SEABIRD BYCATCH IN NEW ZEALAND TRAWL AND LONGLINE FISHERIES, 1998–2004

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(with nine text-figures and 17 tables)

Fisheries bycatch is a threatening process for populations of procellariiform seabirds, and is of particular importance for the conservation of albatross, an especially threatened group at a global scale. There is a high level of endemism of albatross and petrels in New Zealand waters, and around one-third of the world's species of procellariiform seabirds breed in this area. Therefore, understanding the levels of mortality of these species in the New Zealand Exclusive Economic Zone is important for global conservation of the order. For New Zealand fisheries for the 1998–2004 fishing years, we estimated total seabird bycatch using data from scientific observers with model-based estimation procedures. Although sectors of the fishing activity were not evenly covered by observers, we were able to estimate seabird bycatch for large-scale fisheries by vessel size (split at 28 m length), season, area and year. Approximately 5500 seabirds (credible interval between 2000 and 10 000) are estimated to be landed in New Zealand trawl and longline fisheries annually, as a result of interactions with fishing gear. Few data were available for the small vessels, thus estimates are highly uncertain. Mortalities are likely to be most common in trawl fisheries at approximately 2000–3000 seabirds annually, with the greatest contribution coming from large vessels. Around one half of these birds were albatross. For large surface longline vessels we estimated that fewer than 500 seabirds were killed annually during the main tuna fishing season. For large demersal vessels, seabird mortality was estimated to have decreased from around 1800 seabirds in 2001 to 600 seabirds in 2004. We report observed captures by species for each fishing method and area for the fishing years 1998–2004. Thirty-one species of Procellariiformes were identified during this period, over half of which are threatened species. For some species, such as White-chinned Petrel, *Procellaria aequinoctialis* and White-capped Albatross, *Thalassarche steadi*, several hundred individuals were caught. For 15 species, fewer than 10 individuals were identified. However, the unrepresentative deployment of observer coverage across fishery areas makes it difficult to interpret the conservation implications of species captures. A high proportion of the petrel species was observed caught primarily from areas surrounding their breeding sites while albatross were caught across breeding and non-breeding areas. Greatly improved observer sampling ratios, and studies of population status and trends, are needed to understand the conservation implications of the effects of New Zealand trawl and longline fishing mortalities on seabird populations.
Key Words: albatross, petrel, mortality, New Zealand, conservation, Procellariiformes, White-chinned Petrel, White-capped Albatross, model-based population estimates, *Procellaria aequinoctialis*, *Thalassarche steadi*.

INTRODUCTION

Estimating seabird mortality in fisheries is a key factor in assessing the sustainability of fisheries (Small 2005, Lack 2007). Fisheries bycatch has been identified as a threat to most albatross species (Gales 1998), and also results in the deaths of a large number of petrels (Brothers *et al.* 1999). Supplementary feeding of seabird populations on fisheries waste can boost population numbers for some species, as documented for the faster-breeding Lariidae species in the northern hemisphere (Furness 2003). However, the resulting complex changes in seabird community structure can be deleterious, as slower-breeding or more vulnerable populations of seabird can suffer increased predation pressure and competition as a result of increases in some larger predatory gull populations (Furness 2003). Fisheries mortality is identified as an important driver for population decreases for the slower-breeding albatross and petrel populations (Croxall *et al.* 1990, Weimerskirch *et al.* 1997, Tuck *et al.* 2001, Cuthbert *et al.* 2003, Nel *et al.* 2003, Rolland *et al.* 2007), while climate effects and colony-based impacts have more recently been recognised as contributory factors in population changes (Barbraud &Weimerskirch 2003, Rolland *et al.* 2007).

Recent reviews show rapidly worsening conservation status for albatross populations. The International Union for the Conservation of Nature (IUCN) defines albatross (family Diomedeidae) as the most threatened family of birds in the world. In 2008, all of the 22 albatross species are listed as Threatened or Near Threatened, three are Critically Endangered, and seven are Endangered (IUCN 2008). The family Diomedeidae is becoming threatened at a faster rate than any other in the world. Petrels (family Procellariidae) are less well studied, and of 80 extant species listed by the IUCN in 2008, 35 are classified as threatened. Albatross and petrel species are particularly vulnerable to population effects of fisheries mortality due to their demographic characteristics, with delayed breeding, low fecundity (Hamer *et al.* 2002) and migratory habits which take them into areas where they are exposed to fishing mortality throughout large parts of their life-cycles (de L. Brooke 2004, Small 2005).

There is international recognition of the importance of reducing seabird bycatch in fisheries, primarily for surface longline fishing (Brothers *et al.* 1999). This was the focus of the Food and Agriculture Organisation of the United Nations International Plan of Action for Reducing the Incidental Mortality of Seabirds in Longline Fisheries (FAO 1999). The importance of mortality of seabirds in trawl fisheries has been recognised as a problem for species conservation (Bartle 1991, New Zealand Ministry of Fisheries and Department of Conservation 2004, Sullivan *et al.* 2006).

Over one-third of the 104 species in the order Procellariiformes (albatross, petrels, storm- and diving-

TABLE 1
Species of seabird observed caught in New Zealand fisheries in the 1998 to 2004 fishing years, returned by scientific observers and formally identified to species level

Species	Scientific name	IUCN threat status	Breeding distribution	FMA1	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	FMA10	Total observed caught 1997–2004	% individuals caught in breeding areas
White-chinned Petrel	*Procellaria aequinoctialis*	VU	W	1	5	26	357	329	218					936	23
White-capped Albatross	*Thalassarche steadi*	NT	NZ		5	27	4	456	275	32				799	34
Sooty Shearwater	*Puffinus griseus*	NT	W		1	257	29	326	59					681	99
Grey Petrel	*Procellaria cinerea*	NT	W	13	9	7	35		326					471	69
Salvin's Albatross	*Thalassarche salvini*	VU	NZ		16	31	56	14	114					231	55
Buller's Albatross	*Thalassarche bulleri*	VU	NZ		1	19	19	9	6	34				178	16
Antipodean Albatross	*Diomedea antipodensis*	VU	NZ		68	1		2						71	0
Campbell Albatross	*Thalassarche impavida*	VU	NZ	2	3	1	1	3	1	8				46	2
Flesh-footed Shearwater	*Puffinus carneipes*	LC	W	19	16									35	54
Short-tailed Shearwater	*Puffinus tenuirostris*	LC	W					33						33	0
Cape Pigeon	*Daption capense*	LC	W		2		8	7	7	5				29	48
Grey-faced Petrel	*Pterodroma macroptera*	LC	NZ	4	3		1					1		18	39
Black-browed Albatross	*Thalassarche melanophris*	EN	W		8	1	2		3	2				16	19
Southern Royal Albatross	*Diomedea epomophora*	VU	NZ			2	2	1						14	14
Northern Giant Petrel	*Macronectes halli*	NT	W		1	1	7		3					12	83
Chatham Albatross	*Thalassarche eremita*	CR	NZ				11							11	100
Black Petrel	*Procellaria parkinsoni*	VU	NZ	9					3					9	100
Common Diving-Petrel	*Pelecanoides urinatrix*	LC	W					5	3					8	100
Southern Giant Petrel	*Macronectes giganteus*	NT	W		2				4					6	0
Fairy Prion	*Pachyptila turtur*	LC	W							6				6	100
Westland Petrel	*Procellaria westlandica*	VU	NZ		1			1		2				4	50
Light-mantled Albatross	*Phoebetria palpebrata*	NT	W			1				2				3	0
Northern Royal Albatross	Diomedea sanfordi	EN	NZ				2							2	100
White-headed Petrel	*Pterodroma lessonii*	LC	W										2	2	0
Buller's Shearwater	*Puffinus bulleri*	NT	NZ	2										2	100
Fluttering Shearwater	*Puffinus gavia*	LC	NZ	2										2	100
Grey-backed Storm-Petrel	*Garrodia nereis*	LC	W						2					2	0
Antarctic Prion	*Pachyptila desolata*	LC	W				1		1					2	50
White-faced Storm-Petrel	*Pelagodroma marina*	LC	NZ				2							2	100
Black-bellied Storm-Petrel	*Fregetta tropica*	LC	W					1						1	0
Broad-billed Prion	*Pachyptila vittata*	LC	W					1						1	100

The IUCN status (IUCN 2008) and breeding areas (shading indicates breeding locations after Taylor 2000a, b) within Fishery Management Areas (FMA) are provided. Few birds were observed caught in FMA8-10, but little observer coverage was deployed in these areas. New Zealand endemic species (NZ) and species with world-wide breeding distribution (W) are indicated. The percentage of individuals returned following capture in areas where breeding colonies exist is shown (% individuals caught in breeding areas). Species are ranked by the number observed caught.

petrels) breed in New Zealand waters, including 12 of the 22 species of Diomedeidae. There is a high level of endemism among these species in New Zealand waters, with 12 endemic petrels (Procellariidae) and eight endemic albatross (Wilson 2004; table 1). This places considerable responsibility for the conservation of these species in the hands of the managers of the natural resources of New Zealand.

Understanding fisheries effects on populations is complex, as many of the key variables required to examine causal aspects of the relationships cannot be estimated due to the paucity of fisheries bycatch data and uncertainty around environmental influences on populations. Further uncertainty is introduced by the effect of fisheries mortalities out of the breeding areas, such as during the extensive inter-breeding migrations of albatross and petrels.

For New Zealand fisheries, less than 5% of total fishing effort was observed by scientific observers on average during the fishing years 1998–2004. Few fisheries have sufficient observer coverage to allow precise estimation of seabird bycatch. Observer coverage has been particularly poor for small vessels. Not all individuals killed or injured in fishing operations are recovered on board, so there is an underestimation of the total removals of seabirds from populations from observer data.

In this study, we sought to provide a comprehensive analysis of seabird bycatch for all New Zealand fisheries using surface longline (SLL) and bottom or demersal longline (BLL) and trawling (TR) methods. Previous studies of bycatch in New Zealand fisheries have focused on specific target fisheries (Bartle 1991, Murray *et al.* 1993, Baird 2004a, b, c, 2005, Baird & Smith 2007), and do not provide comparative data across the New Zealand Exclusive Economic Zone. The results reported here provide a partial examination of the fishing mortality in New Zealand waters, due to lack of data for some fishing methods, and our inability to include seabirds not landed as part of the fishing operation.

Trawl and longline fishing methods are those recognised as the most likely to catch seabirds in New Zealand waters (New Zealand Department of Conservation and Ministry of Fisheries 2004). Set net (gill net) fisheries may contribute substantially to seabird bycatch (Furness 2003, New Zealand Ministry of Fisheries 2007b), but due to extreme data paucity for these fisheries, data from this fishing method were not included in the current analysis. We used Bayesian methods to predict incidental capture likelihoods, and to identify the regions around the New Zealand Exclusive Economic Zone that are important for incidental mortality of seabirds, and in particular albatross.

MATERIALS AND METHODS

Material presented in this study was reported to the Ministry of Fisheries (MacKenzie & Fletcher 2005).

Data

Data were extracted from the New Zealand Ministry of Fisheries databases for TR, SLL and BLL fisheries for fishing events from 1 October 1997 to 30 September 2004. From these, we examined characteristics of the fishing events in the sample (e.g., start time, location, sea and weather conditions) and the number of captures of each observer-identified seabird species. Fishing effort (the number of fishing events)

is described in units of tows for trawl fisheries. The unit of sets was chosen for longline fisheries as we considered that the data provided more consistency this way, with the number of hooks being a characteristic of a particular set. Therefore these data were used to estimate bycatch rates per unit of effort.

To predict total seabird bycatch, datasets that described the total fishing effort were accessed which were then scaled to total effort to give estimated mortality. Data were checked for obvious errors and omissions (e.g., statistical area or Fishery Management Area (FMA) not recorded) and corrections made where possible.

Fishing years were described for the 12-month periods from 1 October–30 September, named for the latter year in each split-year period. For example, the 1998 fishing year was the period 1 October 1997–30 September 1998.

Initial assessments of the data indicated that it would not be practical to estimate bycatch at the level of individual seabird species; hence the data were pooled for all species. However, for trawl fisheries, bycatch of albatross species was separately estimated. No attempt was made to differentiate between live and dead landed birds due to small sample sizes, or to allow for the possibility that birds released alive may have their long-term survival compromised as a result of injuries sustained during capture. Bycatch was therefore described as the number of individuals caught during fishing operations. These figures do not include individuals that may have struck the vessel superstructure and been found on the vessel as a result. But these birds do contribute to the total mortality caused by the fishing fleet, as do birds striking trawl cables and other non-observed fishing gear-related deaths.

The ten FMAs designated for New Zealand fisheries are shown in figure 1. When grouped these areas correspond roughly to biogeographical regions, with tropical petrel species' breeding areas concentrated in FMA1–2 and FMA9–10, and temperate petrels' and albatross' breeding sites in FMA4–6. Data on individual seabirds captured in New Zealand fisheries
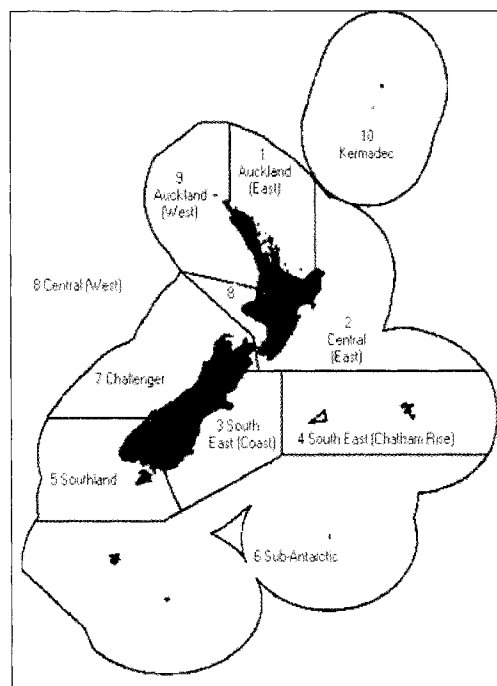

FIG. 1 — *Fishery Management Areas (FMA) in the New Zealand Exclusive Economic Zone.*

were extracted from Ministry of Fisheries databases together with summary information about the location of capture (FMA) and fishing method (TR, BLL and SLL). Around 4500 individual seabirds were reported captured by fisheries observers during the period of the study, of which 3641 were identified to species level by experienced seabird researchers ashore (methods reported in Bartle 2000, Robertson *et al.* 2004). We limited our examination of species data to those species formally identified caught in New Zealand fisheries (table 1). Thirty-one species were identified caught; their conservation status (IUCN 2008) and breeding areas in New Zealand waters were described, based on breeding sites identified by Taylor (2000a, b).

No statistical analyses are undertaken at species level due to the paucity of data, and unrepresentative nature of the observer sampling across the fishing effort. Results for species are reported by summing the captures for each species over the six-year period of the study.

Statistical Methods

Seabird bycatch was estimated using a model-based method in order to account for some sources of variation in bycatch with auxiliary variables, and exploit similarities in bycatch rates among different seasons, years, regions or fisheries. For example, the model could be used to predict seabird bycatch in fisheries where there is little or no observer coverage, under the assumption that the model is a reasonable representation of the biological reality.

However, as for any estimation method, generalising results beyond the observed vessels requires the data to be collected within a statistical valid sampling scheme such as a random or representative sampling scheme. This is because there may be factors influencing bycatch that are not allowed for in the modelling. If the observed sets/tows are not representative of the whole fishery with respect to any of these unmodelled factors, the resulting estimates may be biased. Having as much randomisation in the sampling scheme as possible helps avoid the observed data being unbalanced in this way. The deployment of observers across New Zealand fisheries is neither random nor representative, as observers tend to be placed on larger vessels, and observations occur for a series of fishing events on a fishing trip, rather than being randomly distributed across all effort. The data were distributed across varying proportions of the fishing fleet and seasons, and one needs to be mindful of this when interpreting the results.

To account for the large number of fishing events with zero bycatch, a Poisson mixture model consisting of two components was used. The first component is a binary (0-1) random variable (Z) which is used to model the excess number of zeros. If $Z = 0$ then no seabirds will be caught, but if $Z = 1$, then the number of seabirds caught will be a random value from a Poisson distribution (the second model component). We therefore needed to estimate two parameters; the probability $Z = 1$ (p) and the Poisson rate parameter (λ; lambda). These parameters can be modelled to allow them to vary for fishing events conducted in different years, regions, seasons and so forth. Here, up to five factors were included in the models for p and λ: fishing year, season, fishing area, target species and vessel size class. The seasons were defined to be spring (Oct–Dec), summer (Jan–Mar), autumn (Apr–Jun) and winter (Jul–Sep). Fishing areas were based upon FMAs and vessels were categorised by size, with large vessels being those of greater than 28 m total length.

The probability that $Z = 1$ for a fishing event in fishing year Y, season S, fishing area F by a vessel of size category V was modelled as

$$\text{logit}\,(\rho_{YSFV}) = \alpha + \beta_Y + \delta_S + \gamma_F + \upsilon_V$$

where β, δ, γ and υ denote the year, season, fishing area and vessel class effects respectively. Note that in order to fit this model one level of each of these effects had to be set equal to zero to establish a control, or baseline, situation where the model would reduce to logit (ρ_{YSFV}). For example, in trawl fisheries the "standard" situation was defined to be tows conducted in spring of the 1998 fishing year, in FMA7, by vessels longer than 28 m, and so the constraints $\beta_1 + \delta_1 + \gamma_7 + \upsilon_1 = 0$ were applied. The term "logit" simply denotes that the logit-link function was used to ensure values of p remained on the 0–1 scale. This is the same link function used in standard logistic regression analyses. Biologically, this component could be regarded as modelling the probability that seabirds are at risk of being caught. This will be primarily driven by the seabirds rather than the fishers, and so target species was not included as a factor in this model. Vessel class was included here as a surrogate for effort (e.g., larger vessels may trawl for longer or have more hooks per set than smaller vessels).

The Poisson rate parameter was modelled using a log-link function (to maintain values of λ in the range 0–infinity) with the same factors as above and the addition of target species. Hence, given seabirds were at risk of being caught, the bycatch rate for a fishing event in year Y, season S, fishing area F by a vessel of size category V targeting species T was modelled as,

$$\text{logit}\,(\lambda_{YSFVT}) = \alpha' + \beta'_Y + \delta'_S + \gamma'_F + \upsilon'_V + \tau'_V.$$

The model was fit to the data using Bayesian statistical methods (Markov chain Monte Carlo (McMC)) in the software WinBUGS. The use of McMC methods is becoming more widespread in many areas of applied statistics, including fisheries and wildlife ecology. In a Bayesian analysis a model parameter is considered a random variable. A *prior distribution* is defined for each parameter that represents the state of knowledge about that parameter prior to data collection. Here, vague or uninformative prior distributions were used for all model parameters (normal distributions with mean = 0.0 and variance = 100.0). The observed data were then used to update our knowledge of the model parameters, resulting in the *posterior distribution*. Until recently, the Bayesian approach to statistical inference has been limited in its applications due to difficulties in analytically estimating the posterior distribution for model parameters. However, McMC methods are an iterative, computer intensive method for approximating posterior distributions of parameters. These methods also provide a flexible analysis framework that can be simply applied to problems that are difficult to address with a non-Bayesian philosophy.

For the McMC analysis, three chains with different initial values were used for each model. Initial values were chosen by first using maximum likelihood to get point estimates of the parameters, then selecting a random value from a normal distribution around that point estimate with a standard deviation corresponding to a 30% coefficient of variation. The chains were initially run for 10 000 iterations then visually inspected for convergence and mixing. If it was determined that convergence had been achieved then

the chains were run for a further 25 000 iterations to estimate the posterior distributions of the model parameters (hence 75 000 samples per parameter), otherwise additional iterations were performed until convergence was achieved. To predict the observed and unobserved bycatch, 10 000 post-convergence iterations were used for trawl fisheries and 20 000 iterations for longline fisheries.

As part of the analysis, it is also very easy to predict the outcome of unobserved sampling units. For example in this context, in the summer of fishing year 2004, FMA6, trawl vessels longer than 28 m targeting squid (i.e., Y = 7, S = 2, F = 6, V = 1 and T = 6) conducted 2623 unobserved tows. Given the current estimates of the model parameters ($\hat{p}_{7,2,6,1}$ and $\hat{\lambda}_{7,2,1,6}$), the number of unobserved tows where seabirds are at risk of capture (x) could be predicted as a binomial random variable from 2623 trials with probability of "success" $\hat{p}_{7,2,6,1}$. Likewise, using the properties of Poisson random variables, the number of seabirds caught on unobserved tows would be a random value from a Poisson distribution with rate parameter $x\hat{\lambda}_{7,2,6,1,6}$. The total level of bycatch is then the predicted number plus the number actually observed. Predicting bycatch in this manner automatically accounts for two important sources of variation: uncertainty in the level of bycatch for specific values of $\hat{p}_{7,2,6,1}$ and $\hat{\lambda}_{7,2,1,6}$ (due to the stochastic nature of bycatch), and uncertainty in the values of $\hat{p}_{7,2,6,1}$ and $\hat{\lambda}_{7,2,1,6}$ themselves.

From the model, bycatch is predicted at a relatively fine scale (i.e., year × season × area × vessel class × target species). Here results are reported at coarser scales (e.g., year × vessel class) which were achieved by aggregating the predicted bycatch across the unreported factor levels. However, as the scientific observer program has tended to target larger vessels, results are reported separately for each vessel size class, as those for vessels smaller than 28 m may be less reliable.

The posterior distribution for the estimated level of bycatch is summarised by the median and the 2.5[th] and 97.5[th] percentiles (i.e., the central 95% credible interval).

To verify the reasonableness of the model, the above procedure for predicting bycatch on unobserved tows can also be applied to observed tows. That is, the model can be used to predict the number of seabirds caught for observed tows in each combination of year × season × area × vessel class × target species. If the model is reasonable, then the observed number of captures should lie within the "typical" range of predicted values (i.e., it would be expected that 95% of the observed values lie between the 2.5[th] and 97th percentiles of the distributions for the predicted values). Standardised residuals could also be calculated from the predicted distributions as:

$$R_i = \frac{O_i - P_i^{50}}{(P_i^{97.5} - P_i^{2.5})/4}$$

where O_i is the observed number of seabirds caught in the ith combination of year, season, area, vessel class and target species and P_i^k is the kth percentile from the distribution of the predicted number of seabirds caught (thus P_i^{50} is the median of this distribution). The denominator is simply a between-combination scaling factor that has been used to place the residuals on a common scale, similar to that used in linear regression. Note however that these standardised residuals are not expected to be normally distributed because the data come from an extremely skewed, discrete-valued

distribution. Thus residual Q-Q plots may not result in a straight line even if the model is a reasonable representation of the data. These residuals were plotted against various factors to check for systematic deficiencies within the model, as is typically done for linear regression applications.

Examining risk to seabirds between methods and areas

To assess the risk of bycatch for different subsets of the New Zealand fishing methods, areas and seasons, we used the results from the bycatch modelling to estimate the *bycatch* (number of birds) and the *capture rate* (birds per set or per 100 tows) for TR, BLL and SLL fishing. We aggregated the predictions across target species. This allowed us to calculate an estimate of bycatch and capture rate for different vessel-method-area-season groups (fishery strata) combining different vessel sizes (small or large), method (TR, SL, BLL), fishing area (FMA1 to FMA10) and season (spring, summer, autumn and winter).

We report the results using estimates for the 2004 fishing year, which was similar across all areas to that for an average estimate across all fishing years (1998–2004 for TR and SLL; 1999–2004 for BLL). As 2004 was the most recent year included in our model, we considered it was therefore the most likely to be representative of fishing effort and bycatch in the near future.

RESULTS

Species caught in New Zealand fisheries

Thirty-one species were identified caught, these included 12 threatened species (IUCN 2008, table 1). Fourteen species were endemic to New Zealand. They were observed caught across a range of FMAs, except FMA8–9 where observer coverage was scant. Petrel species were caught predominantly in FMAs where they breed, while albatross were caught across a wider range of areas. Species for which over 100 individuals were returned during the six-year period were White-chinned Petrel, *Procellaria aequinoctialis* Linnaeus, 1758, White-capped Albatross, *Thalassarche steadi* (Falla, 1933), Sooty Shearwater, *Puffinus griseus* (J.F. Gmelin, 1789), Grey Petrel, *Procellaria cinerea* J.F. Gmelin, 1789, Salvin's Albatross, *Thalassarche cauta salvini* (Rothschild, 1893) and Buller's Albatross, *Thalassarche bulleri* (Rothschild, 1893). Examining the area-species relationships shows that albatross were caught mainly in southern areas (FMA3–7; table 2), and petrels spread across a wider range of areas (table 3). Both groups of seabirds were caught in all fishing methods. The number of albatross captured in TR fisheries was due to a preponderance of White-capped Albatross taken in FMA5–6. Similarly, petrel captures were mainly in FMA3–6 due to the influence of large numbers of White-chinned and Grey petrel captures in these areas in BLL and TR fisheries.

Observer sampling of fishing effort

The percentage of fishing effort observed in the different fishing methods varied by vessel size, and was on average 4.6% across all fishing effort during the fishing years 1998–2004 (table 4). Observer coverage was over 10% of the total effort for large vessels across all methods, on average for the period of the study. Large SLL vessels had coverage over 50% in

TABLE 2
Albatross species occurring in bycatch in New Zealand fisheries for the fishing years 1998–2004

Common name	Scientific name	IUCN threat status[2]	BLL[1] FMA3[3]	FMA4	FMA5	FMA6	FMA7	BLL Total	SLL FMA1	FMA2	FMA3	FMA5	FMA7	SLL Total	TR FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	TR Total	Grand Total
White-capped Albatross	Thalassarche steadi	NT				1		1	1	2	33	5		41	4	25	4	423	274	27	757	799
Salvin's Albatross	Thalassarche salvini	VU	1	17	1	111		130		6		1		7	10	30	39	12	3		94	231
Buller's Albatross	Thalassarche bulleri	VU		2			1	3		10	1	60	21	92		18	17	30	6	12	83	178
Antipodean Albatross	Diomedea antipodensis	VU								68		2		70	1						1	71
Campbell Albatross	Thalassarche impavida	VU							2	30	1	2	1	36		1	1	1		7	10	46
Black-browed Albatross	Thalassarche melanophris	EN			2			2		7				7	1	1	2		1	2	7	16
Southern Royal Albatross	Diomedea epomophora	VU									1	5		6	1	2	5				8	14
Chatham Albatross	Thalassarche eremita	CR		7				7									4				4	11
Light-mantled Albatross	Phoebetria palpebrata	NT								1			2	3								3
Northern Royal Albatross	Diomedea sanfordi	EN															2				2	2

[1] Bottom longline (BLL), surface longline (SLL) and trawl (TR) methods.   [2] IUCN (2008).
[3] Fishing Management Area.

all years. For small vessels, coverage was very low, and lower than 2% in all except one method/year group. The proportion of fishing effort for which observer coverage was over 10%, as a result of the placement of observers on the large vessels was 45% for TR, and 8% for SLL and 25% for BLL. For some fishery strata, there was no fishing effort (observed or unobserved) corresponding to that method and vessel size, and these are shown as blanks in the relevant tables.

Model diagnostics

For all methods, comparison of the observed number of seabird captures to that predicted by the model did not indicate any major systematic problems for either albatross or all seabirds combined. There is a tendency for the residuals to be positive which may indicate bycatch estimates are conservative (i.e., slightly underestimated), or this could be a result of the skewed distribution for the number of captures.

Approximately 6% of standardised residuals for TR and 5% for SLL were >3 which seemed reasonable (as the percentage would be 2.5% if they were normally distributed). The fraction of Year × Area × Season × Target Species × Vessel Class observations that lie below the 2.5th percentile of the distribution of the predicted observations is 2.7% and 4.8% lay above the 97.5th percentile for TR and 1.6% and 4.9% respectively for SLL.

For BLL, approximately 12% of standardised residuals are >3, which is high and may be due to insufficient variation in the predicted values or small sample size. There may have been insufficient variation in the predicted compared to the observed data (13.7% of observations were below the 2.5th percentile of the distribution of the predicted observations,

11.8% were above the 97.5th percentile) which may translate to the reported credible intervals being too narrow. However, this result may also be an artefact of only 51 Year × Area × Season × Target Species × Vessel Class combinations being observed (e.g., a small sample problem).

Estimated seabird bycatch

For the 2004 year, estimated total seabird bycatch by area and vessel class is summarised in tables 5, 7 and 9 for TR, SLL and BLL methods, and for albatross bycatch for TR only (table 11). The rates of capture for corresponding groups of fishing effort are shown (tables 6, 8, 10 and 12 respectively). Total estimated seabird bycatch for all years of the study is shown in figures 2, 3, 4 respectively for TR, SLL, BLL, and in figure 5 for albatross in TR fisheries only.

Trawl fisheries

Total seabird bycatch by large TR vessels was estimated to have been increasing during the 1998–2004 fishing years, and was between 2000–3000 birds for most of this period (width of 95% CI's ~800 birds; fig. 2), with bycatch in 1998 estimated to be slightly lower, and that in 2001 estimated to be higher. It has remained stable, at around 2500 birds from 2002 to 2004. For small TR vessels, total seabird bycatch was estimated to be relatively low (<200), but with a high degree of uncertainty (width of 95% CI's ~250 birds; fig. 2). The widths of the confidence intervals for small vessels indicate that these estimates are relatively poorly known. Most of the seabird bycatch is predicted to occur in the Hoki, Macruronus novaezealandiae (Hector, 1871), and squid fisheries (MacKenzie& Fletcher 2005).

TABLE 3
Petrel species occurring in bycatch in New Zealand fisheries for the fishing years 1998–2004

Common name	Scientific name	IUCN threat status[3]	BLL[1]						BLL Total	SLL						SLL Total	TR							TR Total	Grand Total
			FMA1[2]	FMA2	FMA3	FMA4	FMA5	FMA6		FMA1	FMA2	FMA3	FMA5	FMA7	FMA10		FMA1	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7		
White-chinned Petrel	*Procellaria aequinoctialis*	VU			6	338	222	178	744	1	5	7	10			23			13	19	97	40		169	936
Sooty Shearwater	*Puffinus griseus*	NT		2	1	1	88	2	94		6					6		2	256	28	238	57		581	681
Grey Petrel	*Procellaria cinerea*	NT	11	1	6	32		322	372	2	89					91				1	3	4		8	471
Flesh-footed Shearwater	*Puffinus carneipes*	LC	16						16		14					14	3	2						5	35
Short-tailed Shearwater	*Puffinus tenuirostris*	LC																			33			33	33
Cape Pigeon	*Daption capense*	LC		1		7	3	5	16									1		1	4	2	5	13	29
Grey-faced Petrel	*Pterodroma macroptera*	LC								4	3				10	17				1				1	18
Northern Giant Petrel	*Macronectes halli*	NT						3	3		1					1			1	7				8	12
Black Petrel	*Procellaria parkinsoni*	VU	2						2	7						7									9
Common Diving-Petrel	*Pelecanoides urinatrix*	LC					3	1	4												2	2		4	8
Southern Giant Petrel	*Macronectes giganteus*	NT						4	4		2					2									6
FairyPrion	*Pachyptila turtur*	LC																				6		6	6
Westland Petrel	*Procellaria westlandica*	VU									1			1	1	3							1	1	4
White-headed Petrel	*Pterodroma lessonii*	LC													2	2									2
Buller's Shearwater	*Puffinus bulleri*	NT	2						2																2
Fluttering Shearwater	*Puffinus gavia*	LC	2						2																2
Grey-backed Storm-Petrel	*Garrodia nereis*	LC																				2		2	2
Antarctic Prion	*Pachyptila desolata*	LC																		1		1		2	2
White-faced Storm-Petrel	*Pelagodroma marina*	LC				2			2																2
Black-bellied Storm-Petrel	*Fregetta tropica*	LC																			1			1	1
Broad-billed Prion	*Pachyptila vittata*	LC					1		1																1

[1] Bottom longline (BLL), surface longline (SLL) and trawl (TR) methods. [2] Fishery Management Area.
[3] IUCN (2008).

TABLE 4
Fishing events and observed seabird bycatch for New Zealand fisheries, 1998–2004 fishing years

Fishing Year	Fishing method[1]	Vessel size (m)	Total events[4]	% events observed	Total observed seabird (and albatross) bycatch
1998	TR	<28	115481	0	10 (4)[2]
1999	TR	<28	103047	1	17 (7)
2000	TR	<28	86617	1	8 (8)
2001	TR	<28	83571	0	11 (10)
2002	TR	<28	79952	1	5 (5)
2003	TR	<28	80053	0	2 (2)
2004	TR	<28	76065	0	4 (4)
1999	TR	>28	80428	9	269 (128)
2000	TR	>28	71519	10	173 (102)
2001	TR	>28	69376	13	683 (244)
2002	TR	>28	75544	10	322 (189)
2003	TR	>28	72986	9	298 (126)
2004	TR	>28	66097	10	290 (167)
1998	SLL	<28	3119	3	45
1999	SLL	<28	5307	1	10
2000	SLL	<28	6658	1	34
2001	SLL	<28	7631	2	38
2002	SLL	<28	8336	1	87
2003	SLL	<28	7242	0	– [3]
2004	SLL	<28	5007	2	2
1998	SLL	>28	609	59	171
1999	SLL	>28	635	65	74
2000	SLL	>28	380	70	40
2001	SLL	>28	533	51	15
2002	SLL	>28	488	56	80
2003	SLL	>28	663	91	115
2004	SLL	>28	571	82	70
1999	BLL	<28	22796	0	0
2000	BLL	<28	23214	0	–
2001	BLL	<28	22709	0	26
2002	BLL	<28	20376	0	–
2003	BLL	<28	18979	0	1
2004	BLL	<28	17342	1	10
1999	BLL	>28	10456	7	93
2000	BLL	>28	9034	11	203
2001	BLL	>28	7978	11	509
2002	BLL	>28	5387	20	431
2003	BLL	>28	4278	37	426
2004	BLL	>28	6146	12	122
1998	TR	>28	80626	8	96 (37)
Total effort	All	All	1357236	4.6	4790 (1033)

[1] Bottom longline (BLL), surface longline (SLL) and trawl (TR) methods.
[2] Bracketed numbers indicate the number of albatrosses observed for trawl vessels.
[3] – indicates no effort was observed, thus observed seabird bycatch cannot be reported.
[4] Fishing events are tows for trawling, and sets for longlining.
Numbers of birds here are not the same as those identified to species level in tables 1–3, as they include unidentified seabirds.

TABLE 5
Estimated seabird bycatch in New Zealand trawl fisheries in the 2004 fishing year

Vessel length (m)	FMA[1]								
	1	2	3	4	5	6	7	9	Other
>28	0	25	480	215	702	970	164	7	14
	(0, 48)[2]	(4, 67)	(379, 601)	(157, 286)	(589, 831)	(821, 1149)	(125, 214)	(2, 21)	(2, 45)
<28	0	3	39	1	6	2	15	0	0
	(0, 23)	(0, 22)	(17, 134)	(1, 3)	(1, 24)	(0, 8)	(5, 62)	(0, 3)	(0, 2)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.

TABLE 6
Estimated seabird bycatch rates in New Zealand trawl fisheries per 100 tows in the 2004 fishing year

Vessel length (m)	FMA[1]								
	1	2	3	4	5	6	7	9	Other
>28	0.00	0.88	6.36	2.43	11.44	5.63	2.01	0.29	0.12
	(0.00, 4.11)[2]	(0.14, 2.35)	(5.02, 7.96)	(1.77, 3.23)	(9.60, 13.54)	(4.76, 6.66)	(1.54, 2.63)	(0.08, 0.88)	(0.02, 0.38)
<28	0.00	0.03	0.17	0.24	0.17	0.19	0.08	0.00	0.00
	(0.00, 0.20)	(0.00, 0.20)	(0.07, 0.59)	(0.24, 0.73)	(0.03, 0.67)	(0.00, 0.75)	(0.03, 0.33)	(0.00, 0.09)	(0.00, 0.06)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.

TABLE 7
Estimated seabird bycatch in New Zealand surface longline fisheries in the 2004 fishing year

Vessel length (m)	FMA[1]						
	1	2 and 4	3 and 6	5	7	8 and 9	Other
>28	0	164	3	46	18	0	0
	(0, 0)[2]	(46, 590)	(3,3)	(46,49)	(16, 29)	(0, 0)	(0, 3)
<28	678	999	0	1	2	0	2
	(139, 1,602)	(193, 2,205)	(0, 2)	(0,6)	(0, 11)	(0, 1)	(1, 8)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.

TABLE 8
Estimated seabird bycatch rates in New Zealand surface longline fisheries per set in the 2004 fishing year

Vessel length (m)	FMA[1]						
	1	2 and 4	3 and 6	5	7	8 and 9	Other
>28	0.00	1.89	1.00	0.20	0.08	0.00	0.00
	(0.00, 0.00)[2]	(0.53, 6.78)	(1.00, 1.00)	(0.20, 0.21)	(0.07,0.13)	(0.00,0.00)	(0.00, 0.60)
<28	0.44	0.40	0.00	0.03	0.01	0.00	0.07
	(0.09, 1.03)	(0.08, 0.88)	(0.00, 0.15)	(0.00, 0.18)	(0.00,0.03)	(0.00, 0.00)	(0.03, 0.28)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.

TABLE 9
**Estimated seabird bycatch in New Zealand bottom longline fisheries in the 2004
fishing year**

Vessel length (m)	FMA[1]				
	1, 2, 8, 9 and 10	3 and 4	5 and 7	6	Other
>28	1	186	104	341	0
	(0, 6)[2]	(104, 393)	(89, 126)	(251, 465)	(0, 1)
<28	247	14	64	0	0
	(49, 1,671)	(1, 140)	(8, 530)	(0, 3)	(0, 0)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.

TABLE 10
**Estimated seabird bycatch rates in New Zealand bottom longline fisheries per set in
the 2004 fishing year**

Vessel length (m)	FMA[1]				
	1, 2, 8, 9 and 10	3 and 4	5 and 7	6	Other
>28	0.00	0.05	0.23	0.11	0.00
	(0.01, 0.04)	(0.09, 0.19)	(0.27, 0.32)	(0.15, 0.21)	(0.00, 0.00)
<28	0.00	0.00	0.01	0.00	0.00
	(0.02, 0.11)	(0.02, 0.21)	(0.05, 0.38)	(0.00, 0.75)	(0.00, 0.00)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.

TABLE 11
Estimated albatross bycatch in New Zealand trawl fisheries in the 2004 fishing year

Vessel length (m)	FMA[1]								
	1	2	3	4	5	6	7	9	Other
>28	0	17	128	112	368	585	82	0	2
	(0, 5)[2]	(6, 36)	(90, 177)	(74, 163)	(300, 448)	(482, 708)	(57, 115)	(0, 7)	(0, 21)
<28	1	19	81	2	18	7	62	0	0
	(0, 17)	(2, 77)	(18, 349)	(1, 8)	(3, 81)	(1, 27)	(12, 300)	(0, 6)	(0, 6)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.

Table 12
Estimated albatross bycatch rates in New Zealand trawl fisheries per 100 tows in the 2004 fishing year

Vessel length (m)	FMA[1]								
	1	2	3	4	5	6	7	9	Other
>28	0	0.6	1.7	1.27	6	3.39	1.01	0	0.02
	(0.00, 0.43)[2]	(0.21, 1.26)	(1.19, 2.34)	(0.84, 1.84)	(4.89, 7.30)	(2.80, 4.11)	(0.70, 1.41)	(0.00, 0.29)	(0.00, 0.18)
<28	0.01	0.17	0.36	0.49	0.5	0.66	0.33	0	0
	(0.00, 0.15)	(0.02, 0.70)	(0.08, 1.54)	(0.24, 1.95)	(0.08, 2.25)	(0.09, 2.55)	(0.06, 1.58)	(0.00, 0.19)	(0.00, 0.17)

[1] Fishery Management Area.
[2] Figures in brackets indicate the 95% credibility interval for each cell above.
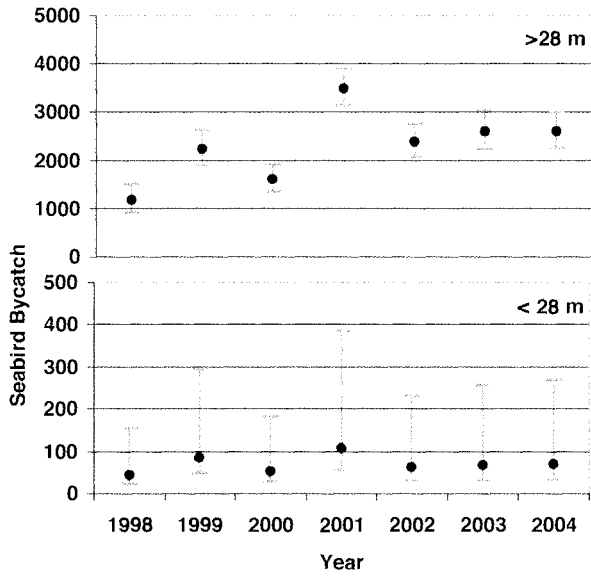
FIG. 2 — *Estimated total seabird bycatch in New Zealand trawl fisheries for the fishing years 1998–2004 for vessels greater than 28 m in length (upper graph) and less than 28 m (lower graph).*
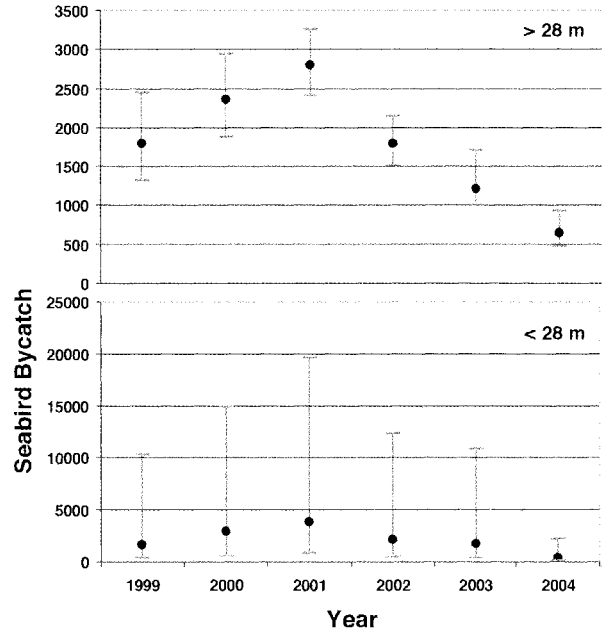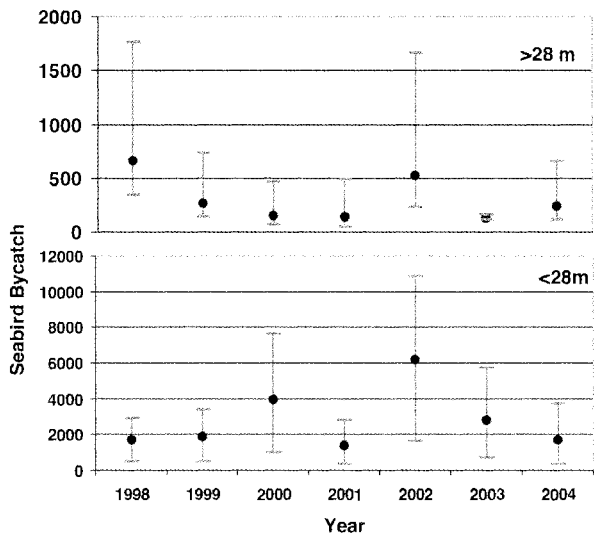

FIG. 3 — *Estimated total seabird bycatch in New Zealand surface longline fisheries for the fishing years 1998–2004 for vessels greater than 28 m in length (upper graph) and less than 28 m (lower graph).*
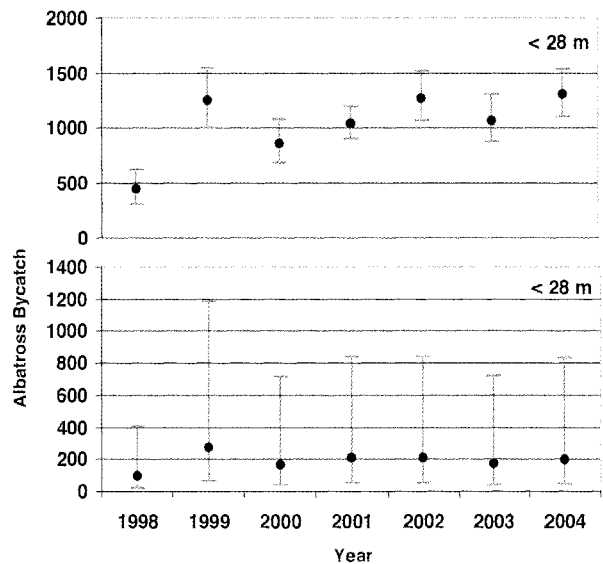

FIG. 4 — *Estimated total seabird bycatch in New Zealand bottom longline fisheries for the fishing years 1999–2004 for vessels greater than 28 m in length (upper graph) and less than 28 m (lower graph).*

FIG. 5 — *Estimated albatross bycatch in New Zealand trawl fisheries for the fishing years 1998–2004 for vessels greater than 28 m in length (upper graph) and less than 28 m (lower graph).*

Capture rates varied by area (table 6) and were highest in FMA3–7 where rates were between 2–11 birds per 100 tows in 2004. There was variation in the rates of capture between years, but since 2002, these had been relatively stable and at similar rates to those in 2004 (MacKenzie & Fletcher 2005).

Surface longline fisheries

Total seabird bycatch by large SLL vessels was generally estimated to be less than 500 birds (width of 95% CI's ~500 birds in most years), although the upper bound of the credible intervals in the 1998 and 2002 fishing years was relatively high at approximately 1700 birds (fig. 3). In 2004, large vessels

were estimated to catch approximately 200 birds (table 7). For small vessels, the 95% credible intervals for total seabird bycatch generally ranged between 500 and 4000 birds, fig. 3), with notable exceptions being those for the 2000 and 2002 fishing years for total bycatch when CIs were larger. Most of the seabird bycatch for SLL fishing was predicted to occur in the Big-eye Tuna, *Thunnus obesus* (Lowe, 1839), fishery (MacKenzie & Fletcher 2005).

Catch rates (birds per set) for large SLL vessels in 2004 were 1.9 birds per set in FMA2 and 4, 1.0 birds per set in FMA3 and 6, with lower rates elsewhere (table 8). On average through the study period, rates were around or less than one bird per set (MacKenzie & Fletcher 2005). For small vessels catch rates showed no particular pattern through time, and had average rates of around 0.4 birds per set in 2003 and 2004 (MacKenzie & Fletcher 2005).

Bottom longline fisheries

Total seabird bycatch for large BLL vessels was estimated to have increased by approximately 500 birds per year from 1999–2001, but was estimated to have steadily decreased in recent years to approximately 600 seabirds (95% CI 500–1,000) in 2004 (table 9, fig. 4, but this apparent increase prior to 2001 may be due to problems with reporting of data). Seabird bycatch by smaller vessels in bottom longline fisheries was estimated with much less precision, with point estimates generally in the range of approximately 2000–4000 birds, but the width of the 95% credible intervals was larger than 10 000 seabirds in five of the six years (fig. 4) indicating a very high degree of uncertainty. Most of the seabird bycatch for large vessels is predicted to occur on sets targeting Ling, *Genypterus blacodes* Block & Schneider 1801, and on sets targeting snapper, *Pagrus auratus* (Block & Schneider, 1801), for small vessels (MacKenzie & Fletcher 2005).

Capture rates for BLL fisheries were highest in FMA3–7 (table 10), and varied between 0.05 and 0.23 birds per set. Catch rates varied through time, in a similar way to capture totals and these differences may reflect problems with observer data reporting in the fishery. These problems were resolved by 2003, and rates in 2003 were around 0.3 birds per set, decreasing to 0.1 birds per set in 2004 on average across areas (MacKenzie & Fletcher 2005). Rates of capture were estimated to be consistently low for small BLL vessels (table 10, MacKenzie & Fletcher 2005).

Albatross bycatch in trawl fisheries

Albatross bycatch by large TR vessels was estimated to be approximately 450 birds (95% credible interval 300–600 birds) in the 1998 fishing year, and between 900 and 1500 in subsequent years (width of 95% CI's ~500 birds; fig. 5). Approximately 1300 albatross were estimated killed on large trawl vessels in 2004 (table 11). For small TR vessels, albatross bycatch tended to be less than 200 birds, but there is a great deal of uncertainty surrounding these estimates (width of 95% CI's ~800 birds; fig. 5). Most of the bycatch is predicted to occur in Hoki and squid fisheries (MacKenzie & Fletcher 2005).

Catch rates of albatross for large TR vessels were highest in FMA5 (table 12), at around six birds per 100 tows in 2004. The average rate for 2004 (near to two birds per 100 tows) was higher than that for large vessels on average for the proceeding five years, when it was close to 1.5 birds per 100 tows (MacKenzie & Fletcher 2005). For small TR vessels, catch rates in FMA3–7 were highest (table 12), but had been stable through time at around 0.2 birds per 100 tows on average (MacKenzie & Fletcher 2005).

Assessing relative risk of seabird capture

Using the outputs of the predictive models developed for estimation of seabird bycatch in each area, season and fishing method, we explored relative importance of bycatch for different fishery areas and methods. Results are tabulated to enable detailed examination of the results (tables 13–16), and represented graphically to present an overall perspective of the relative bycatch and associated error (figs 6–9). During modelling, data for some FMAs were combined to reduce the uncertainty associated with total seabird capture estimates.

The estimates of total bycatch (number of birds) across all vessel sizes, methods, areas and seasons, for both 2004 and the average over 1998–2004 were calculated (table 13). The results for the 2004 fishing year showed similar rankings to those for the six-year average for both datasets. We therefore discuss only the 2004 results for simplicity, ranked in descending order of the estimated bycatch in 2004. For ease of presentation, we have removed those fishery strata for which the estimate in 2004 was less than 0.5% of the total. The estimated seabird bycatch reported included in table 13 comprised 99% of the total estimated bycatch for the 2004 fishing year. Each estimate is also shown as a percentage of the sum of the estimates across all fishery strata (% total in table 13). This indicates where the greatest "risk" of capturing seabirds lies, as estimated from the 2004 predicted capture estimates by vessel size, area, season and method. The uncertainties associated with these estimates are shown as a percentage of the total estimated bycatch for 2004 (table 14).

The analysis indicates that around 63% of total seabird bycatch occurs on large vessels and around 36% on small vessels.

Bycatch was estimated to have been highest in FMA6 (25%), followed by FMA1 and FMA5 (13% each), and FMA3 (9%). Combined estimates for FMA1, 2, 8 and 10 and for FMA3–4 may add up to an additional 4% to the totals for FMA1 and 3. Bycatch was highest in the spring and summer (34% each) and lowest in the spring and winter (19% and 12% respectively). The most important uncertainties were associated with small longline vessels, especially SLL vessels in FMA2 and 4 and BLL vessels in FMA1–2 and FMA8–10 (table 14).

For TR fisheries, which accounted for 46% of the total bycatch (table 13), highest total bycatch occurred in spring and summer across all areas, but particularly in FMA3, FMA5 and FMA6 for large vessels (39% of total captures) (fig. 6).

For SLL fisheries, which accounted for 35% of the total bycatch, the highest bycatch was estimated for FMA2 and 4 in summer and autumn for small vessels (16% of total bycatch), and FMA1, across all seasons for small vessels (13% of total bycatch) (fig. 7). There was high uncertainty associated with these estimates. Large vessels contributed a relatively small proportion of total SLL bycatch (4% of total bycatch), mainly in FMA2 and FMA4 in the summer.

BLL fisheries accounted for around 18% of the total bycatch, and spring showed relatively high bycatch totals across all areas for large vessels (6% of the total bycatch), while most bycatch was recorded in FMA3, FMA4 and FMA6 (3% of the total bycatch). For small vessels, very

TABLE 13
Estimated bycatch of seabirds in New Zealand fisheries for the 2004 fishing year and the
average over the 1998–2004 fishing years

Vessel size (m)[1]	Fishing method[2]	FMA[3]	Season[4]	2004		1998–2004[6]	
				Birds[5]	% Total birds	Birds	% Total birds
Small	SLL	2, 4	Summer	519	10	659	7
Large	TR	6	Autumn	377	7	230	2
Large	TR	6	Summer	372	7	223	2
Large	TR	5	Autumn	338	6	241	3
Small	SLL	2, 4	Autumn	320	6	446	5
Large	TR	5	Summer	298	5	309	3
Small	SLL	1	Winter	248	5	518	6
Large	TR	3	Autumn	225	4	332	4
Large	TR	6	Spring	202	4	120	1
Small	SLL	1	Spring	171	3	396	4
Small	SLL	1	Summer	154	3	297	3
Large	BLL	6	Spring	151	3	333	4
Large	SLL	2, 4	Summer	141	3	45	0
Large	TR	3	Summer	133	2	169	2
Large	TR	7	Winter	108	2	92	1
Large	TR	3	Spring	93	2	109	1
Large	BLL	5, 7	Spring	89	2	191	2
Large	BLL	6	Autumn	88	2	278	3
Large	TR	4	Autumn	87	2	77	1
Small	BLL	1, 2, 8–10	Autumn	87	2	342	4
Small	SLL	1	Autumn	82	2	207	2
Small	BLL	1, 2, 8–10	Summer	81	1	293	3
Small	SLL	2, 4	Spring	77	1	95	1
Large	BLL	6	Summer	66	1	245	3
Small	BLL	1, 2, 8–10	Winter	64	1	294	3
Large	TR	4	Summer	63	1	65	1
Large	TR	5	Spring	57	1	76	1
Small	SLL	2, 4	Winter	56	1	38	0
Large	TR	4	Spring	54	1	56	1
Large	BLL	3, 4	Spring	54	1	260	3
Large	BLL	3, 4	Winter	54	1	191	2
Large	SLL	5	Autumn	46	1	43	0
Large	BLL	3, 4	Autumn	44	1	65	1
Large	TR	7	Autumn	42	1	52	1
Large	BLL	6	Winter	33	1	132	1
Large	BLL	3, 4	Summer	31	1	39	0
Small	BLL	5, 7	Spring	29	1	208	2
Large	TR	3	Winter	28	1	22	0

[1] Small = < 28 m; Large = >28 m.
[2] Bottom longline (BLL), surface longline (SLL) and trawl (TR) methods.
[3] Fishery Management Area.
[4] Spring = Oct–Dec; Summer = Jan–Mar; Autumn = Apr–Jun; Winter = Jul–Sep
[5] Vessel-method-area-season combinations with less than 0.5 of the estimated bycatch in the 2004 fishing year have been omitted from the table.
[6] 1999–2004 for bottom longline.

TABLE 14

Uncertainty (width of 95 credible interval) associated with estimates of bycatch of seabirds New Zealand fisheries

Vessel size[1]	Fishing method[2]	FMA[3]	Season[4]	Birds	% total birds[5]
Small	SLL	2, 4	Summer	991	18
Small	SLL	2, 4	Autumn	803	15
Small	SLL	1	Winter	764	14
Small	BLL	1, 2, 8–10	Summer	564	10
Small	BLL	1, 2, 8–10	Autumn	559	10
Large	SLL	2, 4	Summer	521	10
Small	BLL	1, 2, 8–10	Winter	475	9
Small	SLL	1	Spring	378	7
Small	SLL	1	Summer	268	5
Small	BLL	5, 7	Spring	260	5
Small	SLL	2, 4	Spring	210	4
Small	SLL	1	Autumn	205	4
Small	SLL	2, 4	Winter	197	4
Large	TR	6	Autumn	176	3
Small	BLL	5, 7	Summer	169	3
Large	TR	5	Autumn	155	3
Large	BLL	6	Spring	133	2
Large	TR	3	Autumn	125	2
Large	TR	6	Spring	123	2
Large	TR	6	Summer	119	2
Large	BLL	3, 4	Autumn	115	2
Large	TR	5	Summer	111	2

[1] Small = < 28 m; Large = >28 m.
[2] Bottom longline (BLL), surface longline (SLL) and trawl (TR) methods.
[3] Fishery Management Area.
[4] Spring = Oct–Dec; Summer = Jan–Mar; Autumn = Apr–Jun; Winter = Jul–Sep.
[5] The uncertainty is also shown as a percentage of the total estimated bycatch for the 2004 fishing year. The uncertainties have been ranked in descending order and those vessel-method-area-season combinations for which the uncertainty was less than 2% of the estimated total bycatch in the 2004 fishing year have been omitted from the table.

TABLE 15

Estimated bycatch of albatrosses in New Zealand trawl fisheries, for the 2004 fishing year and the average over the 1998–2004 fishing years

Vessel size[1]	FMA[2]	Season[3]	2004		1998-2004[5]	
			Birds	% total birds[4]	Birds	% total birds
Large	6	Summer	270	18	154	13
Large	5	Summer	186	12	198	16
Large	6	Autumn	183	12	91	7
Large	5	Autumn	153	10	84	7
Large	6	Spring	122	8	65	5
Large	7	Winter	55	4	49	4
Large	3	Summer	48	3	54	4
Large	3	Autumn	44	3	73	6
Large	4	Spring	36	2	36	3
Large	4	Summer	35	2	35	3
Large	4	Autumn	33	2	29	2
Large	3	Spring	28	2	33	3
Small	3	Autumn	28	2	25	2
Small	7	Autumn	26	2	20	2
Small	3	Summer	24	2	26	2
Large	5	Spring	23	2	34	3
Small	3	Spring	23	2	20	2
Large	7	Autumn	17	1	20	2
Small	7	Spring	15	1	11	1
Small	7	Winter	12	1	8	1
Small	7	Summer	9	1	9	1
Large	3	Winter	8	1	7	1
Large	6	Winter	8	1	8	1

[1] Small = < 28 m; Large = >28 m.
[2] Fishery Management Area.
[3] Spring = Oct–Dec; Summer = Jan–Mar; Autumn = Apr–Jun; Winter = Jul–Sep.
[4] Vessel-area-season combinations with less than 0.5% of the estimated bycatch in the 2004 fishing year have been omitted from the table.
[5] 1999–2004 for bottom longline.

high uncertainty was associated with all estimates with an estimated 5 % of total bycatch from this group, and little confidence can be placed in these results.

The bycatch estimates for albatross in TR fisheries and uncertainties in the 2004 fishing year are shown in tables 15 and 16. The fishery strata contained in these tables comprise 94% of the total estimated albatross bycatch for the period, and estimates of less than 2% of the albatross bycatch are not discussed. Large vessels accounted for around 83% of the estimated albatross mortality, and small vessels, around 11%. Most albatross were estimated caught in FMA6 (39%), followed by FMA5 (24%) and FMA3 (15%). Albatross mortalities in these three areas comprised around 78% of the total albatross mortality. Most albatross were caught in the summer (38%) and autumn (32%), followed by spring (17%) and winter (7%).

DISCUSSION

Modelling approach

The approaches used here are novel for New Zealand fisheries for estimation of seabird bycatch, as previously ratio estimators were used to generate estimates for specific target fisheries (Baird 2004a, b, c, 2005, Baird & Smith 2007). Model-based estimation has been used recently, but only for specific target fisheries (Baird & Smith 2007). We approached the problem of estimation from the desire to provide an overall assessment of the importance of bycatch in different sectors of the longline and trawl fishery (e.g., by vessel size, method and area). The modelling approach used was appropriate for this analysis, allowing comparison of likelihood of seabird bycatch across broad areas of the fishery, including areas where observer data were sparse, with corresponding uncertainty estimates to guide the interpretation of the results.

TABLE 16
Uncertainty (width of 95 credible interval) associated with estimates of bycatch of albatross in New Zealand trawl fisheries in the 2004 fishing year

Vessel size[1]	FMA[2]	Season[3]	Birds	% total[4]
Small	7	Autumn	124	8
Small	3	Autumn	121	8
Large	6	Autumn	104	7
Small	3	Summer	104	7
Large	6	Summer	101	7
Large	6	Spring	90	6
Large	5	Summer	86	6
Small	3	Spring	86	6
Large	5	Autumn	81	6
Small	7	Spring	77	5
Small	7	Winter	53	4
Small	7	Summer	45	3
Large	3	Summer	43	3
Large	4	Spring	40	3
Large	3	Autumn	39	3
Large	7	Winter	39	3
Large	4	Summer	37	3
Large	4	Autumn	36	2
Large	3	Spring	30	2

[1] Small = < 28 m; Large = >28 m.

[2] Fishery Management Area.

[3] Spring = Oct–Dec; Summer = Jan–Mar; Autumn = Apr–Jun; Winter = Jul–Sep.

[4] The uncertainty is also shown as a percentage of the total estimated bycatch for 2004. The uncertainties have been ranked in descending order and those vessel-area-season combinations for which the uncertainty was less than 2% of the estimated total bycatch in the 2004 fishing year have been omitted from the table.

We consider the important outstanding problems in the analysis were:

(a) The spread of observer coverage across vessels. This was the single most important problem associated with providing improved estimates of seabird bycatch. Increasing the representativeness of sampling across the fishing effort, seasons and particularly vessel sizes would greatly improve the accuracy of bycatch estimation. Given the manner in which observers have been allocated to vessels in the past, and the very low levels of observer coverage of small vessels, caution should be exercised when interpreting the estimated level of bycatch from currently collected scientific observer data regardless of the statistical method employed to provided that estimate. At present it may only be possible to reliably estimate seabird bycatch for a small number of fisheries. This considerably reduces the utility of the results of the study to understanding the seabird bycatch problem across New Zealand fisheries at a global level and from the perspective of individual populations. The relative importance of different components of the total fishing effort is understood to greatly varying degrees. Those areas with potentially the highest bycatch are those for which sampling is at low proportions of total effort, and consequently very high uncertainty exists (table 17). This is especially important for small surface longline vessels.

(b) The treatment of the very rare occasions when a large number of birds are caught in single fishing events remains a problem for robust statistical analysis as distributions classically used to model the data do not accommodate these occurrences well.

(c) The hierarchical nature of the sampling, i.e., observers are placed on vessels at the beginning of a trip, and observe all or most fishing events on that trip. Hence using tows/sets as the basic sampling unit may not be completely appropriate. The most serious consequence of not accounting for these aspects of the data in the model is that credible intervals will tend to be too narrow.

In summary, we consider that the methods and data requirements for the estimation of seabird bycatch in New Zealand fisheries remain an ongoing area for development. Our study has highlighted where the greatest uncertainties and deficiencies in the data are. Our confidence in the results

TABLE 17
Observer coverage levels, fishing effort, and total predicted bycatch across fisheries in New Zealand in the 2004 fishing year

Fishing method[1]	Vessel size[2]	% fishing events observed	% total fishing events for 2004	% total predicted bycatch
TR	Small	0	44	0
SLL	Small	2	3	31
BLL	Small	1	10	5
TR	Large	10	39	46
SLL	Large	82	<1	4
BLL	Large	12	4	13

[1] Bottom longline (BLL), surface longline (SLL) and trawl (TR) methods.

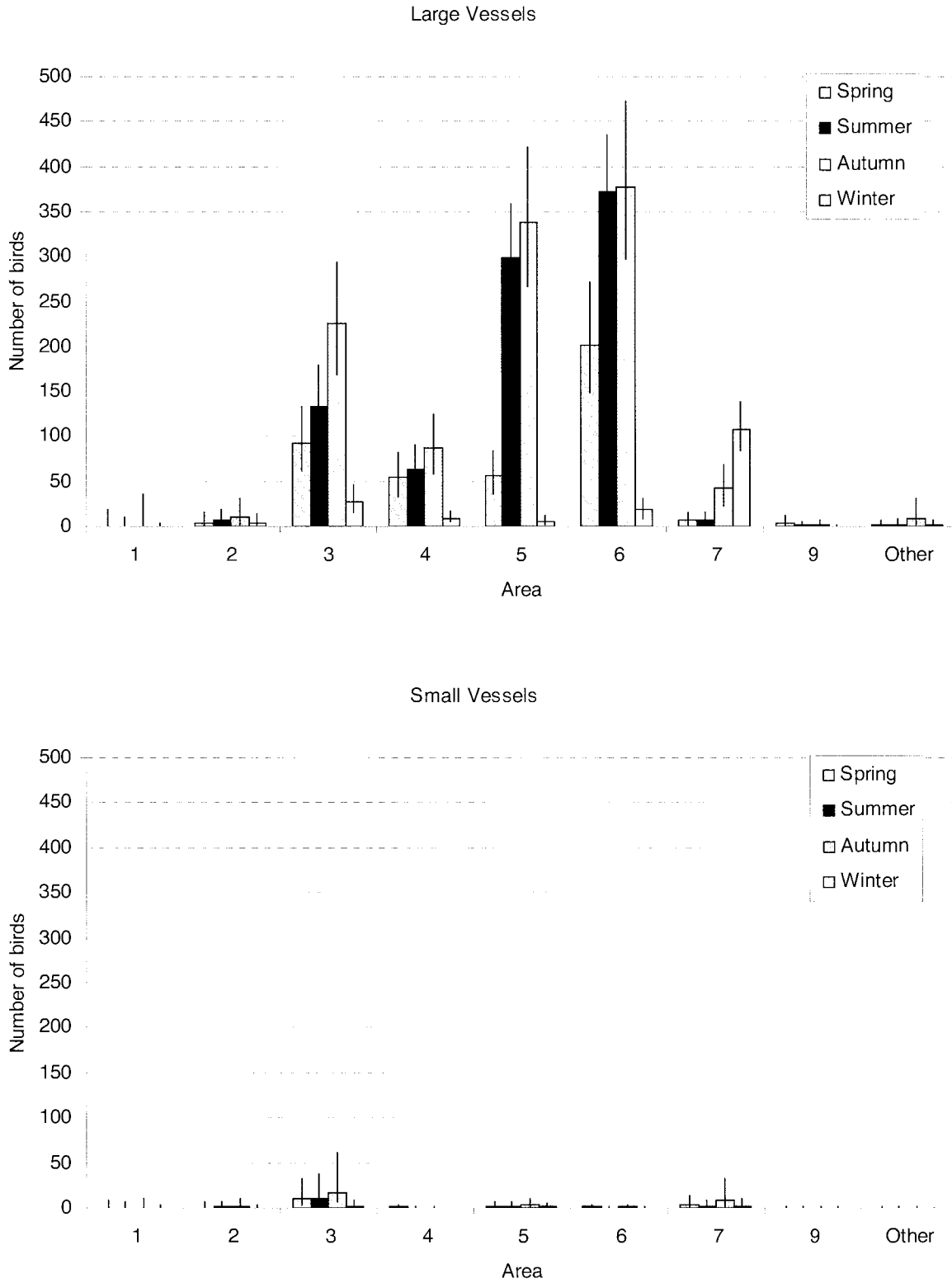[2] Small = < 28 m; Large = >28 m.

Large Vessels

Small Vessels

FIG. 6 — The estimated seabird bycatch (number of birds) in New Zealand trawl fisheries during the 2004 fishing year, together with 95% credible intervals for large and small vessels (split at 28 m length), between seasons for different Fishery Management Areas.
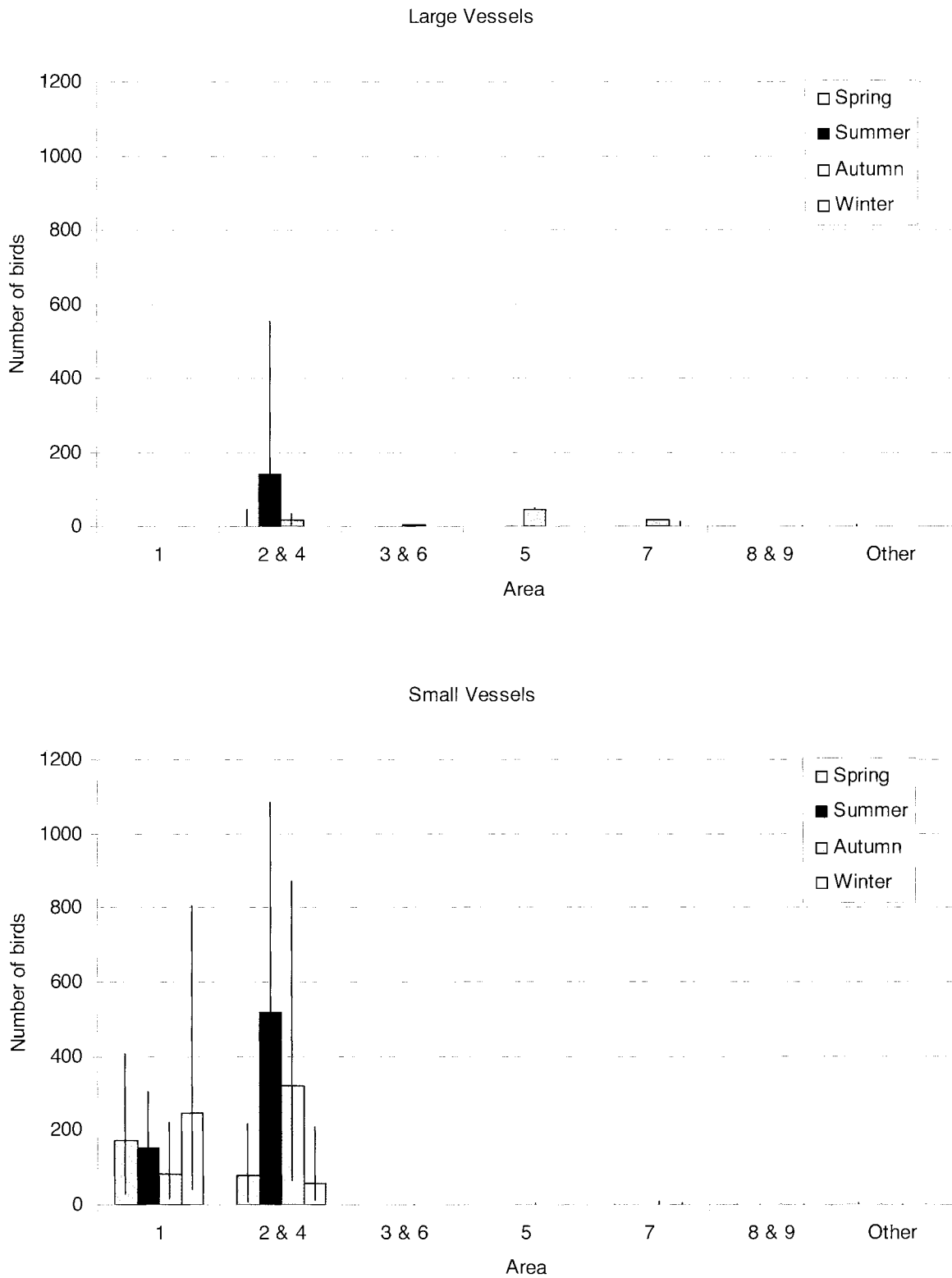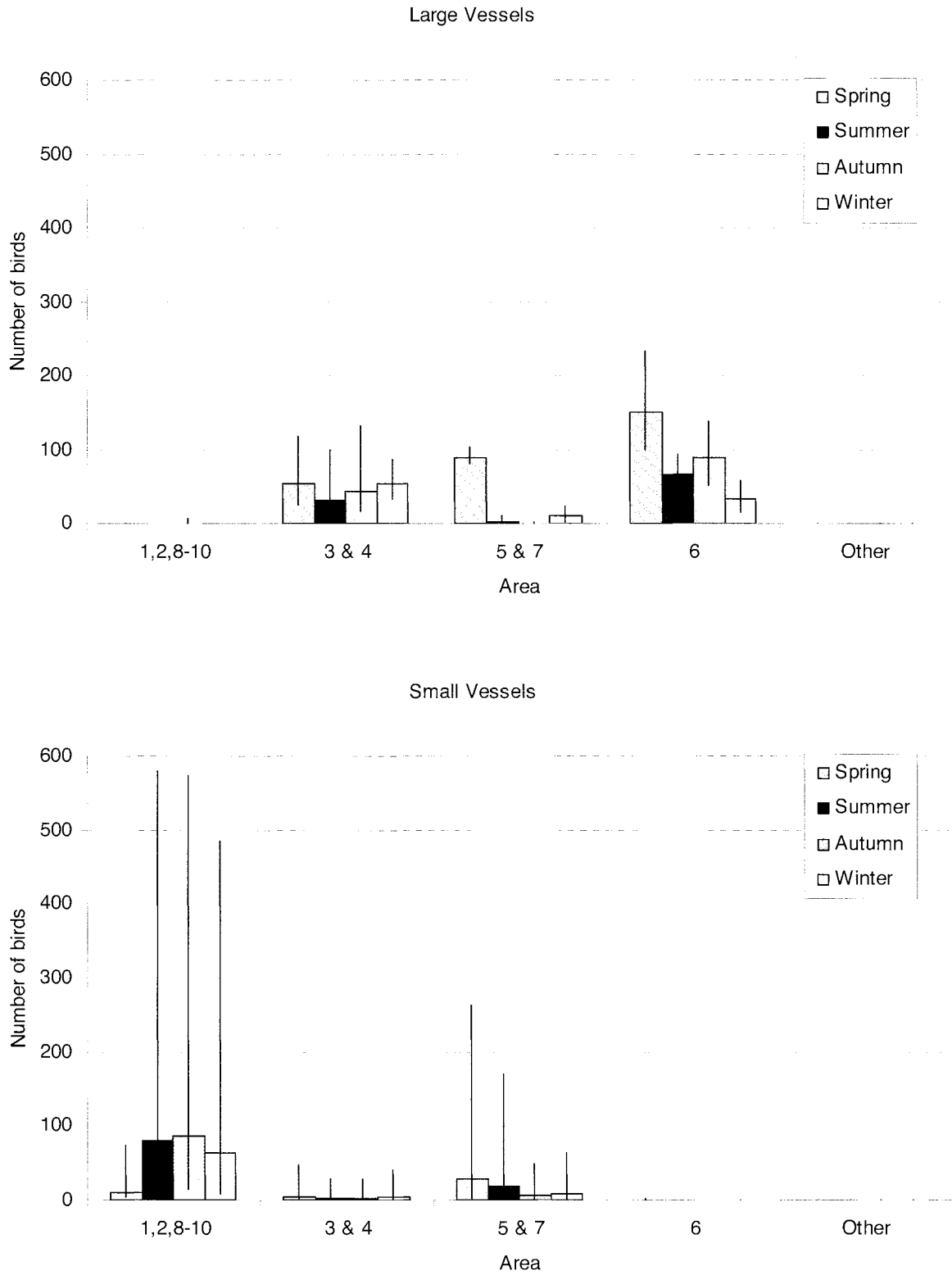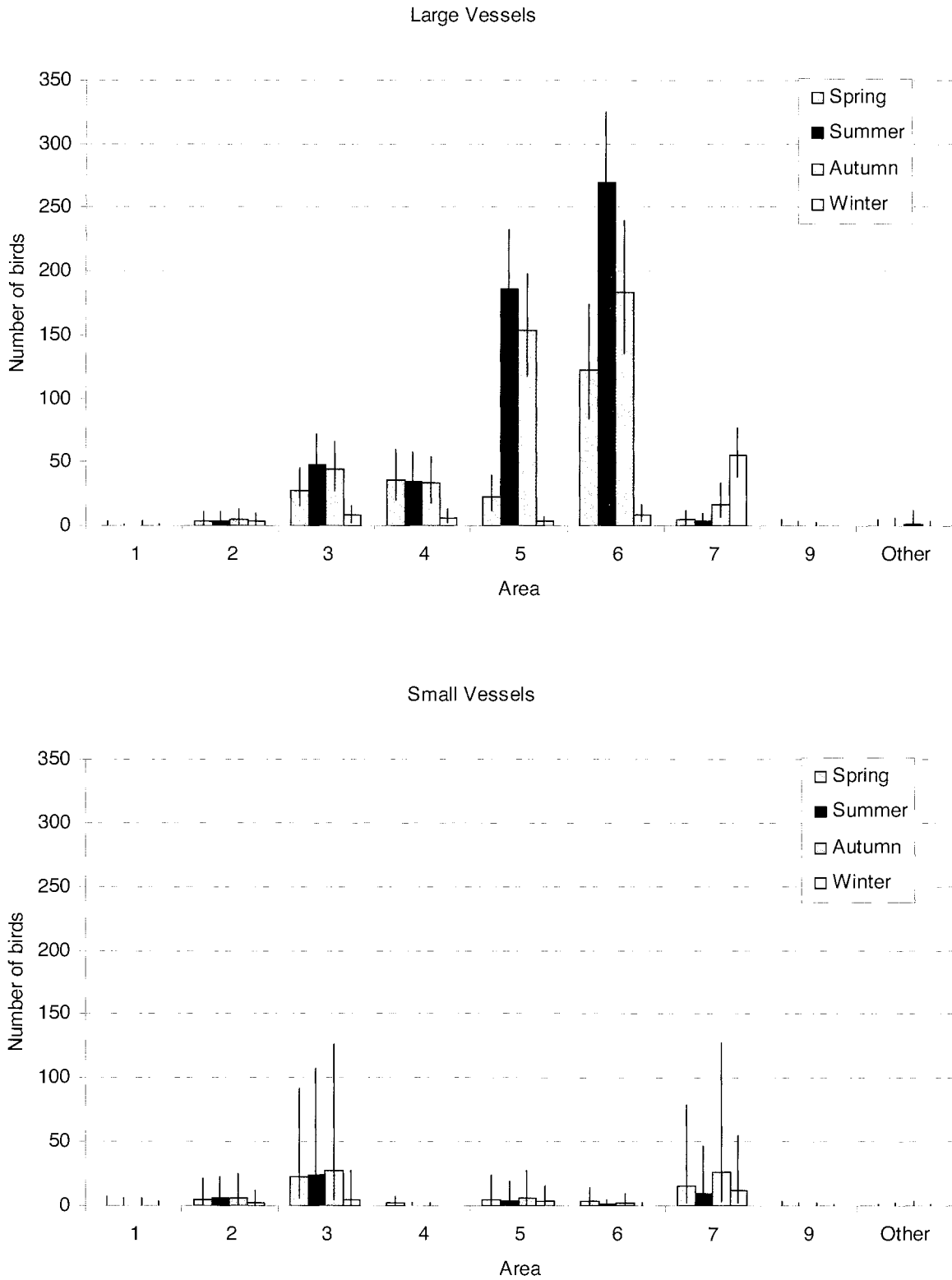
Large Vessels

Small Vessels

FIG. 7— The estimated seabird bycatch (number of birds) in New Zealand surface longline fisheries during the 2004 fishing year, together with 95% credible intervals for large and small vessels (split at 28 m length), between seasons for different Fishery Management Areas.

FIG. 8 — The estimated seabird bycatch (number of birds) in New Zealand bottom longline fisheries during the 2004 fishing year, together with 95% credible intervals for large and small vessels (split at 28 m length), between seasons for different Fishery Management Areas.

Large Vessels

Small Vessels

FIG. 9 — The estimated albatross bycatch (number of birds) in New Zealand trawl fisheries during the 2004 fishing year, together with 95% credible intervals for large and small vessels (split at 28 m length), between seasons for different Fishery Management Areas.

reported is somewhat limited by the matters discussed in this section. In particular, the wide confidence intervals for the estimates of seabird captures on small vessels across methods indicate that a far greater level of observer sampling would be required to gain precise and accurate estimates of captures for these fisheries.

Estimation of New Zealand fisheries bycatch

Observer coverage
Observer coverage across New Zealand fisheries was, on average, around 5% of the total fishing effort for the TR, SLL and BLL fisheries during 1998–2004. Coverage was concentrated in high-value fisheries or those with a high risk for stock sustainability (New Zealand Ministry of Fisheries 2007a), and on large vessels. These are mainly fishing for tuna, ling, and deep-water or middle-depths fish species such as Southern Blue Whiting, *Micromesistius australis* Norman, 1937, Hoki, squid, Orange-roughy, *Hoplostethus atlanticus* Collett, 1889, and oreos. Observer coverage in New Zealand fisheries is not deployed in a manner that facilitates examination of the environmental effects of fishing. In order to estimate more robustly seabird bycatch, we consider that there is a need for deployment of observers to cover a considerably higher proportion of all fishing effort, with observer coverage spread randomly across fleets, areas and seasons in relation to the likelihood of seabird capture (table 13). For the period of the study, observer deployment was not related to the risk of seabird capture or where fishing effort is deployed (table 17). Fishing effort by small vessels was observed at rates of less than 3%, even though they potentially catch 35% of the total seabirds caught and their effort comprised 57% of the total effort in 2004.

In order to understand species level effects of fishing, greater levels of observer coverage are required across all fishing effort, as the capture of individuals of any particular species is a rare event, requiring high sampling ratios to detect.

Estimated total captures
For large vessels in New Zealand fisheries, seabird mortalities are likely to be approximately 3800 individuals annually, with approximately 2000 additional individuals captured on small vessels. There is high uncertainty associated with these estimates, particularly for mortalities associated with small vessels.

Previous estimates of bycatch in New Zealand fisheries have been focused on a small number of target fisheries, where observer coverage was greatest. This has allowed a detailed analysis of capture rates in specific fisheries, but not a comprehensive understanding of the likely scale of the bycatch problem to be established, and in particular where information is uncertain or lacking. Estimation of bycatch using a modelling approach has enabled prediction of where bycatch problems are most likely to be occurring, and has identified areas where a far greater level of observation and management of bycatch problems are necessary.

For fisheries from large TR vessels in 2004, it was estimated that approximately 2500 seabirds were caught in FMA3–7. Albatross bycatch for these areas for 2004 was estimated to be approximately 1300 birds. Previous estimates of seabirds captured in TR fisheries in New Zealand waters were limited to those identified during fishing for Hoki and squid fisheries, and for some areas only of these fisheries (Baird 2004a, b, c, 2005, Baird & Smith 2007). Bycatch

totals previously reported were lower than indicated for large vessels in this study, with between 500 and 1700 seabirds estimated caught annually in TR fisheries where sufficient observer coverage was deployed between 1998 and 2004 (see the source materials for error estimation; Baird 2004a, b, c, 2005, Baird & Smith 2007). The differences in the results between the current study and previous work are not easy to reconcile. Although the primary data sets were the same, the grooming of data and inclusion of fishing effort in the different estimation procedures is likely to have differed considerably. This statement applies across all fishing methods discussed in this study.

Relatively few seabirds were caught on large SLL vessels, and the number has likely decreased through time. For 2004 it was estimated that approximately 230 were caught in FMA2–7, compared with approximately 650 for the same areas in 1998. Previous estimates of bycatch in these fisheries indicated that around 40–140 seabirds were caught on large SLL vessels for the fleet fishing under charter in New Zealand waters annually from 1998–2004, although these did not include all large SLL vessels fishing in New Zealand waters each year (Baird 2004a, b, c, 2005, Baird & Smith 2007).

For BLL fisheries, total seabird bycatch of approximately 630 for FMA3–7 was estimated for large vessels in 2004. The numbers of seabirds estimated caught has decreased through time, from a peak of approximately 2800 in 2001. Prior to 2001, problems with observer recording of data are likely to have resulted in inaccurate estimation, as the number of observed hooks was not reported, and unobserved birds returned by crew were counted in the bycatch totals. Estimated bycatch from BLL vessels from previous studies (Baird 2004a, b, c, 2005, Baird & Smith 2007) indicated levels of around 1400 reducing to around 208 seabirds per year from 2001 to 2004.

Management of New Zealand fisheries seabird bycatch

In 2004, New Zealand implemented its National Plan of Action – Seabirds (NPOA-Seabirds) (New Zealand Department of Conservation 2004) which largely relied on voluntary codes of practice to implement effective mitigation strategies. Streamer lines were required as a mandatory measure for surface longline vessels. In 2005, following captures of large numbers of albatross in the squid trawl fishery, the Minister of Fisheries called for a review of the NPOA-Seabirds, and indicated that it should include a greater range of mandatory measures, and bring New Zealand management of seabird bycatch closer to international best practice. In August 2008, New Zealand continued to revise its NPOA-Seabirds, but has yet to announce a revised framework. Between 2005 and 2008, a range of mandatory mitigation measures was introduced, including trawl-warp scaring devices and the requirement to hold offal for half-hour periods for trawl vessels over 28 m, the use of streamer lines, line weighting or night setting in all longline fisheries (New Zealand Ministry of Fisheries 2006, 2007c, 2008b, c). In July 2008, the Minister of Fisheries announced that the requirement for offal management on trawl vessels was to be revoked due to vessel safety concerns (New Zealand Ministry of Fisheries 2008a).

The bycatch levels in the New Zealand trawl and longline fisheries reported in this study are similar to those observed in Antarctic BLL fisheries for toothfish *Dissostichus* sp., prior to the onset of rigorous management measures under

the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Croxall *et al.* 2007, Waugh *et al.* 2008). In the CCAMLR BLL fishery in areas where the CCAMLR Conservation measures are required to be implemented (which excludes the French sub-Antarctic EEZ areas) seabird bycatch decreased from around 6500 birds in 1996 to zero birds in 2007. This example demonstrates that management of fisheries mortality of seabirds is feasible and achievable within realistic time frames.

The introduction of a range of mitigation requirements for New Zealand fisheries, and particularly those in 2008, represents a significant step towards reducing seabird bycatch in New Zealand waters. It is important to note, however, that the additional resources required for ensuring compliance with the measures and to increase observer coverage have not been allocated. These factors may weaken the New Zealand Government's abilities to either monitor bycatch levels or ensure compliance with the new mandatory requirements. The ongoing lack of a formal framework for seabird bycatch management, such as through a NPOA-Seabirds, also threatens to hamper New Zealand's ability to keep abreast of the continual improvement in bycatch mitigation strategies, such as through offal managment and line weighting currently under research through many trawl and longline fisheries worldwide.

Trends in bycatch estimates

Seabird bycatch totals have remained low and stable through time for SLL fishing, for large vessels. It has decreased from around 2800 bids per year to around 600 birds per year for large BLL vessels. For large TR vessels however, there has been an increase in seabird mortality during the 1998–2004 fishing years, to around 2500 birds in 2002–2004, of which around one half was albatross. For all methods for small vessels, we do not have sufficient confidence in the estimates produced to attribute trends.

CONCLUSIONS

Our study indicates that there is an ongoing level of seabird bycatch in New Zealand fisheries, which merits further monitoring, research and management. Approximately 5500 seabirds may be killed in New Zealand fisheries each year. For large vessels, approximately 3800 seabirds are caught. There were increasing numbers of seabirds estimated for TR fisheries between 1998 and 2004, to a total of approximately 2500 seabirds, of which around one half were albatross in 2004. Large numbers of albatross, and species of threatened status which occur across the fisheries are captured in proximity to their breeding areas, increasing the risk of population effects from the fisheries removals. Highest priority areas for monitoring and management action include fisheries by large TR vessels in southern areas (FMA3–7), small SLL vessels in northern and central areas (FMA1, 2 and 4), and for all BLL fishing.

To better understand the effects of fishing on the species observed caught in the New Zealand fisheries, further monitoring, management and research is warranted. This could include increased observer effort, a re-deployment of observer effort in areas with greatest risk of seabird capture, and detailed demographic studies of the species most at risk due to vulnerable population status. Estimation of fisheries bycatch of seabirds remains an important tool for

the management of the effects of fishing on environmental sustainability. Tracking the evolution of bycatch levels across areas, target fisheries and years is pivotal to allowing targeted mitigation efforts, in areas where it is likely to reduce seabird bycatch. Due to the high conservation value of these species, their iconic status in society and the high level of endemism of the species known to be affected by TR, SLL and BLL fisheries, the management of seabird bycatch in New Zealand should be a high priority.

ACKNOWLEDGEMENTS

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