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At-sea distribution of breeding male and female grey petrels (*Procellaria cinerea*) determined from New Zealand fisheries bycatch

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Abstract Seabird bycatch data collected between 1996 and 2016 in commercial fisheries within the New Zealand Exclusive Economic Zone (EEZ) were analysed to determine if male and female grey petrels (*Procellaria cinerea*) have different at-sea foraging distributions during the breeding season. Data collection includes the return of bycaught (killed) seabirds from commercial fishing vessels by government fisheries observers. A total of 408 bycaught breeding grey petrels with known sex (214 males, 194 females) were analysed for a locational and seasonal sex bias. Data were also examined to determine whether where carcasses were returned from sea, there were different proportions of males and females captured by different fishing methods: offshore bottom longlining, surface longlining, and offshore trawling. There was no significant difference in the totals of male and female grey petrels returned from fishing operations, but capture locations for the sexes varied widely. More males than females were caught in April, May, August, and September. July showed a reverse trend, while June was the only month with no difference in captures between sexes. More males than females were caught in offshore bottom longliners and trawlers, with the opposite for surface longliners. This study emphasises the importance of a large-scale approach to capture locations and season when analysing impacts of fisheries on seabird populations, and highlights different foraging areas according to sex during the breeding season. Spatial segregation has important management implications as changes in fisheries practice in foraging areas may affect the sex ratio of the grey petrel population.

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INTRODUCTION

Fishing operations and the effects on procellariiformes seabird populations worldwide have been widely examined (Bartle 1990; Murray *et al*. 1993; Gales *et al*. 1998; Nel *et al*. 2002; Lewison *et al*. 2005; Waugh *et al*. 2008; Barbraud *et al*. 2009; Barbraud *et al*. 2011). Discussions have focused on the declines in seabird populations as a result of incidental bycatch, and the inability of these long-lived *k*-selected seabird species to cope with, or recover from, high adult mortality rates (Croxall & Prince 1990; Brothers 1991; Cherel *et al*. 1996). Sex-biased mortality in different regions and seasons has also been documented (Bartle 1990; Gales *et al*. 1998; Ryan & Boix-Hinzen 1999; Nel *et al*. 2002; Gandini & Frere 2006; Bugoni *et al*. 2010). As such, mitigation measures have been developed to reduce the impacts of fisheries on seabirds (Delord *et al*. 2005; Sullivan *et al*. 2006; Bull 2007, 2009; Lokkeborg 2011).

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The grey petrel (*Procellaria cinerea*) is a circumpolar species and has a distribution between 32°S and 58°S (Marchant & Higgins 1990). Population size and trends are poorly understood, but Antipodes Island (New Zealand) holds the largest breeding population of approximately 53,000 pairs (Bell 2002; Bell *et al*. 2013). Grey petrels also breed on other subantarctic islands around the Southern Ocean (ACAP 2009). They are winter breeders that are present at colonies from February to December (ACAP 2009). A single egg is laid between late March and early April, chicks hatch from late May to early June, with fledging occurring between October and December (Bell 2013). The species is listed as Near Threatened by the IUCN Red List due to threats from introduced mammalian predators on some of the breeding islands and from fisheries bycatch (BirdLife International 2012). The New Zealand Threat Classification lists the species as Naturally Uncommon (Robertson *et al*. 2013).

Evidence suggests sexual segregation in foraging areas by grey petrels, and other procellariiformes, during the breeding season (Bartle 1990; Croxall & Prince 1990; Murray *et al*. 1993; Gales *et al.* 1998; González-Solí *et al*. 2000; Stahl & Sagar 2000; Bugoni *et al*. 2010; Pereira 2015); Bartle (1990) reported mostly female grey petrels caught off East Cape (New Zealand) over a 10-day commercial surface longlining fishing period in June 1989. There are 20 years of information on seabird bycatch in the New Zealand Exclusive Economic Zone (EEZ), including location and month of captures, and sex of grey petrels caught. This study used these data to (i) determine if there is sexual segregation in foraging areas used by grey petrels during the breeding season, and (ii) explore whether there may be differing levels of susceptibility to fishing methods amongst offshore bottom longlining, surface longlining, and offshore trawling, with offshore defined as beyond the 12 nautical mile territorial limit but within the EEZ.

MATERIALS AND METHODS

The New Zealand Department of Conservation and the Ministry for Primary Industries have been running a fisheries observer programme in the New Zealand EEZ since 1996. Dead seabird specimens caught as bycatch in commercial fisheries were either collected and frozen or photographed and discarded by observers. Any birds caught alive and released were also photographed. Both the frozen specimens and photographs of dead birds were then sent to contracted experts for examination. Full necropsies were conducted on returned dead specimens to determine taxon, sex, age-class, injuries, body condition, stomach contents, and likely cause of mortality. The taxon, and where possible, sex and age-class were determined from photographs.

Information regarding capture location and fishing method was recorded with each specimen returned for necropsy. During necropsies, methods used to determine sex and age-class followed Bartle (2000). Specifically, these methods included examining the gonads for sex (a combination of gonad size and oviduct condition) and brood patch and moult for age-class. Breeding adult grey petrels caught and returned for necropsies between 1 June 1996 and 15 August 2016 were analysed. Grey petrels were caught between the months of April and November, which falls within the breeding period (Bell 2013). This study focused on three commercial fishing methods: offshore bottom longline, surface longline and offshore trawling. As noted previously, for the purpose of this study, offshore has been defined as beyond the 12 nautical mile territorial limit, but within the EEZ. All years were pooled, and inter-annual comparisons were not made as this study examined the long-term and hence cumulative sex bycatch data of grey petrel. Annual analyses may show a sex bias of captures between years; however, these analyses would need to include the variability in fisheries effort and observer coverage, and are therefore considered to fall outside the scope of this study.

Because the sex of each bird was required for analysis in this study, photographed dead birds not collected by observers were excluded (n = 6). Necropsied individuals for which sex was not identified due to injury or damage by sealice were excluded (n = 217). Sub-adults were also not used, to avoid potential bias in foraging areas between non-breeding and breeding birds (n = 44). The 408 selected specimens were mapped by combining all years, but by differentiating sex and fishing method and month of capture. Using SPSS version 23 (IBM, Armonk, NY), differences between total number of males and females returned by fisheries observers as well as differences between the number of each sex returned per month were tested from a 1:1 ratio with a χ^2 test.

RESULTS

The final sample on which the analyses was conducted was 408 breeding birds (214 males, 194 females), for which there was no statistically significant difference between sexes in occurrence in the sample (i.e. carcasses returned by observers) (χ^2 (1, n = 408) = 0.98, P = 0.32). Capture locations, however, differed between sexes (Fig. 1). Males were captured north and south of, as well as at, the Chatham Rise. Females were predominantly captured north of the Chatham Rise. Capture location by sex and month are illustrated in Fig.

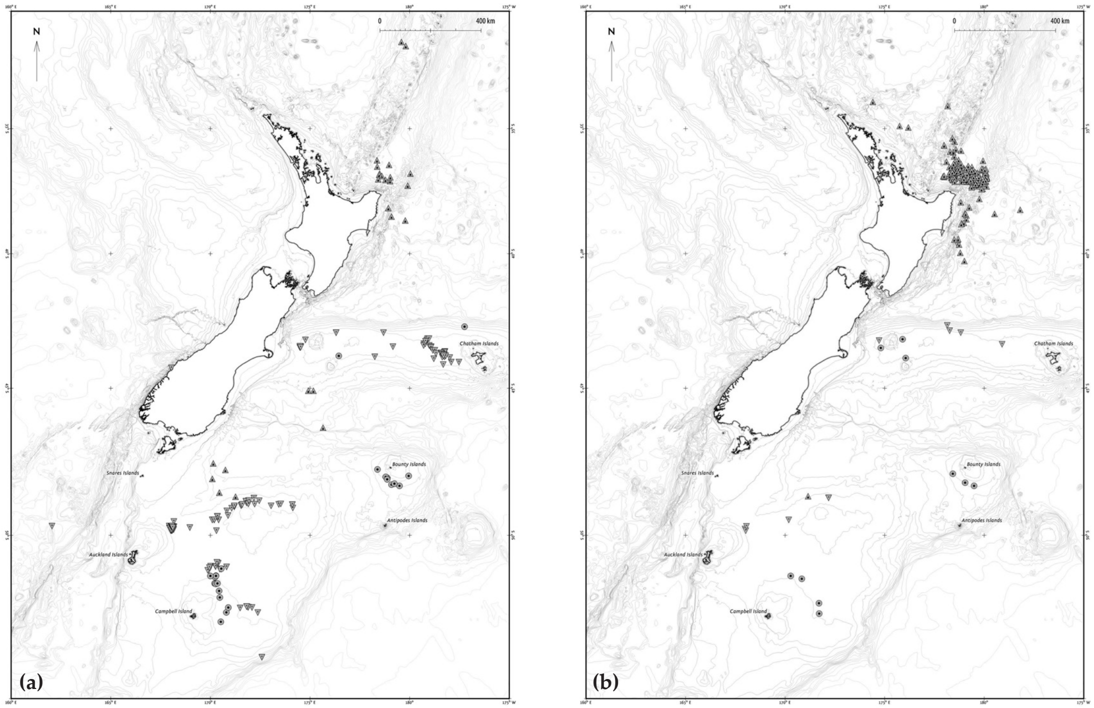

Fig. 1. Locations, by fishing method, of sexed (a) male (n = 214) and (b) female (n = 194) grey petrels killed in commercial fishing operations between 1996 and 2016 in New Zealand and retained by government observers for necropsy. Upward pointing triangles indicate surface longliners, downward pointing triangles indicate offshore (beyond the 12 nautical mile territorial limit but within the EEZ) bottom longliners, and circles indicate offshore trawlers. (Note not all commercial vessels carry government observers. Therefore, captures shown here are a documented minimum).

2. Males congregated at, or south of, the Chatham Rise in April, but were primarily to the south in May. Females were spread out along the whole of the east coast during both April and May. Males appeared to move northward during June and more so during July, but this was far more evident in females which were only caught at or north of the Chatham Rise in June and July. In August and September, males were caught at or south of the Chatham Rise. Females continued to be captured in the north but also appear to disperse along the rest of the east coast.

There was a large fluctuation in bycatch between the sexes according to the month of year (Fig. 3). The number of males caught fluctuated early in the breeding season (April to June) but stabilized after a peak in July. The number of females caught was low early in the breeding season (April and May) but rose and fell rapidly before and after a large peak in July. On a monthly basis, there were more males than females caught in April and May (χ^2 (1, n= 15) = 5.40, P = 0.02 and χ^2 (1, n = 39) = 21.56, P< 0.001, respectively). The same pattern was seen in August and September (χ^2 (1, n = 74) = 5.41, P = 0.02 and χ^2 (1, n = 54) = 39.19, P< 0.001, respectively). July showed a reverse trend with more females captured than males (χ^2 (1, n = 185) = 32.09, P< 0.001), and June was the only month with no significant difference (χ^2 (1, n = 41) = 1.20, P = 0.27).

With captures differentiated by fishing method (Fig. 4), significantly more males than females were killed by offshore bottom longliners (χ^2 (1, n = 172) = 127.35, P< 0.001). Males were caught by offshore bottom longliners every month between April and September whereas fewer than five females were caught by offshore bottom longliners per month. Significantly more females than males were caught by surface longliners (χ^2 (1, n = 195) = 113.85, P< 0.001), particularly between June and August. Males were more frequently caught in offshore trawlers than females (χ^2 (1, n = 41) = 10.76, P = 0.001), particularly in August and September.

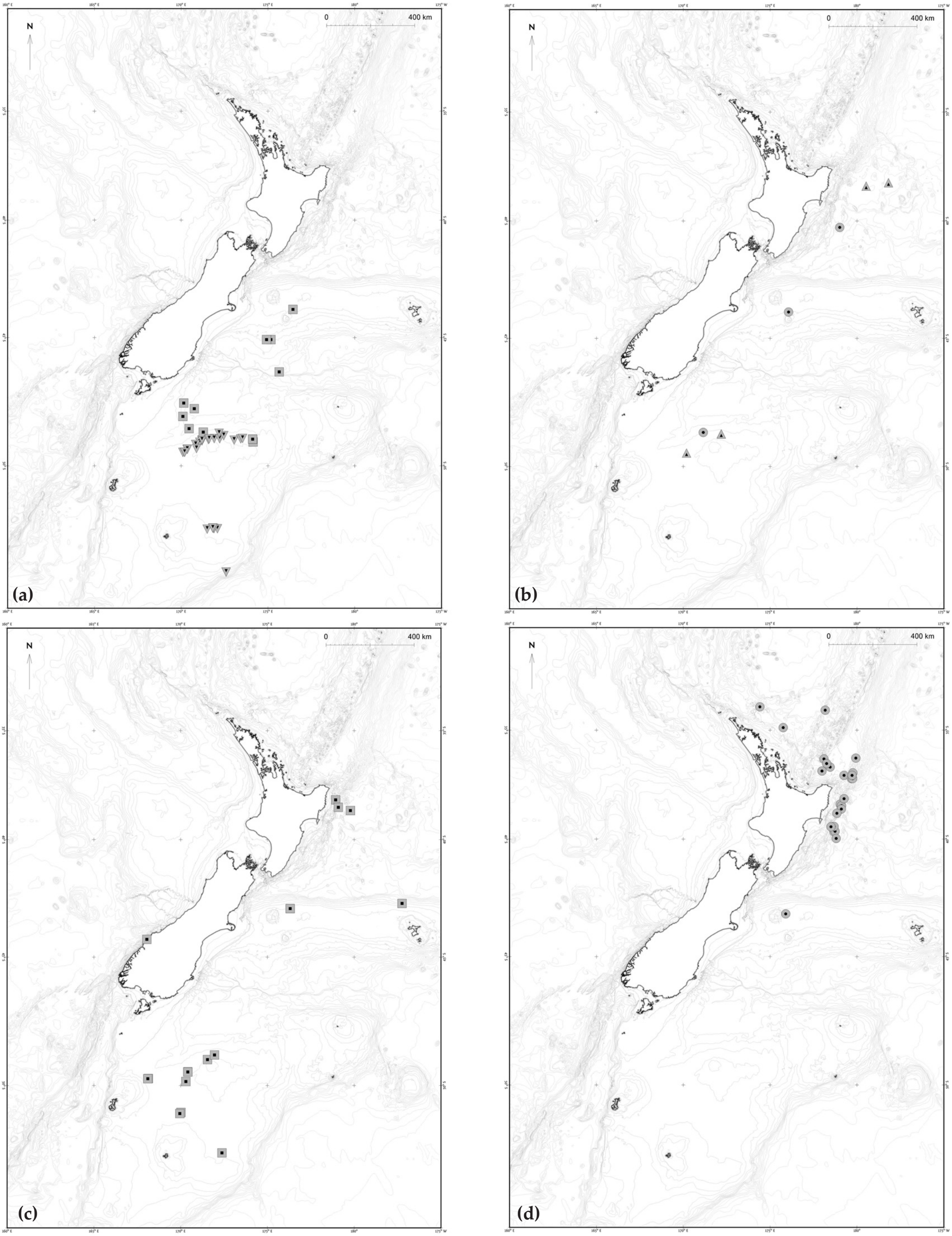

Fig. 2 (continued overpage). Locations of grey petrels killed in commercial fishing operations between 1996 and 2016 in New Zealand and retained by government observers for necropsy differentiated by sex and month. (a) Males caught in April (n = 12, squares) and May (n = 34, downward triangles); (b) females caught in April (n = 3, circles) and May (n = 5, triangles); (c) males caught in June (n = 17), (d) females caught in June (n = 24). (Note that not all commercial vessels carry government observers. Therefore, captures shown here are a documented minimum).

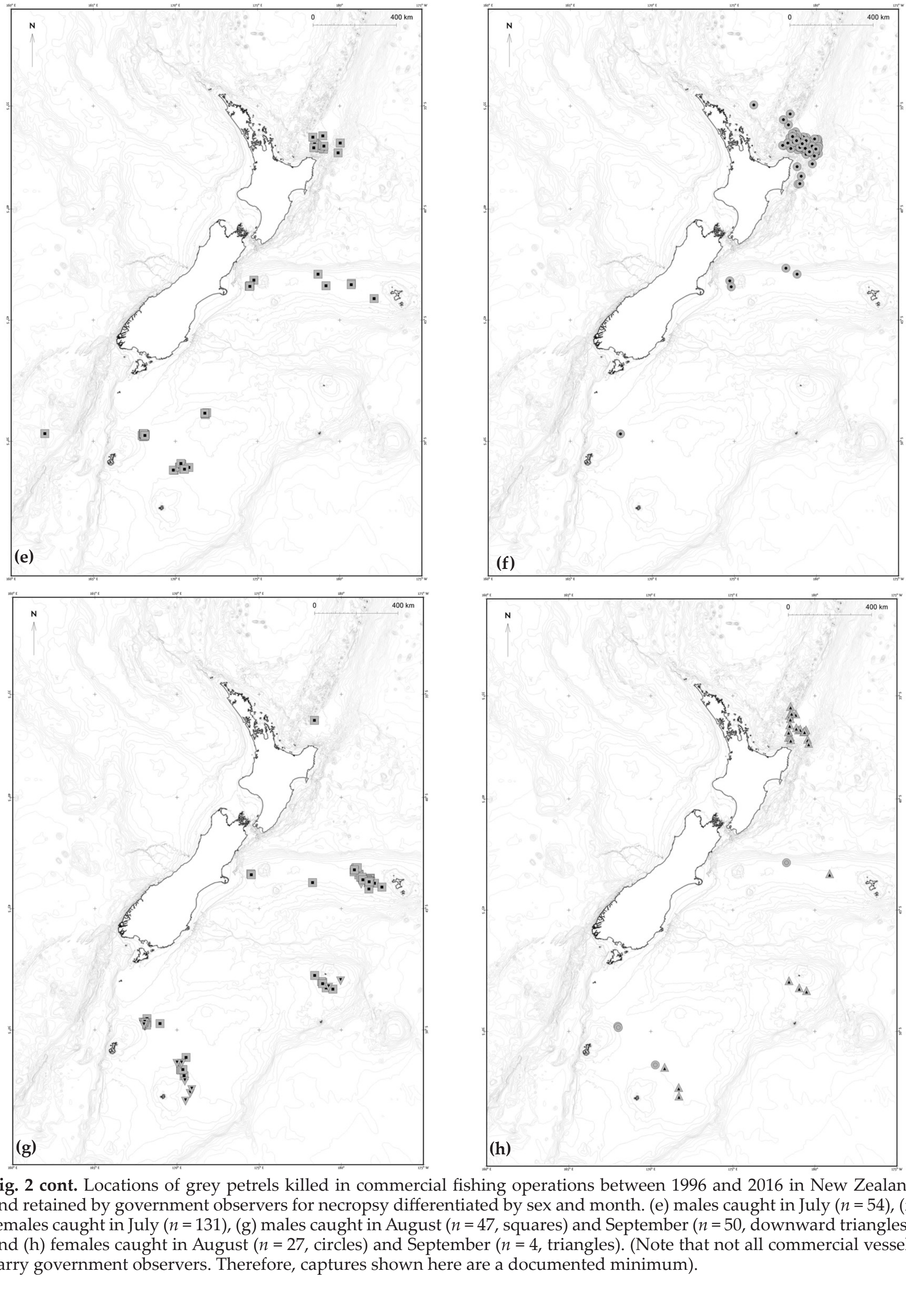

Fig. 2 cont. Locations of grey petrels killed in commercial fishing operations between 1996 and 2016 in New Zealand and retained by government observers for necropsy differentiated by sex and month. (e) males caught in July ($n = 54$), (f) females caught in July ($n = 131$), (g) males caught in August ($n = 47$, squares) and September ($n = 50$, downward triangles), and (h) females caught in August ($n = 27$, circles) and September ($n = 4$, triangles). (Note that not all commercial vessels carry government observers. Therefore, captures shown here are a documented minimum).

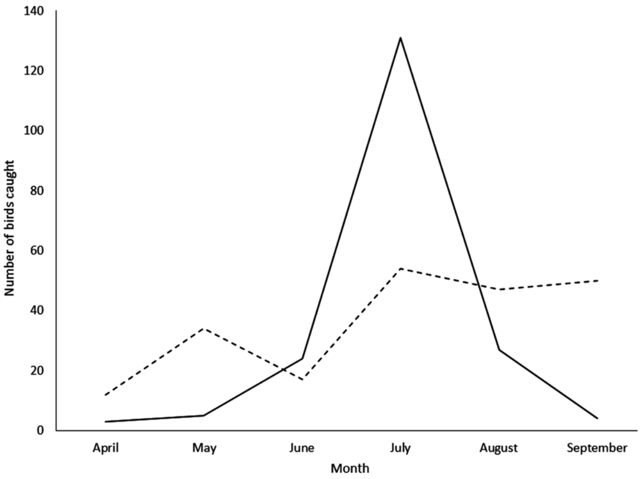

Fig. 3. Number of male (dashed line) and female (solid line) grey petrels caught on fishing gear and returned per month by government fisheries observers deployed on selected commercial fishing vessels in New Zealand between 1996 and 2016.

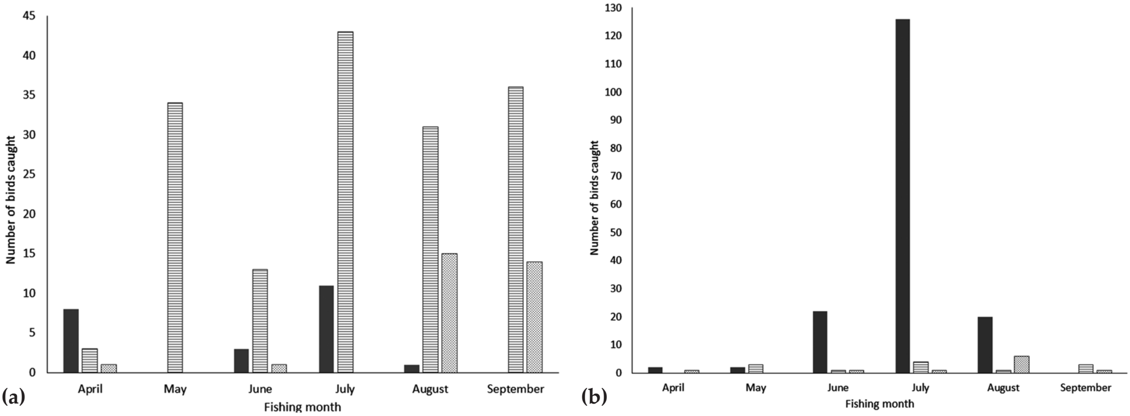

Fig. 4. Number of sexed (a) male and (b) female grey petrels killed by fishing gear and retained by government fisheries observers deployed on selected commercial fishing vessels per month in New Zealand between 1996 and 2016. Specimens returned are shown by fishing method. Solid dark bars represent surface longline, horizontal lined bars represent offshore (beyond the 12 nautical mile territorial limit but within the EEZ) bottom longline, and dotted bars represent offshore trawlers.

DISCUSSION

There was no difference in the total number of male and female grey petrels caught and returned in New Zealand between 1996 and 2016. This large-scale finding contradicts the results of earlier studies which were spatially and temporally restricted. For example, Bartle (1990) and Murray *et al*. (1993) studies around New Zealand suggested a bias towards the capture of females. However, Bartle (1990) focused solely on surface longlining northeast of the North Island in New Zealand, hundreds of kilometres away from the grey petrel breeding site, and Murray *et al*. (1993) focused on surface longlining around New Zealand but reported that grey petrels were only caught northeast of the North Island. Nel *et al*. (2002) analysed bottom longline fisheries around the Prince Edward Islands which occur close to the South African breeding location, and suggested a bias towards capture of males. Gales *et al*. (1998) found a bias towards females caught by surface longliners around Tasmania, also hundreds of kilometers away from the Australian breeding site. Thus it is possible that differences in sex ratio of grey petrels in bycatch may be associated with the scale of the study area and distance from breeding locations. The need to look at a large geographical area has been raised as an important issue because different fishing areas show different catch rates of birds (Gales *et al*. 1998, Waugh *et al*. 2008, Delord *et al*. 2010, Gianuca *et al.* 2017), one which we emphasized here. In contrast, Rollinson *et al*. (2016) GPS-tracked 10 male and 5 female grey petrels breeding on Gough Island during mid- to late incubation (early April) and found no difference in foraging areas between the sexes. The difference could be due to the stage of breeding, or different foraging behaviour between the South Atlantic Ocean and the South Pacific Ocean. As such, we recommend that grey petrels breeding on Antipodes Island be GPS-tracked to determine the extent of foraging areas around New Zealand and to be able to compare the tracking results with the fisheries bycatch observations described in this study.

The monthly shifts in capture locations suggest different movement of the sexes during the breeding cycle. Foraging patterns during incubation differ from chick rearing (Stahl & Sagar 2000; Péron *et al*. 2010; Mackley *et al*. 2011); it is not uncommon for females to travel farther than males during chick rearing, as shown for southern Buller's albatross (*Diomedea b. bulleri*; Stahl & Sagar 2000), Cory's shearwater (*Calonectris borealis*; Pereira 2015) and wandering albatross (*Diomedea exulans*; Shaffer *et al*. 2001). Females traveling farther than males during chick rearing can also be seen in the current study, where the majority of females were caught off the northeast coast of the North Island in July.

That more males were caught in offshore bottom longliners and trawlers and more females caught in surface longliners can be explained by sexual segregation of foraging areas. Competitive exclusion by one sex over another has been suggested in other studies using fisheries data (Ryan & Boix-Hinzen 1999) but is not supported by our results given both sexes were caught in all three fisheries. Similarly, Bugoni *et al*. (2010) found no correlation between a skewed adult sex ratio and sexual dimorphism. Gianuca *et al.* (2017) concluded that sex-biased bycatch can better be explained by differences in distribution between the sexes rather than competitive advantage of one sex. Competitive exclusion would not explain the large number of females caught off the northeast coast of the North Island because some males were also caught there. Seabird captures are complex as they are influenced by the species aggregations present when bycatch occurs, as well as individual behaviour such as aggression (Brothers *et al.* 2010, Barbraud *et al.* 2013). Fishing method cannot explain our results because the number of each sex captured was likely a consequence of the type of fishery that is primarily conducted in a specific area. Surface longlining mostly occurs north of the Chatham Rise, which is where the majority of female grey petrels appeared to forage. A small amount of surface longlining has also been conducted off the southeast coast of Stewart Island where more males were caught, suggesting more males in that area than females. Offshore bottom longlining and trawling primarily takes place at or south of the Chatham Rise which appeared to be where the majority of male grey petrels foraged. Females, however, were also caught by offshore bottom longliners and trawlers possibly during travel to and from the breeding site, or while exhibiting both long and short trips (Weimerskirch *et al*. 1993).

It is also possible that males had a different foraging strategy to females, as noted by Bugoni *et al*. (2010). Males may be more prolific divers than females thereby getting caught more frequently by offshore bottom longliners and trawlers. Rollinson *et al*. (2016) did not find any significant difference in diving behaviour between male and female grey petrels breeding at Gough Island; however, the sample size was small (four males, three females) and may therefore not be representative.

Overall, it seems that both sexes were susceptible to all fisheries. Due to sexual segregation of foraging areas, each sex was affected by the primary fishing method conducted in the respective foraging area. This study emphasizes the importance of a large scale approach when analysing impacts of fisheries on seabird species since small areas may not be representative. For a species such as the grey petrel, management decisions in one area may affect one sex but not the other, thereby potentially affecting the gender structure of the population.

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