest that both the minced and mealed treatments were reducing the numbers of strikes on the tori lines relative to unprocessed discharge; however the number of strike observations was low. Since strike data can be highly skewed, with large numbers of zeros and occasional observations with high strike numbers (Abraham et al., in preparation), small numbers of observations may lead to poor estimates of the underlying strike rates.

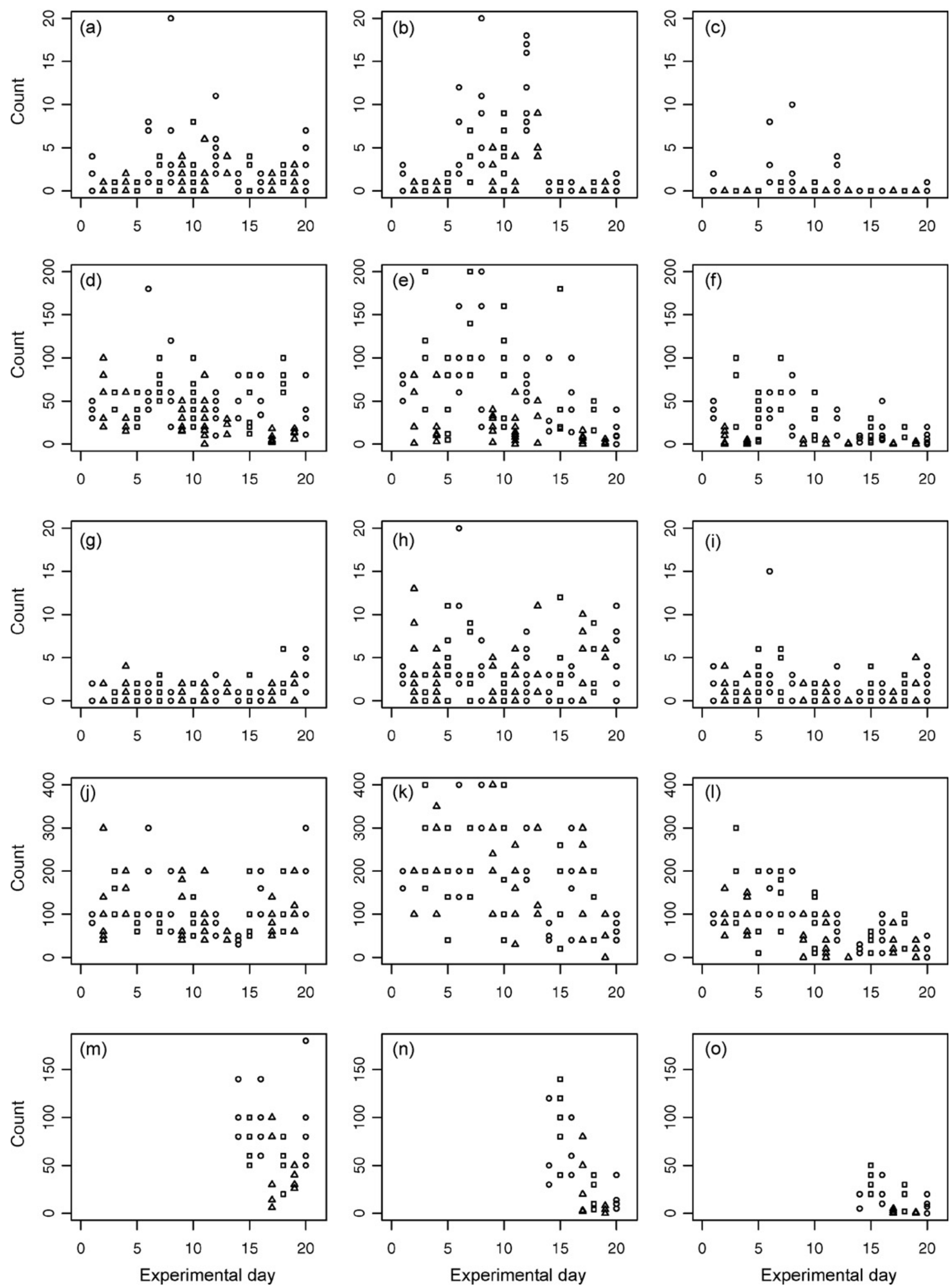

Fig. 2. Raw sweep counts for each of the 15 species group and behavioural categories. The different symbols represent the different treatments (○ – Unprocessed, □ – Minced, △ – Mealed), and all data used in the statistical analysis is shown. (a) Large albatross/Flying. (b) Large albatross/Sitting. (c) Large albatross/Feeding. (d) Small albatross/Flying. (e) Small albatross/Sitting. (f) Small albatross/Feeding. (g) Giant petrel/Flying. (h) Giant petrel/Sitting. (i) Giant petrel/Feeding. (j) Cape petrel/Flying. (k) Cape petrel/Sitting. (l) Cape petrel/Feeding. (m) Other petrel/Flying. (n) Other petrel/Sitting. (o) Other petrel/Feeding.

The median values of the posterior distribution produced from the statistical modelling show that for both the mealed and the minced treatments, and for both the large and small bird groupings, the treatments reduced the numbers of tori-line strikes (Table 3). However, the only effect that was significant, at the 95% credible level, was a reduction in tori-line strikes by large birds associated with the mealing treatment. When the bird count was introduced into the model, through adding a covariate log(count + 1), then bird count was significant (in the albatross model) and the effect of the mealed treatment was no longer significant. The coefficient of the bird count in the albatross model was similar to the coefficient derived in other warp-strike modelling for this group using

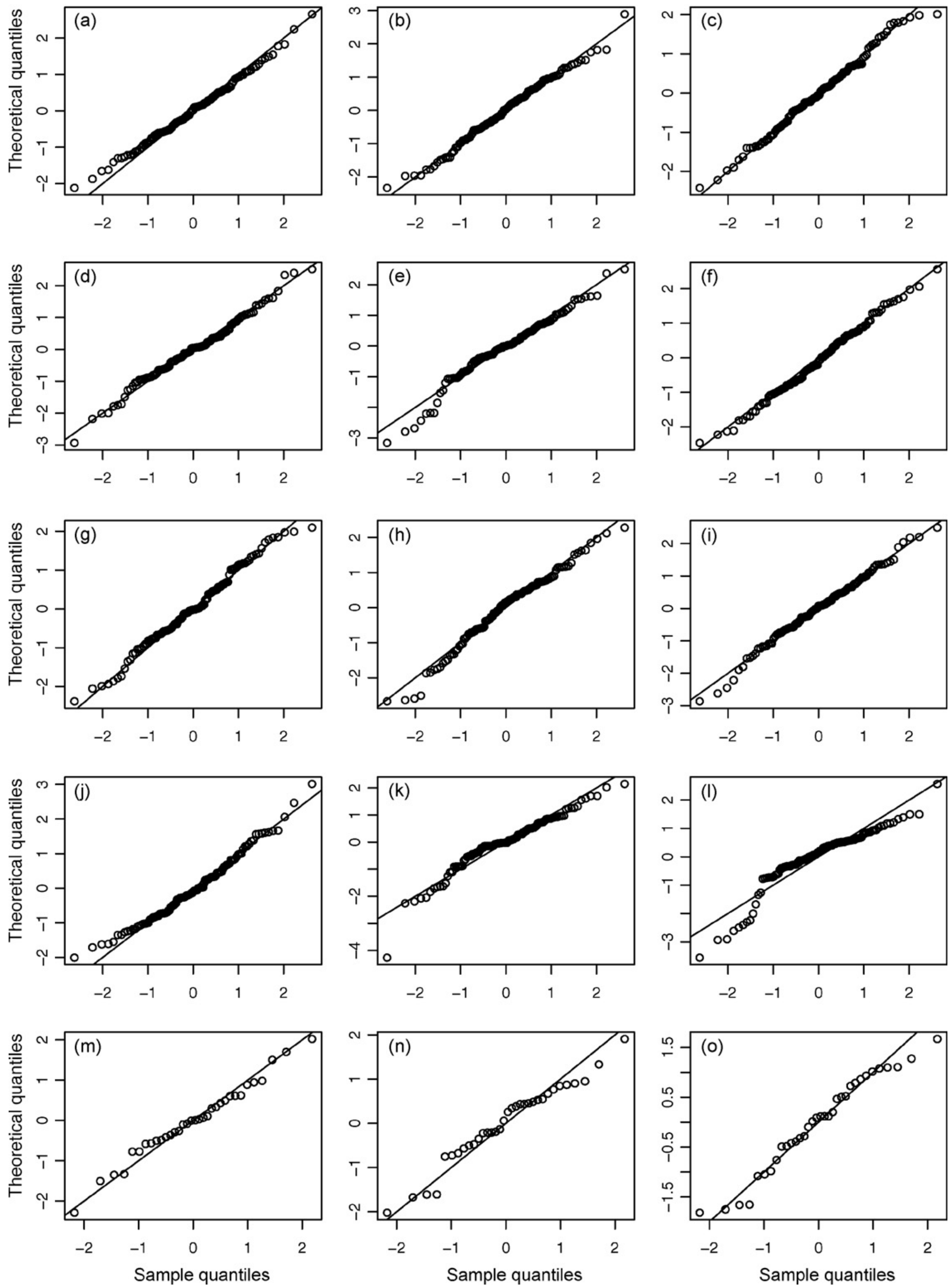

Fig. 3. Summary of the residuals between the model estimated and actual data. If the model represented the data exactly, all points would lie along the one to one diagonal. (a) Large albatross/Flying. (b) Large albatross/Sitting. (c) Large albatross/Feeding. (d) Small albatross/Flying. (e) Small albatross/Sitting. (f) Small albatross/Feeding. (g) Giant petrel/Flying. (h) Giant petrel/Sitting. (i) Giant petrel/Feeding. (j) Cape petrel/Flying. (k) Cape petrel/Sitting. (l) Cape petrel/Feeding. (m) Other petrel/Flying. (n) Other petrel/Sitting. (o) Other petrel/Feeding.

the same protocol (1.45, 95% C.I.: 1.38–1.96, Abraham et al., in preparation) and provides some reassurance that this model did not over-fit the data. The loss of significance of the treatment effect when bird count was included is consistent with the treatment primarily reducing the tori-line strikes by reducing the numbers of birds around the vessel.

4. Discussion

In this experiment, mealing of fish waste resulted in a significant reduction in the numbers of all seabird groups feeding in the 40 m observation zone astern of the vessel (relative to when unprocessed fish waste was discharged). The numbers of flying or

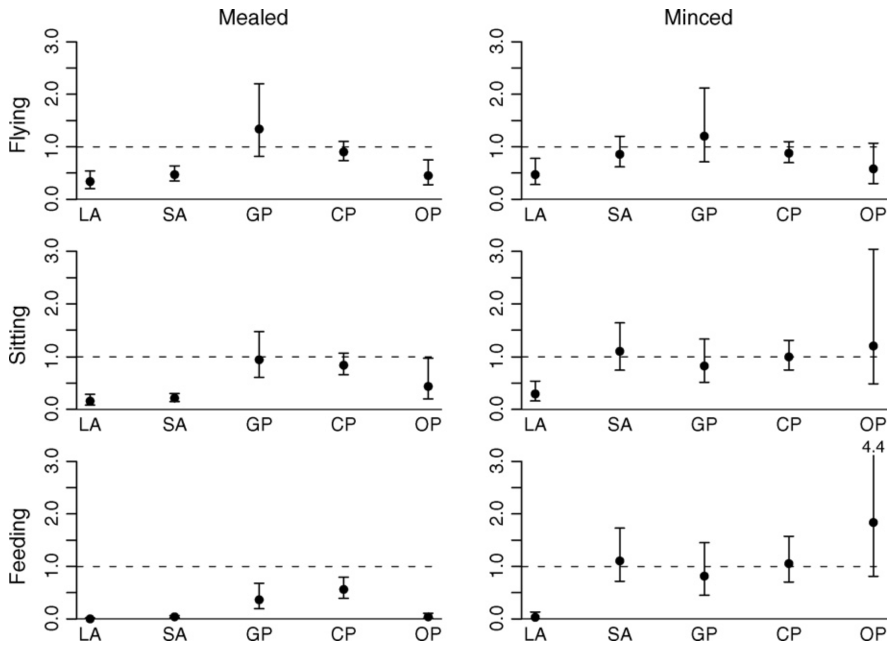

Fig. 4. Summary of the treatment effects for the 15 models of the bird counts, by behaviour and species group. The figure shows the median of the posterior distribution and the 95% credible interval for the coefficients of the mincing and mealing treatment effects. The values are exponentiated, so that they are multiplicative, with no effect having a value of one. The letters indicate the species group (LA = large albatross, SA = small albatross, GP = giant petrel, CP = cape petrel, OP = other petrels). Credible intervals that go above a factor of 3 are truncated, and the upper limit is then indicated by a number.

Table 2
Mean numbers of tori line strikes per 15 min observation, for each of the three treatments

	Treatment		
	Unprocessed	Minced	Mealed
Number of observations	17	11	16
Albatrosses and giant petrels	2.1 (1.1–3.2)	0.6 (0–1.9)	**0.3** (0–0.7)
Other birds	2.4 (1.6–3.1)	**0.8** (0.3–1.4)	1.7 (0.8–2.8)
All strikes	4.5 (3.2–5.9)	**1.4** (0.5–2.6)	**2(0.8–3.4)**

The confidence intervals are 95% percentiles from 1000 bootstrap samples of the data. Strike rates that are significantly different from the unprocessed treatment are shown in bold.

sitting albatrosses and petrels, other than giant and cape petrels, were also significantly reduced in the mealed treatment. In contrast, the mincing treatment had no significant effect on any of the bird groups attending the vessel, except the large albatrosses of the genus *Diomedea*. This group of seabirds attended the vessel in significantly lower numbers during the mincing treatment across all behavioural categories, with the greatest reduction observed in numbers feeding. The tori-line strike data suggest that both mincing and mealing fish waste may have resulted in reduced strike rates. However, due to the low numbers of observations, this result is inconclusive.

Table 3
Summary of models of the tori-line strike data, giving the coefficients of the fixed effects

	Fixed effects		
	Mealed	Minced	log(bird count)
Albatross group			
Treatment only	**0.14** (0.02–0.85)	0.3 (0.045–2.1)	–
With bird count	1.1 (0.09–12)	0.37 (0.059–2.5)	**1.7** (0.27–3.5)
Other birds			
Treatment only	0.69 (0.27–1.8)	0.34 (0.1–1.1)	–
With bird count	0.77 (0.27–2.1)	0.5 (0.12–2.4)	0.98 (−0.83–2.9)

The values give the median of the posterior distributions for each parameter, together with the 95% credible interval. The coefficients of the treatment effects have been exponentiated, so that they are multiplicative effects, with no effect having a value of one. Effects shown in bold are significant at 95% level. Two models are shown for each group: one with the bird counts included, and one without.

A differential effect of mincing for the two groups of albatross in our study is consistent with knowledge of the natural diet of their congeners in other areas. While the size range of their prey is broad, the wandering albatross (*Diomedea exulans*) tends to feed on larger squid than the smaller grey-headed (*Thalassarche chrysostoma*) and black-browed albatrosses (*Thalassarche melanophrys*) (Xavier and Croxall, 2007). For other seabirds, including those comprising the assemblage in our study area, relationships between body size and prey size are not well documented (Ainley et al., 1992; Balance et al., 2001). However, we expect that the smaller gape size of petrels and shearwaters will restrict them to smaller whole prey than the larger albatrosses (Hulsman, 1981).

In New Zealand, albatrosses of the genus *Diomedea* are rarely observed caught by trawl fishing vessels (Baird, 2004a,b, 2005). Observations during this trial, and previous reports, suggest that this is in part because these albatrosses do not generally attend trawl vessels in large numbers, or in as close proximity, as the smaller *Thalassarche* species (Petyt, 1995). As a result, while discharging minced waste produced a significant reduction in attendance by this group, it may be of relatively little benefit overall for seabird bycatch reduction.

Anecdotal reports from government observers and vessel crews note seabird attendance (including in close proximity) at trawlers discharging mince, but suggest that this form of discharge may result in less frenzied feeding activity at the stern of vessels. This behavioural change would not be captured by the protocol, and its effect on seabird interactions with fishing gear is unknown. Observers also note that mince streams are visible further out from the stern of vessels than unprocessed offal streams. While the effects of the relative visibility of waste streams are undocumented, it is expected that mince streams are attractive to seabirds, and consequently, the more widely dispersed minced discharges may attract seabirds to vessels more effectively than ‘unprocessed’ offal discharge. The location of discharge chutes may also affect seabird distribution around vessels, although this is not easily manipulated on fishing vessels. As noted above, mince was discharged at the stern in our trial, while unprocessed waste was discharged from the side of the vessel. However, this situation is reflective of most trawl vessels, in that fish waste will generally be discharged from various points (e.g. sump pumps, one or two offal/discard chutes, meal plant outflows). It is also possible that discharging mince with smaller particle size than achieved here may result in stronger effects on seabirds, beyond those observed in this trial.

Globally, the recognition of the relationship between the discharge of fish waste and seabird mortality in both longline and trawl fisheries has prompted interest in vessel waste management strategies that reduce and control discharge. For example, deepwater trawl vessels in New Zealand now operate under Vessel Management Plans that prescribe waste management measures intended to reduce the risk of seabird interactions. Internationally, other fisheries have also adopted offal management strategies to reduce the risk of seabird interactions. For example, fisheries operating under the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) must hold waste onboard at all times, or retain it during longline setting and discharge it on the opposite side to longline hauling (CCAMLR, 2002). Although holding waste may be operationally difficult for many trawlers, minimising discharge is likely to lead to a direct reduction in the numbers of seabirds foraging behind the vessel.

Given the global association between fishing vessels, waste discharge, and seabird bycatch, and suggestions that reducing particle size may reduce seabird attraction to fish waste, our results have widespread application amongst trawl fisheries. In this experiment, mealing offal and discards and so reducing discharge to sump water only, significantly reduced the number of seabirds feeding behind the vessel, across all species groups. This decrease was especially large for the small albatross group, principally species of the genus *Thalassarche*. Less than five percent of the number of small albatrosses fed around the vessel when fish waste was sent to the meal plant, relative to when unprocessed fish waste was discharged. For vessels with capability to make fish meal, our results indicate that the mealing of all fish offal and discards reduces seabird attendance and, therefore, the risk of incidental seabird mortality. If vessels are unable to install meal plants, holding waste as long as possible, ideally until fishing gear is out of the water, would be a somewhat analogous alternative. However, this may be limited in practice by vessels' holding capacities. Our results show that mealing (or otherwise holding) fishery waste is expected to deliver greater reductions in seabird bycatch than discharging minced fish waste. Consequently, we cannot currently recommend mincing fish waste prior to discharge as a means to reduce bycatch of all seabirds, or bycatch of all albatrosses.

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