

# Tracking reveals limited interactions between Campbell Albatross and fisheries during the breeding season

Lisa A. Sztukowski<sup>1</sup> · Mariëlle L. van Toor<sup>2</sup> · Henri Weimerskirch<sup>3</sup> ·  
David R. Thompson<sup>4</sup> · Leigh G. Torres<sup>5</sup> · Paul M. Sagar<sup>6</sup> · Peter A. Cotton<sup>1</sup> ·  
Stephen C. Votier<sup>7</sup>

Received: 11 April 2016 / Revised: 26 November 2016 / Accepted: 13 December 2016  
© Dt. Ornithologen-Gesellschaft e.V. 2017

**Abstract** Fisheries-related mortality has been influential in driving global declines in seabird populations. Understanding the overlap between seabird distribution and fisheries is one important element in assessing bycatch risk, and may be achieved by tracking the movements of individual birds and fishing vessels. Here, we assess the spatiotemporal overlap between the vulnerable Campbell Albatross *Thalassarche impavida* and large (>28 m) commercial fishing boats in New Zealand's Exclusive Economic Zone (EEZ). We used a novel analytical approach, bivariate Gaussian bridge movement modelling, to compute spatiotemporal utilization distributions of bird-

borne global positioning system (GPS) loggers and data from the Vessel Monitoring System. We tracked birds for 28,815 h during incubation and chick brooding, with half of this time spent within New Zealand's EEZ, utilizing 6.7% of the available area. However, there was no evidence that albatrosses and fishing vessels were in the same location simultaneously. We accounted for the broader ecological footprint of fishing vessels by calculating the distance between GPS-fix locations for albatrosses and fishing vessels, revealing that albatrosses were within 30 km of fishing vessels in 8.4% of foraging trips. This highlights differences in estimated fine-scale spatiotemporal overlaps which may be due to the distance between albatrosses and vessels or the methods used. Overall, the low levels of spatial overlap could be a result of Campbell Albatross' preference for foraging in areas without fishing activity or competitive exclusion by other species. Our results reinforce the importance of multi-scale, temporally explicit, and multi-national approaches to risk assessment, as Campbell Albatrosses spend approximately half of their time foraging outside New Zealand's EEZ.

**Electronic supplementary material** The online version of this article (doi:10.1007/s10336-016-1425-4) contains supplementary material, which is available to authorized users.

Communicated by C. Barbraud.

✉ Lisa A. Sztukowski  
lisa.sztukowski@plymouth.ac.uk

- <sup>1</sup> Marine Biology and Ecology Research Centre, Plymouth University, Plymouth PL4 8AA, UK
- <sup>2</sup> Department of Migration and Immuno-Ecology, Max Planck Institute for Ornithology, Radolfzell, Germany
- <sup>3</sup> Centre D'Etudes Biologiques de Chizé, CNRS, Villiers-en-Bois, France
- <sup>4</sup> National Institute of Water and Atmospheric Research Limited (NIWA), Wellington, New Zealand
- <sup>5</sup> Department of Fisheries and Wildlife, Marine Mammal Institute, Oregon State University, Newport, OR, USA
- <sup>6</sup> National Institute of Water and Atmospheric Research Limited (NIWA), Christchurch, New Zealand
- <sup>7</sup> Environment and Sustainability Institute, University of Exeter, Cornwall Campus, Penryn, Cornwall TR10 9EZ, UK

**Keywords** Seabird–fishery interactions · *Thalassarche impavida* · New Zealand Exclusive Economic Zone · Bivariate Gaussian Bridge movement models · Spatiotemporal overlaps · Bycatch

## Zusammenfassung

**Besonderung zeigt limitierte Interaktionen zwischen Campbell Albatrossen und der Fischerei während der Brutzeit**

Die durch Fischfang verursachte Sterblichkeit hat einen entscheidenden Einfluss auf die globalen Rückgänge von

Seevogelpopulationen. Ein wichtiges Element zur Abschätzung des Beifangrisikos ist das Verständnis der Überschneidung von Seevogelverbreitungen und Fischerei. Ein solches Verständnis kann erlangt werden durch die Verfolgung der Bewegungen einzelner Seevogelindividuen und der von Fischereiboote. In der vorliegenden Studie untersuchen wir die räumlich-zeitliche Überschneidung zwischen dem gefährdeten Campbell Albatross *Thalassarche impavida* und großen (> 28 m) kommerziellen Fischereischiffen in der neuseeländischen Ausschließlichen Wirtschaftszone (AWZ) ab. Dazu nutzten wir einen neuen Analyseansatz, „Bivariate Gaussian Bridge Movement“-Modelle, um aus den GPS-Loggerdaten der Vögel und Daten des Schiffsmonitorings die räumlich-zeitliche Nutzungsverteilung zu berechnen. Wir verfolgten besenderte Vögel über 28.815 Stunden während der Inkubations- und Huderphase. Die Hälfte dieser Zeit verbrachten die Vögel in der neuseeländischen AWZ, wobei sie 6,7% der insgesamt verfügbaren Fläche nutzten. Jedoch gab es keine Belege dafür, dass sich Albatrosse und Fischereiboote gleichzeitig im selben Gebiet aufhielten. Wir berücksichtigten auch den breiteren ökologischen Fußabdruck der Fischerei durch die Berechnung der Distanz zwischen den GPS-Punkten der Albatrosse und den Fischereiboote. Es zeigte sich, dass sich die Albatrosse in 8,4% ihrer Nahrungsflüge in einem 30 km Radius um die Fischereiboote aufhielten. Dies zeigt die Unterschiede zwischen den berechneten feinskaligen räumlich-zeitlichen Überschneidungen auf, die wahrscheinlich auf die Distanzen zwischen Albatrossen und Schiffen oder auf die angewendeten Methoden zurückzuführen sind. Die geringe räumliche Überschneidung kann die Folge davon sein, dass die Albatrosse Nahrungsgebiete präferieren, in denen nicht gefischt wird, oder von Konkurrenzausschluss durch andere Arten. Unsere Ergebnisse bekräftigen die Wichtigkeit mehrskaliger, zeitlich expliziter und multinationaler Ansätze der Gefährdungsabschätzung, da Campbell Albatrosse schätzungsweise die Hälfte der Zeit zur Nahrungssuche außerhalb der neuseeländischen AWZ verbringen.

## Introduction

Population declines in seabirds, particularly albatrosses and petrels, have been attributed to fisheries-related mortality from accidental bycatch (Brothers 1991; Nel et al. 2002; Sullivan et al. 2006; Rolland et al. 2010; Anderson et al. 2011). Globally, it is estimated that tens of thousands of seabirds are killed every year—levels of mortality which are unsustainable. However, bycatch estimates vary greatly by location as well as among

species (Lewison and Crowder 2003; Anderson et al. 2011) and within species (Nel et al. 2002; Votier et al. 2010; Tuck et al. 2015).

Conservation efforts to reduce the seabird bycatch have been aided by identifying regions of greatest seabird–fishery overlap. Recently, bird-borne tracking has been used in tandem with spatially explicit fisheries data to better quantify the nature and extent of such overlap (Votier et al. 2010; Granadeiro et al. 2011; Torres et al. 2011; Catry et al. 2013; Torres et al. 2013a; Votier et al. 2013; Bodey et al. 2014; Collet et al. 2015; Patrick et al. 2015). Various scales and analytical methods have been applied to study the movement of seabirds and fishing vessels with contrasting results, in some cases due to the resolution of the data as well as our limited ability to distinguish between interactions and overlap (e.g. Torres et al. 2013a). Thus, combining and contrasting multiple spatial and temporal scales, as well as different methodologies, may provide complementary information necessary to enhance our understanding of the nature of seabird–fishery interactions.

In the present study, we examine the spatial and temporal overlap between fishing vessels and the ‘vulnerable’ (IUCN 2016) Campbell Albatross *Thalassarche impavida*. Following a decline of 72% from 1966 to 1984 (Waugh et al. 1999), the population of this endemic species has been comparatively stable, with some suggestion of a slight decrease in recent years (Sagar 2014). In common with other species of albatross, the steep population decline coincided with increased fishing effort in the Southern Ocean and the development of long-line and trawl fisheries within their foraging range (Waugh et al. 1999; Moore 2004; Sagar 2014). Previously, Campbell Albatross, and the closely related Black-browed Albatross *Thalassarche melanophris*, were regularly killed by trawlers and longliners (Murray et al. 1993; Croxall and Gales 1998; Gales et al. 1998), but the current situation is less well understood. We tracked the movements of individual Campbell Albatross with global positioning system (GPS) loggers and related these to fishing vessel movements to provide an update on the extent to which these species are at risk of bycatch within New Zealand’s Exclusive Economic Zone (EEZ).

We used two approaches to identify potential interactions between fisheries within New Zealand’s EEZ and Campbell Albatross during the breeding season. First, we used a novel method, bivariate Gaussian bridges (BGB), to identify direct spatiotemporal overlap using utilization distributions. Second, we used distance measures to investigate when birds came within a 30-km radius of vessels—the maximum distance at which birds respond to vessels (Bodey et al. 2014; Collet et al. 2015).

BGB movement models (Kranstauber et al. 2014) track movement heterogeneity across time and use two-

directional components, parallel and orthogonal, instead of isotropic diffusive motion. Tracking movement in two directional components is more accurate than Brownian bridge movement models for directed movement or Lévy-like movements that do not adhere to the assumption that movement between consecutive locations is equally likely to happen in all directions (Kranstauber et al. 2014). Moreover, compared to classic approaches like straight-line interpolation or kernel home ranges, BGBs provide more precise estimates of space use, and have the additional advantage of being temporally explicit. BGB inherently incorporates different behaviours affecting the estimate of space use by using a segmentation approach based on the behavioural change point analysis (Gurarie et al. 2009). This results in separate estimates of motion variance for directed and tortuous movement, where the former will result in a narrow corridor, and the latter in a larger area of utilization (see Kranstauber et al. 2012, 2014). Consequently, fast and directed movements of the albatrosses, as would be expected for commuting from the foraging area to the nest, will thus result in smaller areas of space use than tortuous movements that we expect to observe for foraging individuals. If albatrosses and vessels use shared space, commuting behaviour should thus contribute less to the observed overlap than foraging behaviour. While inherent in spatiotemporal utilization distribution estimates, behavioural categories were not used here, as they did not improve our ability to estimate or filter areas of bird-vessel overlap.

By applying BGBs to trajectories of both albatrosses and fisheries vessels, we can estimate the area of the EEZ used by both, as well as where, and how often, albatrosses and fisheries use the same area at multiple temporal scales. These results can be aggregated over time, such as breeding stage or season, which provides estimates similar to population-level or multi-species assessments of overlap between fishing activity and species distribution (e.g. kernel density analysis by Phillips et al. (2006)). Additionally, if BGB-based overlap between albatrosses and vessels occurs at the same time, our technique produces results comparable to the fine-scale tracking data on Black-browed Albatross and fisheries in waters around the Falkland Islands (Granadeiro et al. 2011; Catry et al. 2013).

Second, as recent work has shown that birds may change their behaviour in response to fishing vessels even as far away as 30 km (Bodey et al. 2014; Collet et al. 2015), we investigated events during which albatrosses were in proximity to fishing vessels, and explored differences in overlap as a function of the spatial scale over which fishing vessel occurrence may affect bird behaviour. These seabird-vessel overlaps may indicate potential interactions, as spacing between seabirds and vessels may fluctuate at shorter time periods than were recorded (e.g. <10 min).

This is similar to the results estimated by buffering known locations by distance and/or time (i.e. Votier et al. 2010; Patrick et al. 2015). Whenever we identified such a potential interaction event, we investigated if the frequency of bird-boat interactions was explained by sex, stage of reproduction (incubation and chick brooding), and differed between 2 years. Because albatrosses have shorter foraging trips during chick brooding and therefore spend more time in the EEZ (Sztukowski 2016), we expected that there would be more interactions with fisheries during this stage compared with incubation. Furthermore, because female Campbell Albatrosses tend to use areas that are closer to the New Zealand mainland than males (Sztukowski 2016), we hypothesise that females are more likely to encounter fishing vessels within the EEZ. Therefore, by examining albatross–fishery overlap as a function of variations in distance between birds and boats, we may increase our understanding of the factors, such as breeding stage and sex, that impact interactions at various spatial scales, with concomitant implications for assessing the risk of bycatch.

## Methods

### Albatross tracking

We studied the endemic Campbell Albatross on Campbell Island, New Zealand (52°32'24"S, 169°8'42"E) during two breeding seasons (10 November 2011 to 29 December 2011, and 19 October 2012 to 27 December 2012; hereafter referred to as study years 2011 and 2012, respectively). To record albatross movement, we attached modified GT-600 i-gotU GPS loggers (Mobile Action Technology, New Taipei City, Taiwan) to the central back feathers of incubating and brooding adults using Tesa tape. GPS loggers were modified by removing the external plastic housing, and then sealed with heat-shrink tubing (FiniShrink, UK) to waterproof each unit. The loggers weighed 33 g, approximately 1.1% of albatross body mass, and were set to record location every 10 min. Birds were re-captured on the nest following one or more complete foraging trips, as determined by nest-attendance surveys. During capture, a small aliquot (~0.05 ml) of blood was taken from each individual for molecular sexing (Avian Biotech, Truro, Cornwall) under permit from the New Zealand Department of Conservation.

### Vessel monitoring system

We acquired data on the distribution and movement of fishing vessels via ship-borne GPS transponders provided by the New Zealand Ministry of Fisheries fishing vessel-monitoring system (VMS). Data were obtained for the

same temporal period and spatial extent as the bird tracks (i.e., 10 November 2011 to 29 December 2011 and 19 October 2012 to 27 December 2012). These data covered all fishing vessels >28 m in length operating within the New Zealand EEZ. Additionally, smaller vessels fishing for Orange Roughy (*Hoplostethus atlanticus*) or New Zealand Scampi (*Metanephrops challengeri*) were also tracked. VMS transponders record vessel identification, speed, and location every 1–2 h; gear type was not reported. Catch-effort data for our study period lacked the usual corresponding information needed to combine datasets. Catch-effort data also have low accuracy of event locations with unknown error (Torres et al. 2011), and thus were not used in our analyses. VMS data for areas outside the New Zealand EEZ were not available. Our analyses are therefore restricted to overlaps between albatrosses and VMS-enabled vessels within the New Zealand EEZ, representing 49.7% of the 28,814.9 h during which we logged Campbell Albatrosses on foraging trips.

### Data analysis

We used BGB movement models to calculate the temporally explicit space use of both foraging Campbell Albatrosses and fisheries vessels to examine their encounter probabilities. To prepare the tracking data, we split the VMS data into separate fishing trips with the same format as the albatross data; each fishing vessel trip was defined as a series of GPS fixes that were separated by a maximum of 24 h. To prevent computational issues with birds and fishing vessels crossing the international dateline, we shifted the dateline of the data by 180 ° prior to all analyses. All computations were done using the software R, and BGB were calculated using the R package *move* [version 1.2 (Kranstauber et al. 2012, 2014)].

#### *Coarse-scale spatiotemporal overlap between albatross and fisheries using BGB*

First, we calculated the total area utilized by each individual albatross and vessel to estimate the total spatial overlap during the complete study period. This coarse-scale spatiotemporal index is similar to population-level or multi-species assessments of overlap between fishing activity and species distribution (e.g. Phillips et al. 2006). We calculated the total space use of birds and fishing vessels during each foraging/fishing trip by computing BGBs on each complete trip, assuming a spatial location error of the GPS devices of 18 m for both the albatross data loggers and the VMS units of the vessels (Duncan et al. 2013). From these, we extracted the 95% estimates of total

space use with a spatial resolution of 5 km, and re-projected them to an equal-area projection. We then combined the space-use estimates for all bird foraging trips and fishing vessel trips separately, and calculated the coarse-scale spatial overlap of these population-level space-use estimates.

#### *Fine-scale spatiotemporal overlap between albatross and fisheries using BGB*

Secondly, we investigated whether birds and vessels shared similar areas during the same time period, creating a potential for interactions. To do so, we split the BGB for each albatross and vessel trip into its smallest temporal units: the space use between two consecutive locations (i.e., every 10 min for Albatrosses, every 2 h for vessels). From these we extracted the 95% utilization distributions with a spatial resolution of 1 km<sup>2</sup>. For each potential encounter (utilization distributions with overlapping time intervals), we calculated the spatial overlap of the distribution estimates to estimate the area that was shared in space and time.

#### *Distance between GPS-fix locations for albatross and fishing vessels: sex, stage and year effects*

The assessment of spatiotemporal overlap using BGBs (above) estimates simultaneous space use of foraging albatrosses and fishing vessels. However, fisheries vessels can alter the behaviour of foraging seabirds at greater spatial scales; it has been shown that Northern Gannets (*Morus bassanus*) alter their behaviour as a response to the presence of fishing vessels within a range of up to 11 km (Bodey et al. 2014), and Wandering Albatross (*Diomedea exulans*) up to a distance of 30 km (Collet et al. 2015). To encompass the full effects of fishing vessels on foraging Campbell Albatross, we determined potential interaction events by calculating the distance to fishing vessels that were close in space and time using known locations. This is similar to modelling fishing vessel activity using windows of time and distance employed previously to avoid the assumptions associated with linear interpolation (i.e. Votier et al. 2010) or adding buffers to known locations (Patrick et al. 2015). First, we calculated the rhumb line distance from every GPS-fix of an albatross to every fishing vessel GPS-fix recorded within 2 h (the temporal resolution of VMS tracks). Analyses used the full data set as well as the subset of the data where albatross and fishing vessel were <11 km apart, assuming a conservative effect of the fishing vessel (Bodey et al. 2014), or <30 km apart (Collet et al. 2015).

To investigate the effect of sex and stage of reproduction on the likelihood of observing potential interactions, we modelled the minimum observed distances between albatross and any fishing vessel using linear mixed-effects models. The models included individual birds as a random effect (to control for repeat samples of the same bird) with year, sex and stage of reproduction (incubation and chick brooding) as fixed-level factors. We also fitted the two-way interaction between sex and stage of reproduction, to determine whether any sex-specific effects of fisheries varied as a function of breeding stage.

## Results

Over the two breeding seasons, we collected data from 299 foraging trips made by 81 Campbell Albatrosses (43 males and 38 females). The total area used by albatrosses within the EEZ was 291,128.2 km<sup>2</sup> (6.7% of the EEZ, representing 32.0% of the total area used by birds). The rest of their foraging took place in the Tasman Sea, Australian waters, or in international waters (Fig. 1). For the fishing vessels ( $n = 83$ ), a total of 320,510 VMS fixes were recorded during the same period of time, of which 99.9% were within the EEZ. Subsequent results are thus based upon the EEZ only.

During their foraging trips, the albatrosses used a mean of  $3835.1 \pm 5930.2$  km<sup>2</sup> (mean  $\pm$  SD; 95% home range) and travelled over distances of  $1577.0 \pm 2222.5$  km per trip (great-circle distances, see Supplemental materials). Albatrosses spent 14,316.1 of the 28,814.9 h within the EEZ (49.7%).

### Coarse-scale spatiotemporal overlap between albatross and fisheries using BGB

During the tracking period, we found that Campbell Albatrosses and vessels spatially overlapped across 42,325.60 km<sup>2</sup> within the EEZ when overlaying the full 95% utilization distributions (pooled data). Despite albatrosses using 6.7% of the EEZ, they overlapped with fisheries vessels in just 0.97% of the EEZ, mostly in the south (Fig. 1).

### Fine-scale spatiotemporal overlap between albatross and fisheries using BGB

When calculating whether shared space use by albatrosses and fisheries occurred at the same time, we used the temporally explicit 95% utilization distributions and found no overlap between vessels and birds (Table 1). Overall,

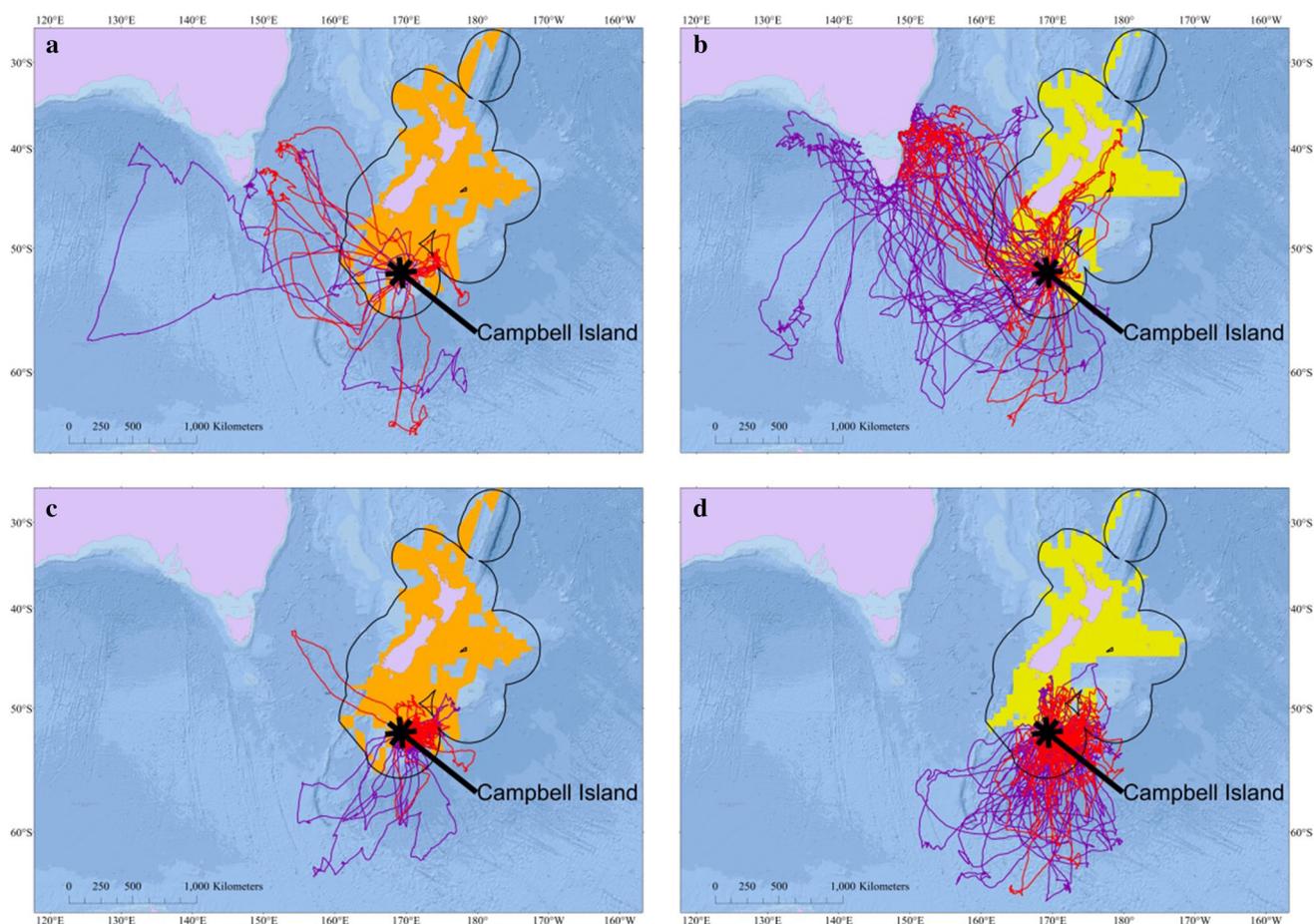
albatrosses used 291,128.2 km<sup>2</sup> within the EEZ, and of this area, 42,325.6 km<sup>2</sup> were also utilized by fishing vessels (Supplemental materials).

### Distance between GPS-fix locations for albatross and fishing vessels: sex, stage and year effects

The minimum distance between GPS-fix locations of albatrosses and fishing vessels on foraging trips was significantly affected by breeding stage and year (Table 1). However, when using all spatial and temporal distances within 11 km and 2 h of at least one vessel, albatrosses only overlapped during 17 of the 299 foraging trips (5.7%; Table 2). These 17 trips were performed by 15 individual birds that were within 11 km and 2 h of a fishing vessel (range 1–8 vessels) at some stage during their foraging trip. Under this analysis, year was marginally significant in the subset of foraging trips as all but one of these foraging trips occurred in 2012. Fisheries overlap was most common during incubation and, while sex had no significant effect, 12 of the 17 foraging trips with fisheries overlap were by males, which may be due to sample size (Table 2). Under the scenario of a vessel footprint of 30 km, albatross foraging behaviour was potentially affected by fishing vessels on 25 foraging trips (8.4%) made by 21 individuals. Eighty percent of those foraging trips occurred during incubation with a sex ratio of 9:16 (female:male). The maximum number of vessels an individual potentially encountered increased from eight within the 11-km footprint to 11 within the 30-km footprint. When testing the larger (30-km) footprint, sex, breeding stage, and year were not significantly associated with the minimum distance between albatrosses and fishing vessels. In most cases, the period of overlap between Campbell Albatrosses and vessels lasted < 10% of the foraging trip within the EEZ (Table 2). However a few individuals spent up to 65% of the foraging trip near vessels.

## Discussion

Here we provide the first estimate of association between fisheries and breeding Campbell Albatross within New Zealand's EEZ. We used a combination of BGBs to study both coarse- and fine-scale associations, and distance between albatrosses and vessel locations based on variation in vessel footprints. Despite Campbell Albatrosses utilizing 6.7% of the New Zealand EEZ, they only overlapped with fishing vessels in a remarkably small section, in the southern portion of the EEZ (0.97% of the area). The extent of spatiotemporal overlap depended not only on the



**Fig. 1** Spatial overlap between fishing vessels [2011 (orange), 2012 (yellow)] and foraging trips within New Zealand's Exclusive Economic Zone (black) during **a** incubation in 2011 ( $n = 18$ ), **b** incubation in 2012 ( $n = 41$ ), **c** chick brooding during 2011

( $n = 79$ ), and **d** chick brooding during 2012 ( $n = 161$ ). Foraging trips were undertaken by females (red) and males (purple). Vessel monitoring data were transformed into a polygon (colour figure online)

**Table 1** The effects of sex, breeding stage, and year on the minimum distance between Campbell Albatross and fishing vessels using linear mixed-effects models

	<i>df</i>	<i>F</i> -value	<i>p</i> -value
Distance between albatross and fishing vessels (full dataset)			
Intercept	17,659	3882.03	
Sex	79	0.16	0.69
Stage	17,659	572.41	<0.0001
Year	17,659	6.57	0.01
Sex × stage	17,659	2.28	0.13
Distance between albatross and fishing vessels (within 2 h and ≤11 km)			
Intercept	21	23.94	
Sex	12	0.38	0.55
Stage	21	0.019	0.92
Year	12	4.73	0.05
Distance between albatross and fishing vessels (within 2 h and ≤30 km)			
Intercept	55	59.39	
Sex	18	1.70	0.21
Stage	55	1.04	0.31
Year	18	0	0.98

Models included individual bird as a random effect (to control for repeat samples of the same bird)

**Table 2** Interaction characteristics of foraging trips within 11 km or 30 km and 2 h of fishing vessel location

Individual	Foraging trip	Sex	Stage	Year	Within 11 km and 2 h			Within 30 km and 2 h		
					Number of vessels	Number of locations	Proportion of trip	Number of vessels	Number of locations	Proportion of trip
1	1	Female	Incubation	2011	0	0	0	1	7	0.00
2	2	Female	Incubation	2012	0	0	0	4	8	0.00
3	3	Female	Incubation	2012	8	103	0.04	11	232	0.09
3	4	Female	Incubation	2012	6	246	0.14	6	506	0.30
3	5	Female	Chick brooding	2012	0	0	0	3	6	0.02
4	6	Female	Incubation	2012	0	0	0	3	32	0.02
4	7	Female	Incubation	2012	1	7	0.01	1	18	0.02
5	8	Female	Incubation	2012	1	3	0.00	7	46	0.03
6	9	Female	Incubation	2012	1	2	0.00	1	30	0.01
7	10	Male	Chick brooding	2011	1	2	0.00	1	11	0.01
8	11	Male	Incubation	2012	0	0	0.00	4	28	0.01
9	12	Male	Incubation	2012	6	962	0.49	7	1274	0.65
10	13	Male	Incubation	2012	1	5	0.01	1	53	0.10
10	14	Male	Chick brooding	2012	2	17	0.05	3	71	0.20
11	15	Male	Incubation	2012	1	11	0.01	1	20	0.01
12	16	Male	Incubation	2012	1	21	0.01	5	50	0.02
13	17	Male	Chick brooding	2012	1	39	0.14	1	65	0.23
14	18	Male	Incubation	2012	1	15	0.01	2	32	0.01
15	19	Male	Incubation	2012	1	53	0.02	3	122	0.04
16	20	Male	Incubation	2012	1	1	0.00	1	12	0.00
17	21	Male	Incubation	2012	0	0	0	2	22	0.01
18	22	Male	Incubation	2012	0	0	0	1	5	0.00
19	23	Male	Chick brooding	2012	0	0	0	1	16	0.04
20	24	Male	Incubation	2012	3	23	0.02	6	107	0.07
21	25	Male	Incubation	2012	1	3	0.00	1	12	0.00

temporal resolution of utilization distribution used, but also the method of analyses. However, regardless of the method employed, we found very limited spatiotemporal overlap suggesting that albatrosses and vessels may occupy the same areas, but seldom at the same time. Such findings are in contrast to similar studies on White-capped Albatross *Thalassarche steadi*, which showed much fisheries overlap in the EEZ during chick guarding (Torres et al. 2011). Our results suggest that during the breeding season the risk of fisheries bycatch for Campbell Albatross is low within the New Zealand EEZ. In addition, they reveal that fishing vessels are not always important as foraging opportunities for albatrosses. Below we discuss the implications of these findings for studying seabird–fishery interactions and for the Campbell Albatross in particular.

### Overlap of Campbell Albatross with fisheries in the New Zealand EEZ and beyond

Spatial area of overlap between albatrosses and vessels within the EEZ varied strongly depending upon the spatiotemporal resolution used, the method employed (see Methodological considerations), and the assumed vessel footprint. Distance between albatrosses and fishing vessels showed variation by sex and breeding stage. When accounting for an 11-km footprint (Bodey et al. 2014), we found overlap in 5.7% of trips, and these overlap periods generally lasted < 10% of the trip within the EEZ. However, a few individuals show substantial spatiotemporal overlap and they may be at a higher risk of mortality. When we expanded this area to 30 km, assuming that Campbell

Albatrosses may behave like Wandering Albatrosses (Collet et al. 2015), we found the potential for interactions increased to 8.4% of foraging trips. We expected females to have a higher risk of fisheries interactions based on time spent in proximity to the New Zealand mainland, where the highest fishing activities occur but, contrary to our expectations, 12 of the 17 foraging trips within 11 km of fisheries vessels were by males. Further investigation is needed to determine if the skewed sex ratio is due to the small number of foraging trips with seabird–fisheries overlap or represent different survival probabilities. It would also be useful to examine behavioural responses to assess if Campbell Albatross are attracted to vessels, avoid them, or co-occur/use the same habitat.

Campbell Albatross is a “high risk” species within New Zealand waters, based upon a semi-quantitative assessment of spatial overlap, observed captures, and fishing effort to assess fisheries vulnerability (Ministry for Primary Industries 2014). Prior to 1998, information on bycatch rates for Campbell Albatross was limited, as they were considered a subspecies of Black-browed Albatross (Robertson and Nunn 1998; Sangster et al. 2013); thus bycatch rates prior to 1998 were often a combination of those of Campbell and Black-browed Albatrosses. From 1989 to 1995, bycatch of Campbell Albatrosses in Australian waters was estimated at 780 year<sup>-1</sup> (Gales et al. 1998), and thus could have had serious impacts on the estimated 24,600 annual breeding pairs in 1995–1998 (Moore 2004; Sagar 2014). Bycatch rates in this longline tuna fishery were higher (up to 1.26 birds per 1000 hooks) in summer than in winter, and skewed toward juveniles. Murray et al. (1993) reported declines in bycatch in New Zealand waters from 3662 seabirds in 1988 to 360 seabirds in 1992, suggesting mitigation measures may have reduced bycatch. Alternatively, individuals that associated with fishing vessels could have been removed from the population, limiting the number of albatrosses around vessels (Tuck et al. 2015). More recently, there were from zero to three observed captures of Campbell Albatross per year from 2004 to 2013 within New Zealand’s EEZ (Abraham and Thompson 2015). Thus current annual estimates of potential fatalities for Campbell Albatrosses within New Zealand waters range from 44 to 356 birds (Ministry for Primary Industries 2014); 0.20–1.69% of the estimated breeding population from 2006 to 2012 (Sagar 2014). Most of the bycatch is associated with surface longline fisheries (Ministry for Primary Industries 2014). Observed captures from trawls were associated with fisheries for Hoki (*Macruronus novaezealandiae*), Arrow Squid (*Nototodarus sloanii*, *Nototodarus gouldi*), New Zealand Scampi and Southern Blue Whiting (*Micromesistius australis*), and occurred outside the incubation and chick-brooding stages (Abraham and Thompson 2012). This is consistent with the diet of Campbell

Albatross as they forage primarily on fish, particularly Southern Blue Whiting, but also consume cephalopods, crustaceans and carrion (Cherel et al. 1999; NIWA 1999). If we assume that there are 21,648 individuals foraging at any one time, then over our study time period, we could expect up to 1803 albatross foraging trips to overlap with fishing vessels within New Zealand’s EEZ (8.4% of trips within a 30-km footprint). Although it is unknown how many interactions with fishing vessels result in mortalities, these low bycatch rates agree well with the low overlap rates and lack of spatiotemporal overlap recorded in our tracking study. During the Austral summers of 2011/2012 and 2012/2013, Campbell Albatross spent about half their time foraging within the EEZ; however, the rest of their foraging took place in areas without available vessel monitoring data, mostly in the Tasman Sea or Australian waters. Thus, by focusing on VMS data within New Zealand’s EEZ we probably underestimate the frequency of overlap between Campbell Albatross and fishing vessels, and our results are limited to the breeding season. Campbell Albatross may be vulnerable to fisheries-related mortality in areas not studied here, and at different ages and breeding stages (Murray et al. 1993; Gales et al. 1998), but our tracking data are consistent with other sources of data indicating that bycatch risk of adult Campbell Albatross within the New Zealand EEZ is low during the breeding season.

There are a number of factors that may impact the nature of interactions between seabirds and fisheries, including the presence and timing of discards, the use of mitigation measures, weather, inter-species competition, and the availability of other resources (Votier et al. 2008; Dietrich et al. 2008; Jiménez et al. 2009; Favero et al. 2011; Croxall et al. 2013). On the Patagonia Shelf, the frequency of Black-browed Albatross–fisheries interactions was associated with wind conditions, season, time of day, and the presence of discards (Favero et al. 2011). Management of discards, such as offal mincing, reducing discharge to sump water, or waste holding/batch discharge, can reduce the abundance of seabirds around fisheries vessels, with concomitant reductions in mortality risk (Abraham et al. 2009; Pierre et al. 2010). Additionally, mitigation measures, such as night setting, weighted lines, and Tori lines, have reduced bycatch rates and may also deter seabird–fisheries interactions (Løkkeborg 2003; Dietrich et al. 2008). Inter-species competition may also reasonably account for the low interaction rates as fisheries within New Zealand’s EEZ frequently kill other albatross species. White-capped Albatross, for example, regularly attend fishing vessels in New Zealand waters and may outcompete Campbell Albatross (Bartle 1991; Torres et al. 2011). However, competition may vary with age or sex. Annual variation in these factors combined with environmental variation could

account for annual influences found in our models; for example, the area utilized during foraging trips was larger during 2012.

### Methodological considerations

Research studying associations between fisheries and seabirds has included a range of methods including hidden Markov models (e.g. Bodey et al. 2014), kernel density analysis (e.g. Bugoni et al. 2009), area-restricted search (e.g. Weimerskirch et al. 2008) and bird borne-cameras (e.g. Votier et al. 2013), as well as knowledge gained through bycatch surveys (e.g. Karpouzi et al. 2007). Here we use BGB and distance between known locations to estimate bird-vessel overlap. BGB temporal resolutions can be applied to multiple temporal scales to produce outcomes similar to convex polygons or kernel density analysis used for population-level or multi-species assessments (e.g. Phillips et al. 2006), and other methods used to estimate fine-scale overlap between seabirds and vessels (Granadeiro et al. 2011; Catry et al. 2013). Whereas estimating distance between known locations is similar to modelling fishing vessel activity using windows of time and distance employed previously to avoid the assumptions associated with linear interpolation (i.e. Votier et al. 2010) or adding buffers to known locations (Patrick et al. 2015).

When focused on fine-scale spatiotemporal overlap in spatial use, our methods provided different results due to either the methods themselves or because of the behaviour of foraging seabirds near fishing vessels. The minimum distance between known locations of albatrosses and vessels suggest that 5.7 or 8.4% of foraging trips are within 11 or 30 km of fishing vessels, respectively. However, no overlap was found using BGB utilization distribution, which accounts for the error associated with GPS locations (18 m). We would expect at least a few of these instances to result in albatross-fisheries overlap unless Campbell Albatross are within the general area of fishing vessels but are not in close proximity to the boats. This is supported in many cases by the very limited number of locations near vessels suggesting albatross investigate (fly by) vessels but do not remain associated with them. If this is the case, interactions with fisheries and the risk of mortality due to entanglement are at a minimum. Alternatively, the mismatch between the results of BGB and distance estimates may be due to uncertainties associated with the minimum distance calculations, as only known locations are used, which occurred at approximately 10-min intervals for albatross and within 2 h for vessels.

Our results indicate that studying seabird-vessel overlap at multiple temporal and spatial scales is important to get better insight into the complete picture. Examining coarse-scale spatiotemporal overlap with fisheries may provide an

overestimate of risk if not accounting for fine-scale temporal components that may be further reduced if the behavioural state of the bird is added. These finer scale analyses of spatiotemporal overlap may both improve risk assessments and provide insight into foraging behaviour (Votier et al. 2010; Granadeiro et al. 2011; Croxall et al. 2013; Torres et al. 2013a, b). While BGBs provide an excellent new tool to examine movements and overlaps between animals and fishing vessels at multiple spatiotemporal scales, they require spatially and temporally explicit data. At higher resolution, these data would also provide an opportunity to examine behaviour from close encounters between birds and vessels, which would help differentiate overlaps and interactions.

### Conservation implications

Our results suggest limited overlap between Campbell Albatross and fisheries in New Zealand waters during the breeding season, implying that bycatch risk in this region is relatively low. This is in contrast to the “high-risk” assessment proposed by the Ministry for Primary Industries (2014). However, the probability of Campbell Albatrosses interacting with fisheries may vary in other areas or with other fisheries in the area (e.g. small vessels) for which we did not have data. The regional focus of our study was constrained due to lack of data, thus reinforcing the need to increase the availability of high-resolution fisheries data. Current estimates suggest that the population of Campbell Albatross is slightly declining or stable (Sagar 2014). If declines continue without an increase in bycatch, other factors such as food availability or environmental change should be carefully assessed. More importantly, conservation and fisheries management for this species needs to be implemented across all age classes and on a multi-national scale, as juvenile Campbell Albatross may be more vulnerable to bycatch, adult albatrosses spend half of their time foraging outside New Zealand waters during the breeding season, and albatrosses use a wider area during non-breeding. The timing and duration of mitigation measures could be improved by incorporating fine-scale spatiotemporal distributions into dynamic ocean management, in which management efforts to reduce bycatch change in response to spatial and temporal alteration in the ocean or species movements rather than protecting largely static marine conservation areas (Howell et al. 2008; Hobday et al. 2010, 2014).

**Acknowledgements** We would like to thank the Campbell Island field crews, boat crews (particularly the RV *Tiama*), and the Department of Conservation personnel, who made the data collection possible. Special thanks to Caitlin Kroeger for field assistance, her company and project discussions. Thanks also to Samantha Patrick, Nils Piechaud, Grant Humphries, Emilie Hall, Holly Armstrong,

Clare Embling, Samantha Cox, and Andy Foggo for geographic information system (GIS) assistance, thoughtful discussions, and comments on drafts. We are grateful to the New Zealand Ministry of Fisheries for providing access to the VMS data. This study was funded through a MARES grant (FPA 2011-0016), the National Institute of Water and Atmospheric Research Limited, the New Zealand Department of Conservation and the New Zealand Ministry of Business, Innovation and Employment. Maps were created using ArcGIS software (Ocean Basemap Sources—Esri, GEBCO, NOAA, National Geographic, De Lorme, HERE, Geonames.org, and other contributors) by Esri. ArcGIS and ArcMap are the intellectual property of Esri and are used herein under license.

### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All scientific procedures and site access were conducted under permit issued by the New Zealand Department of Conservation and were approved by the Animal Ethics Committee at Plymouth University. Great care was taken to minimize stress to the animals during handling.

### References

- Abraham ER, Thompson FN (2012) Captures of birds in trawl fisheries, in the New Zealand Exclusive Economic Zone, during the 2010–11 fishing-year. <http://data.dragonfly.co.nz/psc/v20121101/explore/>. Accessed 15 Apr 2013
- Abraham ER, Thompson FN (2015) Captures of all birds in trawl fisheries, in the New Zealand Exclusive Economic Zone, during the 2013–14 fishing year. <https://data.dragonfly.co.nz/psc/v20150002/birds/trawl/all-vessels/eez/2013-14/>. Accessed 20 Jan 2017
- Abraham ER, Pierre JP, Middleton DA et al (2009) Effectiveness of fish waste management strategies in reducing seabird attendance at a trawl vessel. *Fish Res* 95:210–219
- Anderson O, Small C, Croxall J et al (2011) Global seabird bycatch in longline fisheries. *Endanger Species Res* 14:91–106. doi:10.3354/esr00347
- Bartle JA (1991) Incidental capture of seabirds in the New Zealand subantarctic squid trawl fishery, 1990. *Bird Conserv Int* 1:351–359
- Bodey TW, Jessopp MJ, Votier SC et al (2014) Seabird movement reveals the ecological footprint of fishing vessels. *Curr Biol* 24:R514–R515
- Brothers N (1991) Albatross mortality and associated bait loss in the Japanese longline fishery in the Southern Ocean. *Biol Conserv* 55:255–268
- Bugoni L, D'Alba L, Furness RW (2009) Marine habitat use of wintering Spectacled Petrels *Procellaria conspicillata*, and overlap with longline fishery. *Mar Ecol Prog Ser* 374:273–285
- Catry P, Lemos RT, Brickle P et al (2013) Predicting the distribution of a threatened albatross: the importance of competition, fisheries and annual variability. *Prog Oceanogr* 110:1–10
- Cherel Y, Waugh S, Hanchet S (1999) Albatross predation of juvenile Southern Blue Whiting (*Micromesistius australis*) on the Campbell Plateau. *NZ J Mar Freshw Res* 33:437–441
- Collet J, Patrick SC, Weimerskirch H (2015) Albatrosses redirect flight towards vessels at the limit of their visual range. *Mar Ecol Prog Ser* 526:199–205
- Croxall JP, Gales R (1998) An assessment of the conservation status of albatrosses. In: Robertson G, Gales R (eds) *Albatross biology and conservation*. Surrey Beatty and Sons, Chipping Norton, pp 46–65
- Croxall J, Small C, Sullivan B et al (2013) Appropriate scales and data to manage seabird–fishery interactions: comment on Torres et al. (2013). *Mar Ecol Prog Ser* 493:297–300
- Dietrich KS, Melvin EF, Conquest L (2008) Integrated weight longlines with paired streamer lines—best practice to prevent seabird bycatch in demersal longline fisheries. *Biol Conserv* 141:1793–1805. doi:10.1016/j.biocon.2008.04.023
- Duncan S, Stewart TI, Oliver M et al (2013) Portable global positioning system receivers: static validity and environmental conditions. *Am J Prev Med* 44:e19–e29
- Favero M, Blanco G, García G et al (2011) Seabird mortality associated with ice trawlers in the Patagonian shelf: effect of discards on the occurrence of interactions with fishing gear. *Anim Conserv* 14:131–139. doi:10.1111/j.1469-1795.2010.00405.x
- Gales R, Brothers N, Reid T (1998) Seabird mortality in the Japanese tuna longline fishery around Australia, 1988–1995. *Biol Conserv* 86:37–56
- Granadeiro JP, Phillips RA, Brickle P, Catry P (2011) Albatrosses following fishing vessels: how badly hooked are they on an easy meal? *PLoS One* 6:e17467. doi:10.1371/journal.pone.0017467
- Gurarie E, Andrews RD, Laidre KL (2009) A novel method for identifying behavioural changes in animal movement data. *Ecol Lett* 12:395–408
- Hobday AJ, Hartog JR, Timmiss T, Fielding J (2010) Dynamic spatial zoning to manage Southern Bluefin Tuna (*Thunnus maccoyii*) capture in a multi-species longline fishery. *Fish Oceanogr* 19:243–253
- Hobday AJ, Maxwell SM, Forgie J et al (2014) Dynamic ocean management: integrating scientific and technological capacity with law, policy and management. *Stanf Environ Law J* 33:125–165
- Howell EA, Kobayashi DR, Parker DM et al (2008) TurtleWatch: a tool to aid in the bycatch reduction of Loggerhead Turtles *Caretta caretta* in the Hawaii-based pelagic longline fishery. *Endanger Species Res* 5:267–278
- IUCN (2016) The IUCN Red List of Threatened Species. Version 2016-3
- Jiménez S, Domingo A, Brazeiro A (2009) Seabird bycatch in the Southwest Atlantic: interaction with the Uruguayan pelagic longline fishery. *Polar Biol* 32:187–196
- Karpouzi VS, Watson R, Pauly D (2007) Modelling and mapping resource overlap between seabirds and fisheries on a global scale: a preliminary assessment. *Mar Ecol Prog Ser* 343:87–99
- Kranstauber B, Kays R, LaPoint SD et al (2012) A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. *J Anim Ecol* 81:738–746
- Kranstauber B, Safi K, Bartumeus F (2014) Bivariate Gaussian bridges: directional factorization of diffusion in Brownian bridge models. *Mov Ecol* 2:5
- Lewis RL, Crowder LB (2003) Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecol Appl* 13:743–753
- Løkkeborg S (2003) Review and evaluation of three mitigation measures—bird-scaring line, underwater setting and line shooter—to reduce seabird bycatch in the north Atlantic longline fishery. *Fish Res* 60:11–16
- Ministry for Primary Industries (2014) Aquatic environment and biodiversity annual review 2014. Compiled by the Fisheries Management Science Team. Ministry for Primary Industries, Wellington
- Moore PJ (2004) Abundance and population trends of mollymawks on Campbell Island. Science for Conservation 242, Department of Conservation, Wellington
- Murray TE, Bartle JA, Kalish SR, Taylor PR (1993) Incidental capture of seabirds by Japanese Southern Bluefin Tuna longline

- vessels in New Zealand waters, 1988–1992. *Bird Conserv Int* 3:181–210
- Nel DC, Ryan PG, Watkins BP (2002) Seabird mortality in the Patagonian toothfish longline fishery around the Prince Edward Islands, 1996–2000. *Antarct Sci* 14:151–161. doi:[10.1017/S0954102002000718](https://doi.org/10.1017/S0954102002000718)
- Niwa P (1999) Exploitation of the marine environment by two sympatric Albatrosses in the Pacific Southern Ocean. *Mar Ecol Prog Ser* 117:243–254
- Patrick SC, Bearhop S, Bodey TW, Grecian WJ, Hamer KC, Lee J, Votier SC (2015) Individual seabirds show consistent foraging strategies in response to predictable fisheries discards. *J Avian Biol* 46:431–440
- Phillips RA, Silk JR, Croxall JP, Afanasyev V (2006) Year-round distribution of White-chinned Petrels from South Georgia: relationships with oceanography and fisheries. *Biol Conserv* 129:336–347
- Pierre JP, Abraham ER, Middleton DA et al (2010) Reducing interactions between seabirds and trawl fisheries: responses to foraging patches provided by fish waste batches. *Biol Conserv* 143:2779–2788
- Robertson CJR, Nunn GB (1998) Towards a new taxonomy for albatrosses. *Albatross Biol Conserv Surrey Beatty Sons Chip-ping Nort Aust* 23:13–19
- Rolland V, Weimerskirch H, Barbraud C (2010) Relative influence of fisheries and climate on the demography of four albatross species. *Glob Change Biol* 16:1910–1922. doi:[10.1111/j.1365-2486.2009.02070.x](https://doi.org/10.1111/j.1365-2486.2009.02070.x)
- Sagar PM (2014) Population estimates and trends of Campbell and Grey-headed Albatrosses at Campbell Island. National Institute of Water & Atmospheric Research Ltd, Christchurch, New Zealand. <http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservationservices/reports/pop2012-04-campbell-and-grey-headed-albatross-population-estimates.pdf>
- Sangster G, Collinson JM, Crochet P-A et al (2013) Taxonomic recommendations for Western Palearctic birds: ninth report. *Ibis* 155:898–907
- Sullivan BJ, Reid TA, Bugoni L (2006) Seabird mortality on factory trawlers in the Falkland Islands and beyond. *Biol Conserv* 131:495–504
- Sztukowski LA (2016) Foraging ecology of the Campbell Albatross: individual specialisation and fisheries interactions. Dissertation, Plymouth University
- Torres L, Thompson D, Bearhop S et al (2011) White-capped Albatrosses alter fine-scale foraging behavior patterns when associated with fishing vessels. *Mar Ecol Prog Ser* 428:289–301. doi:[10.3354/meps09068](https://doi.org/10.3354/meps09068)
- Torres LG, Sagar PM, Thompson DR, Phillips RA (2013a) Scaling down the analysis of seabird–fishery interactions. *Mar Ecol Prog Ser* 473:275–289
- Torres LG, Sagar PM, Thompson DR, Phillips RA (2013b) Scale-dependence of seabird–fishery data analysis and management: reply to Croxall et al. (2013). *Mar Ecol Prog Ser* 493:301–304
- Tuck GN, Thomson RB, Barbraud C et al (2015) An integrated assessment model of seabird population dynamics: can individual heterogeneity in susceptibility to fishing explain abundance trends in Crozet Wandering Albatross? *J Appl Ecol* 52:950–959
- Votier SC, Bearhop S, Fyfe R, Furness RW (2008) Temporal and spatial variation in the diet of a marine top predator—links with commercial fisheries. *Mar Ecol Prog Ser* 367:223–232
- Votier SC, Bearhop S, Witt MJ et al (2010) Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. *J Appl Ecol* 47:487–497
- Votier SC, Bicknell A, Cox SL et al (2013) A bird’s eye view of discard reforms: bird-borne cameras reveal seabird/fishery interactions. *PLoS One* 8:e57376
- Waugh SM, Weimerskirch H, Moore PJ, Sagar PM (1999) Population dynamics of Black-browed and Grey-headed Albatrosses *Diomedea melanophrys* and *D. chrysostoma* at Campbell Island, New Zealand, 1942–96. *Ibis* 141:216–225
- Weimerskirch H, Le Corre M, Bost CA et al (2008) Foraging strategy of Masked Boobies from the largest colony in the world: relationship to environmental conditions and fisheries. *Mar Ecol Prog Ser* 362:291–302