Year-round GLS tracking of Northern Buller's Albatross and comparison with Southern Buller's Albatross

Johannes H. Fischer[1]*, Mike Bell[2], Peter Frost[3], Paul M. Sagar[4], David R. Thompson[4], Karen L. Middlemiss[1], Igor Debski[1] & Graeme A. Taylor[1]

[1] Biodiversity Systems and Aquatic Unit, Department of Conservation, Wellington, Aotearoa.
[2] Toroa Consulting Ltd., Chatham Islands, Aotearoa.
[3] Science Support Service, Whanganui, Aotearoa
[4] National Institute of Water and Atmospheric Research, Wellington, Aotearoa.
* Corresponding author: jfischer@doc.govt.nz.

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Executive summary

Fisheries risk assessments for seabird bycatch rely on accurate, year-round, and up-to-date information on seabird distribution. Such information exists for virtually all albatross species that breed in Aotearoa, but not for Northern Buller's Albatross. This data gap may compromise the estimates of bycatch risk for both Northern and Southern Buller's Albatross in Aotearoa fisheries.

We deployed GLS tags on Northern Buller's Albatross on the privately-owned Motuhara (the Forty-fours) during 2021-22 and Southern Buller's Albatross on Tini Heke (The Snares), which ultimately resulted in 69 and 28 year-round datasets, respectively. We used these data to assess each taxon's breeding phenology, generate population-level utilization distributions, quantify spatiotemporal overlap between taxa, and document geopolitical responsibilities for each taxon.

Our results highlighted considerable spatiotemporal segregation between the two taxa. Average breeding phenology of Southern Buller's Albatross was delayed by four months in comparison to Northern Buller's Albatross. During the breeding period, Northern Buller's Albatross core range was centred around the Chatham Rise, whereas the Southern Buller's Albatross core range was centred around the south of te Waipounamu (South Island). The taxa only co-occurred in space and time during July-September off the coast of South America. Despite this spatiotemporal segregation, geopolitical responsibilities for both species were similar. Both species spent most their time in Aotearoa waters, the high seas, Chilean, and Peruvian waters. However, Southern Buller's Albatross also spent considerable amounts of time in Australian waters.

Our analyses of GLS tracking data fills a major knowledge gap and suggests that the generated information on spatiotemporal segregation of Northern and Southern Buller's Albatross should be accounted for in future national and international fisheries risk assessments. In addition, we recommend that the information provided here is used in future integrative taxonomic assessments aimed to resolve the status of both taxa.

Introduction

Albatross (Diomedeidae) are among the most threatened taxa on the planet (Dias *et al.* 2019), with many of the risks these birds face occurring at sea (e.g., bycatch in commercial fisheries). Therefore, Albatross are also among the most comprehensively tracked seabird species (Bernard *et al.* 2021). Virtually every albatross taxon has been tracked, yet a few taxa that breed on remote offshore islands remain understudied and without year-round tracking data: the Senkaku-type Short-tailed Albatross (*Phoebastria albatrus sensu lato*; Eda *et al.* 2020) and the Northern Buller's Albatross (*Thalassarche bulleri platei*). These two taxa are threatened (i.e., currently listed as "Vulnerable" under the IUCN Red List; IUCN 2023) and clearly warrant further study.

Northern Buller's Albatross breed on extremely remote, rugged, and privately-owned islands in the Chatham Island archipelago in Aotearoa (New Zealand): Motuhara (The Forty-fours; ~15,700 breeding pairs) and Rangitatahi (The Sisters; ~3,300 breeding pairs) (ACAP 2023). Due to the remoteness and limited accessibility of these islands, research on Northern Buller' s Albatrosses has been largely restricted to aerial surveys to assess population size (e.g., Baker *et al.* 2017, Frost 2022) or short visits to study vital rates (e.g., Bell *et al.* 2017a,b, Bell 2022, 2023). In contrast, the Southern Buller's Albatross (*T. b. bulleri*) has been subject to an extensive long-term study on its breeding grounds on Tini Heke (The Snares; ~8,700 breeding pairs; ACAP 2023) (e.g., Thompson & Sagar 2020, 2022) and multiple tracking studies across decades, utilising a range of different tracking technologies (e.g., Sagar & Weimerskirch 1996, Stahl & Sagar 2000a, 2006, Goetz *et al.* 2020). Even the less accessible Hautere (Solander Islands) Southern Buller's Albatross colony (~5500 breeding pairs; ACAP 2023) has been studied and tracked (e.g., Stahl & Sagar 2000b, Waugh *et al.* 2017), albeit at a much lower intensity than the Tine Heke colony.

Both Buller's Albatross taxa are highly vulnerable to fisheries bycatch (Abraham *et al.* 2016, Richard *et al.* 2020, Edwards *et al.* 2023a), but to better understand risk, and mitigate bycatch, further insights into the offshore distribution of Northern Buller's Albatross is required. Southern and Northern Buller's Albatross rank as the 1st and 7th most vulnerable seabird taxa to bycatch in Aotearoa, respectively (Edwards *et al.* 2023a). Estimated totals of 165 and 716 and Northern and Southern Buller's Albatross, respectively, are caught in Aotearoa fisheries annually as indicated by the most recent Aotearoa spatially explicit fisheries risk assessment (SEFRA) for seabird bycatch (Edwards *et al.* 2023a; Table 1). A Southern Hemisphere SEFRA estimated that an annual total of 2260 Buller's Albatross ssp. are caught annually in surface longline fisheries throughout their annual range (Abraham *et al.* 2017). However, as these taxa are challenging to differentiate morphologically (i.e., only using the yellow markings on the lower mandible and shape of the upper mandible in adults) and no recent, or year-round tracking data exist for Northern Buller's Albatross, results of SEFRAs are limited to a lower taxonomic resolution (e.g., Abraham *et al.* 2017), or depend on limited assumptions of spatial segregation. The most recent SEFRA attempted to improve bycatch estimates of Northern and Southern Buller's Albatross by using genetic testing of bycaught individuals to create a spatial probability layer Wold *et al.* 2018, Roberts *et al.* 2022, Wold *et al.* 2021). This likely caused the contrasting bycatch estimates between the current (Edwards *et al.* 2023a) and the previous Aotearoa SEFRA (Richard *et al.* 2020) (next to some technical differences between the SEFRAs). While the approach of Roberts *et al.* (2022) is an improvement, clearly to better estimate bycatch risk to both taxa, domestically and internationally, year-round tracking of Northern Buller's Albatross is required.

Table 1. Estimated annual fishing-related mortalities of Northern and Southern Buller's Albatross through various spatially explicit fisheries risk assessments (SEFRAs) in means and 95% CIs.

Species	Area	Trawl	Bottom longline	Surface longline	Set-net	Total	Reference
Northern Buller's Albatross	Aotearoa EEZ	109 (65-178)	22 (9-47)	34 (20-55)	0 (0-1)	165 (94-281)	Edwards *et al.* 2023a
Northern Buller's Albatross	Aotearoa EEZ	148 (91-226)	53 (20-110)	213 (158-275)	0 (0-1)	414 (321-524)	Richard *et al.* 2020
Southern Buller's Albatross	Aotearoa EEZ	512 (389-675)	12 (5-24)	192 138-268)	0 (0-2)	716 (532-969)	Edwards *et al.* 2023
Southern Buller's Albatross	Aotearoa EEZ	368 (245-543)	24 (8-46)	94 (68-125)	1 (0-3)	486 (358-664)	Richard *et al.* 2020
Northern/Southern Buller's Albatross	Southern Hemisphere	-	-	2260 (2040-2480)	-	-	Abraham *et al.* 2017

To address the knowledge gap of Northern Buller's Albatross year-round distribution, assess spatial segregation with Southern Buller's Albatross, and improve the estimation of bycatch to both species, a global location-sensing (GLS) tracking program for the Northern Buller's Albatross was initiated in 2021 (alongside further island-based studies of demographic parameters). Subsequently, the Conservation Services Programme (CSP) of the Department of Conservation (2022) identified the following objectives for project POP2022-05 (Northern Buller's Albatross population monitoring):

1. Describe the at-sea distribution of Northern Buller's Albatross based on GLS tags deployed in 2021 (under CSP POP2021-03).

2. Estimate breeding success from nest monitoring cameras deployed in 2021.

Here, we report on the first objective, while Frost *et al.* (2023) report elsewhere on the second objective. To improve the utility of the spatiotemporal data collected from Norther Buller's Albatross for future bycatch risk assessments, we included the GLS tracking data collected from Southern Buller's Albatross under CSP POP2019-04 during 2020-21 (Thompson & Sagar 2020, 2022) in the analyses presented here.

Methods

GLS tag attachment and retrieval

A total of 55 adult breeding Northern Buller's Albatross were equipped with Intigeo-C330 GLS tags (Migrate Technology, London, UK) on the privately-owned Motuhara (-43.96° S, -175.84° W) in January 2021 (Table 2). Similarly, 50 adult breeding Southern Buller's Albatross were equipped with the Intigeo-C330 GLS tags on Tini Heke (-48.03° S, 166.61° E) in March 2020 (Thompson & Sagar 2020). GLS tags were programmed to record light (in lux) every 5 minutes for Northern Buller's Albatross and every 10 minutes for Southern Buller's Albatross (to extend battery life), as well as saltwater immersion on a constructed scale every 10 minutes, and sea surface temperature (SST; in ° C) when immersed in saltwater for >20 minutes, while saving values every eight hours). Tags were attached to stainless-steel leg bands with UV-proof cable ties for both taxa (Gummer 2013). Two cable ties were used for attachment to Northern Buller's Albatross, whereas only one cable tie was used for attachment to Southern Buller's Albatross. Birds equipped with GLS tags of both taxa were sexed morphometrically, using bill length, minimum bill depth, and tarsus width, while cross-referencing with their partner (e.g., the bird with the longer, deeper bill was considered the male; see Sagar *et al.* 1998, Thompson & Sagar 2020).

Data from GLS tags on Northern Buller's Albatross were downloaded after one year during January 2022 (n = 47; 85%), but the tags physically remained on the birds. Ultimately, tags were retrieved from Northern Buller's Albatross in December 2022 and January 2023 (n = 30; 64%) and from Southern Buller's Albatross in March and April 2022 (n = 31; 62%; Thompson & Sagar 2022). However, not all retrieved tags resulted in year-round tracks. In particular, tags on Southern Buller's Albatross suffered high tag failure rates (55%), most likely due to the use of a single cable tie for attachments, allowing tags to move slightly and wear down against stainless steel leg bands, ultimately causing water ingress and tag failure. In the end, we obtained 44 and 25 year-round datasets from Northern Buller's Albatross covering 2021 and 2022, respectively, whereas we obtained 14 year-round datasets from Southern Buller's Albatross covering 2020 and 2021 (Table 2).

Table 2. Summaries of GLS tag deployments, retrievals, and data sets obtained.

Taxon	Year	n deployed	n retrieved	n year-round datasets obtained	Sex (F; M; U)	Successful breeders (%)
Northern Buller's	2021	55	47 (85%)	44 (94%)	24; 23; 0	68%
Albatross	2022	47	30 (64%)	25 (83%)	15; 11; 0	58%
Southern Buller's	2020	50[1]	31 (62%)[1]	14 (45%)[1]	2; 11; 1[1]	64%
Albatross	2021	50[1]	31 (62%)[1]	14 (45%)[1]	2; 11; 1[1]	57%

[1] Southern Buller's Albatross tags were retrieved in 2022 only, resulting in identical summary statistics.

GLS data processing

To infer year-round locations of both Buller's Albatross taxa from the data collected by GLS tags, the threshold method was applied followed by an iterative step-selection function which was combined with a twilight model, a movement model, and sea-ice, land, and SST masks through the R package *probGLS* (Merkel *et al.* 2016, R Core Team 2023). A threshold of 10 was selected for twilight events and a solar angle window of -7° to -1° was selected for the twilight model (Fischer *et al.* 2021, 2023). We applied movement models for dry periods (mean ± SD = 12 ± 6 m/s, max = 45 m/s (Merkel *et al.* 2016), and wet periods (mean ± SD = 1 ± 1.3 m/s, max = 5 m/s) (Merkel *et al.* 2016, Fischer *et al.* 2023). For the applied SST spatial masks, values recorded by GLS tags were cross-referenced with satellite-recorded values (Reynolds *et al.* 2007), while allowing satellite-derived values to deviate 0.5° C from GLS records (Fischer *et al.* 2021). All parameters provided to *probGLS* were kept the same when inferring locations of either taxon, apart from the boundary box and the flexibility parameter k of the LOESS filter. Specifically, we used a boundary box with a longitudinal range of 140° to -65° and latitudinal range of -65° to 0° for Northern Buller's Albatross whereas we used a longitudinal range of 110° to -65° for Southern Buller's Albatross, allowing for the more westward movements of the latter (Stahl & Sagar 2000, Goetz *et al.* 2022). We used a LOESS filter with k = 4 for Northern Buller's Albatross, whereas we used k = 2 for Southern Buller's Albatross to account for the lower resolution of light records of the latter.

The median geographical tracks were then estimated by generating a cloud of possible locations (1,000 locations per step), selecting the most probable location, and repeating this process for 100 iterations. This approach allowed year-round inference of Northern and Southern Buller's Albatross locations, including during the equinoxes with an error of ~145 km (Merkel *et al.* 2016). The final number of locations used for subsequent analyses were 40,712 locations for Northern Buller's Albatross and 17,592 locations for Southern Buller's Albatross. These data can be accessed via the BirdLife International Seabird Tracking Database (www.seabirdtracking.org/; IDs: 2057 for the Northern Buller's Albatross dataset and 2058 for the Southern Buller's Albatross data set).

Data analysis

Data analyses were conducted in three successive steps. First, each track was temporally dissected according to its migration phenology (departure from breeding range, arrival at non-breeding period, departure from non-breeding period, arrival at breeding period). Departures and arrivals were identified by assessing the commencement and end of distinct east-west (or vice versa) movements across the Pacific (Rexer-Huber *et al.* 2021). Then, temporal cut-offs were used to identify breeding success from tracks. Based on expert opinion (MB, PF, PS & GT) and published information (Sagar & Warham 1998, Frost *et al.* 2023), if a Northern Buller's Albatross was still within its breeding range by the 1st of May, it was considered a successful breeder and if a Southern Buller's Albatross was still within its breeding range by the 1st of August it was considered a successful breeder (Table 2).

Secondly, to quantify year-round Northern and Southern Buller's Albatross distributions, kernel utilization distributions (UDs) were produced at the population-level per taxa per relevant time period (i.e., breeding vs. non-breeding period, year, and annual quarter), overlap among which was then calculated using Bhattacharyya's affinity (BA). Specifically, to calculate individual-level 50% UDs (UD_{50}; core area) and the 95% UDs (UD_{95}; full range), locations were projected on a 50 km grid using a Lambert azimuthal equal area projection and a 145 km kernel smoothing factor (*h*), based on the GLS error (Merkel *et al.* 2016, Fischer *et al.* 2021) within the R package *adehabitatHR* (Calenge 2006). To subsequently create population-level UDs, individual UDs were merged while accounting for unequal number of locations among individuals (Clay *et al.* 2017). Spatial overlap was then calculated using conditional BAs (BA = 0 suggests no overlap, BA = 1 suggests complete overlap for an overall UD, but for UD_{95} BA = 0.95 suggests complete overlap, and for UD_{50}, BA = 0.5 suggests complete overlap; Fieberg & Kochanny 2005). BAs were calculated for 1) breeding and non-breeding UDs between taxa to quantify spatial segregation between Northern and Southern Buller's Albatross, 2) between annual breeding and non-breeding population level UDs per taxon to quantify interannual variation, and 3) among breeding and non-breeding UDs among individuals per taxon to quantify individual level variation.

Thirdly, to explicitly examine geopolitical responsibilities for Northern and Southern Buller's Albatross, the jurisdiction (i.e., range state or high seas) per location per year-round track of was identified following Beal *et al.* (2021). Based on the assumption that light-level location inference generally produced two estimated locations per day (i.e., one every ~12 hours; Merkel *et al.* 2016), the percentage of time within each jurisdiction was calculated on an individual and annual level, which allowed subsequent taxon-level summaries. Additionally, SEFRA (Richard *et al*, 2020) can be further improved by incorporating population-level intra-annual variation in the use of space within the jurisdiction under investigation (in this case, the Aotearoa EEZ). Therefore, the percentage of time spent within the EEZ per month per individual was also calculated, which was then also summarised (calculation of means and 95% CIs) to taxon-level.

Results

In general, and as expected based on previous studies, both taxa utilized the western and central Pacific waters around Aotearoa during the breeding period (Fig. 1), after which both taxa rapidly migrated across the Pacific and spent their non-breeding periods off the west coast of South America. While their annual cycles seemed superficially similar, closer inspection of temporal (i.e., migration phenology) and spatial (i.e., distribution) revealed differences between taxa with consequences for geopolitical responsibilities.

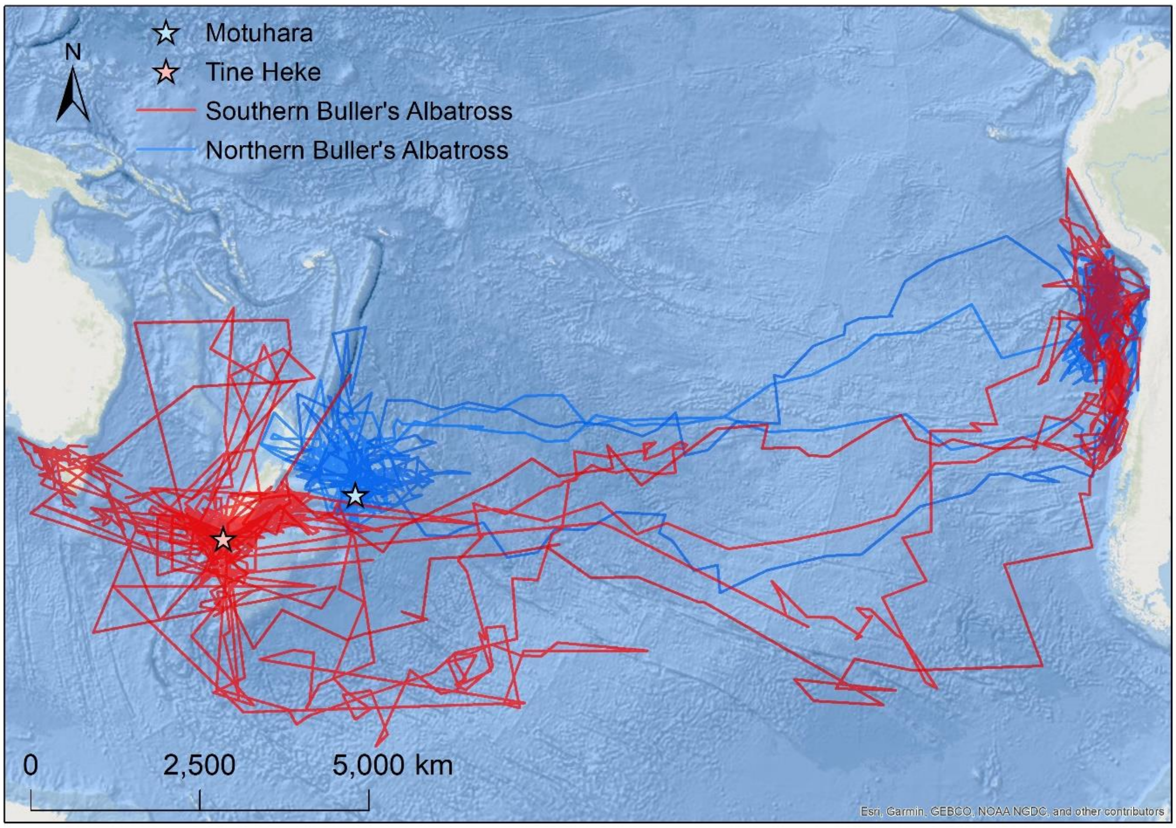

Fig. 1. Examples of Northern (n = 2) and Southern Buller's Albatross (n = 2) annual movements as inferred from GLS tags.

Migration phenology

The annual cycle between the two taxa differed considerably on temporal scale (Fig. 2). On average, Northern Buller's Albatross departed Motuhara on 11 May, arrived at their South American non-breeding range on 28 May, after completing their trans-Pacific migrations in 17 days, departed their non-breeding range on 3 October and arrived back at their breeding range on 20 October, after completing their return migrations in 17 days. On average, Southern Buller's Albatross departed Tini Heke on 30 July, arrived at their South American non-breeding range on 11 Aug, after completing their trans-Pacific migrations in 12 days, departed their non-breeding range on 24 December and arrived back at their breeding range on 14 Jan, after completing their return migrations in 21 days. In both taxa, breeding success had a pervasive influence on migration phenology, with limited interannual variation, potentially as a result of small sample sizes (Table 3).

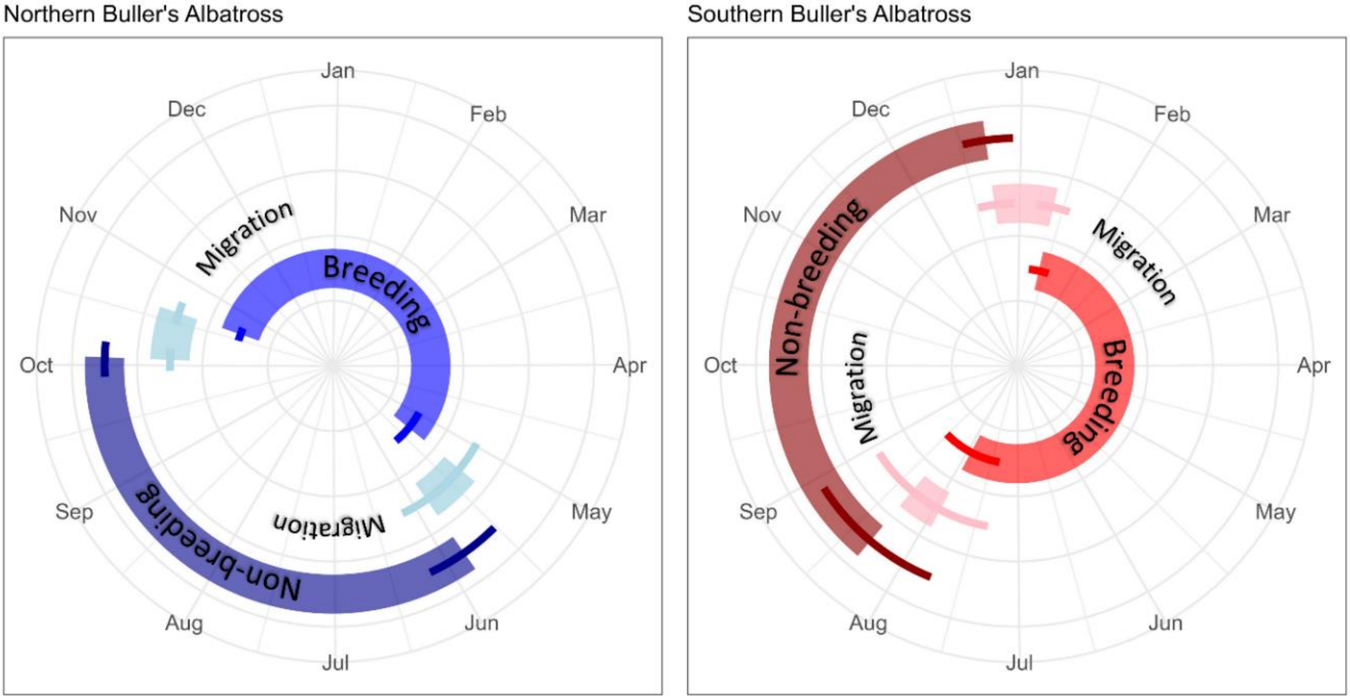

Fig. 2. Summarised annual cycles of Northern and Southern Buller's Albatrosses. Start and end points of bars represent means, error bars represent 95% CIs.

Table 3. Summaries of Buller's Albatross migration phenology as illustrated through means. B = breeding range, NB = non-breeding range, Mig_1 = outbound migration, Mig_2 = homebound migration.

Taxon	Year	Breeding success	Dep. B	Arr. NB	Duration Mig_1 (days)	Dep. NB	Arr. B	Duration Mig_2 (days)
Northern Buller's Albatross	2021	✗	22 Mar	11 Apr	20	16 Sep	6 Oct	15
	2022	✗	08 Mar	26 Mar	18	9 Sep	25 Sep	16
	2021	✓	11 Jun	26 Jun	14	13 Oct	28 Oct	15
	2022	✓	13 Jun	27 Jun	15	18 Oct	5 Nov	18
Southern Buller's Albatross	2020	✗	5 Jun	17 Jun	12	3 Dec	26 Dec	23
	2021	✗	5 Jun	20 Jun	15	12 Dec	4 Jan	23
	2020	✓	12 Sep	24 Sep	12	7 Jan	25 Jan	18
	2021	✓	27 Aug	6 Sep	10	30 Dec	21 Jan	22

Year-round distribution

The breeding distribution of the tracked Northern Buller's Albatross was centred around the Chatham Islands and east of Aotearoa (Fig. 3A). The breeding distribution of the tracked Southern Buller's Albatross was centred around Tini Heke and Southern Aotearoa (Fiordland, Murihiku, and Otago in particular) but extended widely to the north (towards Norfolk Island and New Caledonia), west (encompassing Lutruwita | Tasmania), and south (reaching Polar waters). Spatial segregation during the breeding period between the two taxa was pronounced (BA UD_{50} = 0.00, BA UD_{95} = 0.07) and only a limited area of overlap around the Cooks Strait, the east coast of te Ika-a-Māui (North Island), and the Chatham Rise was evident. Inter-annual variation in the breeding distribution was absent in both taxa (Northern Buller's Albatross BA UD_{50} = 0.48, BA UD_{95} = 0.94, Southern Buller's Albatross BA UD_{50}

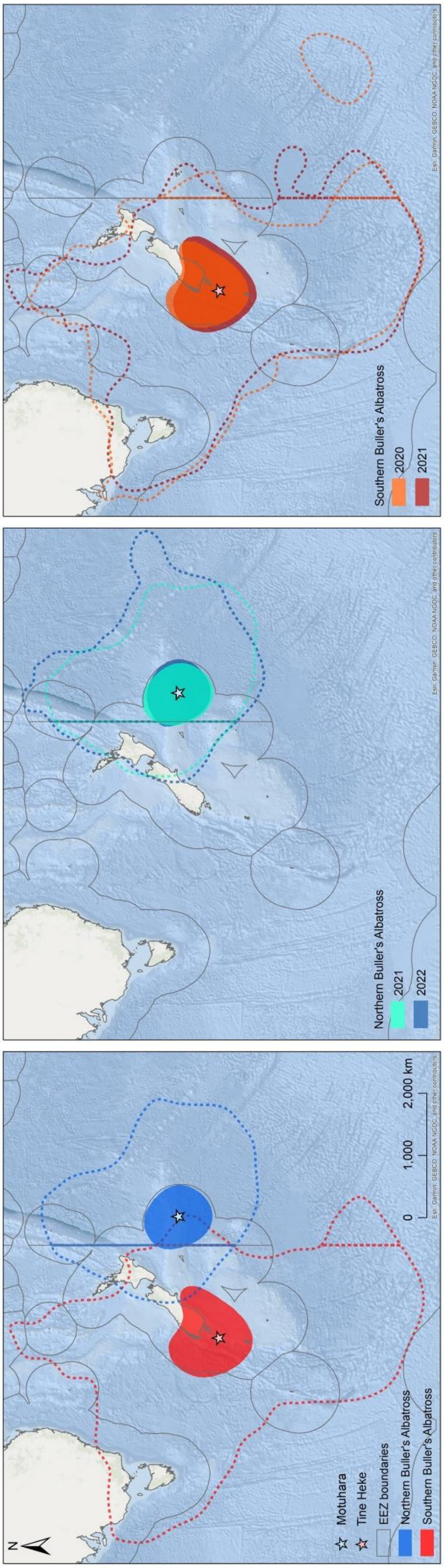

Fig. 3. Breeding distribution of Northern and Southern Buller's Albatross (A) and interannual variation therein for each taxon (BC) as represented D$_{50}$ and UD_{95}.

= 0.47, BA UD_{95} = 0.92; Fig. 3BC) and inter-individual variation was limited (Northern Buller's Albatross BA UD_{50} = 0.33, BA UD_{95} = 0.78, Southern Buller's Albatross BA UD_{50} = 0.34, BA UD_{95} = 0.74).

The non-breeding distribution of the tracked Northern Buller's Albatross was centred around the international waters off northern Chile and Southern Peru (UD_{50}) but extended from central Chile to northern Peru and encompassed the domestic waters as well (UD_{95}; Fig. 4A). The non-breeding distribution of the tracked Southern Buller's Albatross was centred more around both international and domestic waters off central and northern Chile (UD_{50}), but similarly, extended up to northern Peru (UD_{95}). Spatial segregation during the non-breeding period between the two taxa was limited (BA UD_{50} = 0.27, BA UD_{95} = 0.86). Inter-annual variation in the non-breeding distribution was absent in Northern Buller's Albatross (BA UD_{50} = 0.41, BA UD_{95} = 0.90; Fig 4B) and limited in Southern Buller's Albatross (BA UD_{50} = 0.31, BA UD_{95} = 0.89; Fig. 4C). Inter-individual variation in the non-breeding distribution was limited in Northern Buller's Albatross (BA UD_{50} = 0.23, BA UD_{95} = 0.70) but potentially evident in Southern Buller's Albatross (BA UD_{50} = 0.15, BA UD_{95} = 0.58). However, the latter may be driven by the smaller sample size.

Segregation between the two taxa, however, was best assessed through a more fine-scale spatiotemporal approach (Fig. 5). Northern and Southern Buller's Albatrosses clearly segregated across space and time, particularly in their core area of use (UD_{50}). The species used slightly different migration corridors as well, with Northern Buller's Albatross migrating further to north compared to Southern Buller's Albatross (both on out- and homebound migrations). Only during the third annual quarter (July-September), was there some evidence for limited overlap between the two taxa in their non-breeding distribution off South America (Table 4).

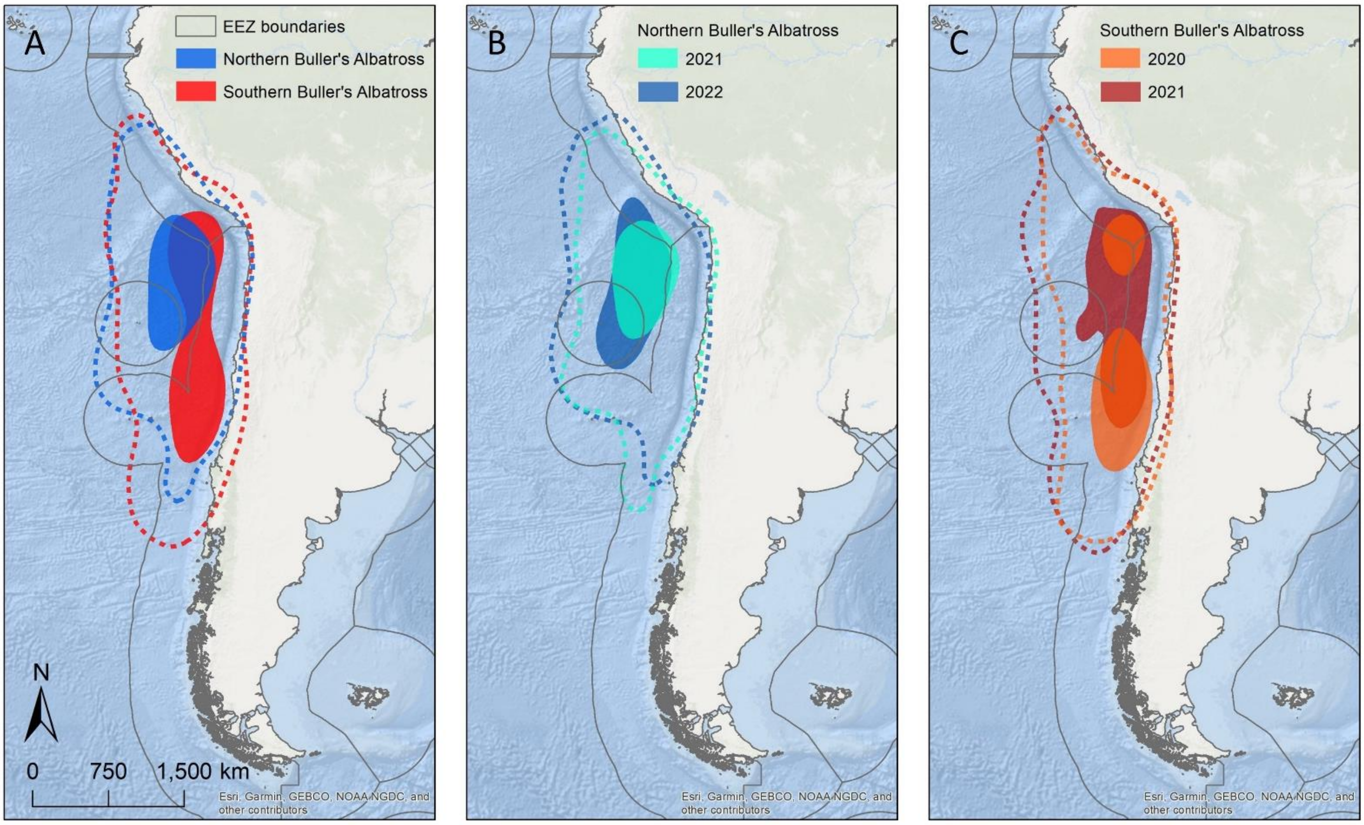

Fig. 4. Non-breeding distribution of Northern and Southern Buller's Albatross (A) and interannual variation therein for each taxon (BC) as represented by UD_{50} and UD_{95}.

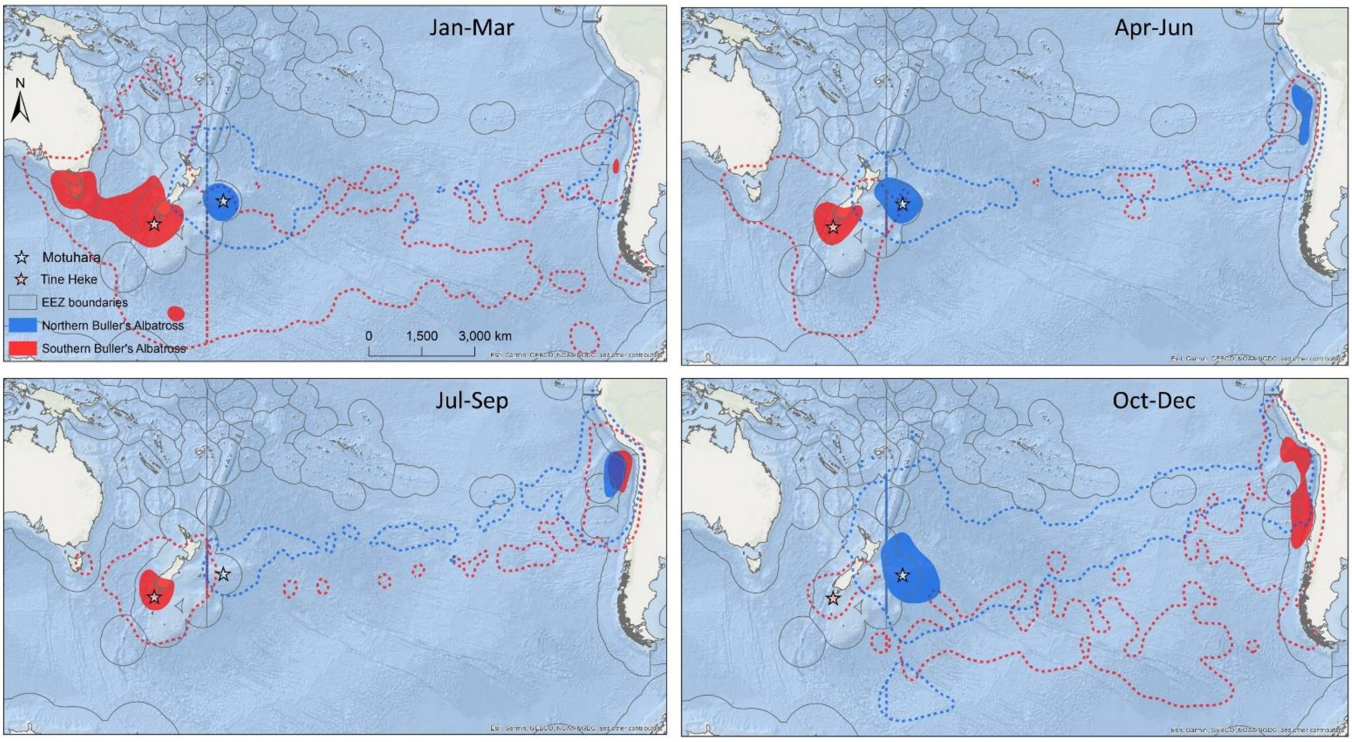

Fig. 5. Distribution of Northern and Southern Buller's Albatross per annual quarter as represented by UD_{50} and UD_{95}.

Table 4. Bhattacharyya's affinity (BA) representing Northern and Southern Buller's Albatross overlap of respective core areas (UD_{50}) and full ranges (UD_{95}) per annual quarter. BA = 0 suggests complete segregation, BA UD_{50} = 0.50 or BA UD_{95} = 0.95 suggests complete overlap (Fieberg & Kochanny 2005).

Annual quarter	BA UD_{50}	BA UD_{95}
January-March	0.00	0.13
April-June	0.00	0.20
July-September	0.26	0.64
October-December	0.00	0.25

Geopolitical responsibilities

Northern Buller's Albatross were recorded in 16 different EEZs and the high seas, whereas Southern Buller's Albatross were recorded in 14 different EEZs and the high seas. Northern and Southern Buller's Albatross spent only 40% and 38% of their annual cycle, respectively, within the jurisdiction of Aotearoa (Fig. 6A). Northern Buller's Albatross spent substantial portions of their annual cycle in the high seas (40%), followed by Chilean (16%) and Peruvian waters (4%). Southern Buller's Albatross spent also spent considerable amounts if time in the high seas (29%), as well as Chilean (21%), Australian (6%), and Peruvian waters (6%).

At closer examinations, Northern Buller's Albatross, on average, spent most of their time within the Aotearoa EEZ during Jan-Mar (71-79%) and were virtually absent from the EEZ during Jul -Sep (0-3%). Southern Buller's Albatross spent, on average, most of their time within the Aotearoa EEZ during Apr-Jun (62-82%) and were virtually entirely absent from the EEZ during Oct -Dec (0-2%) (Fig. 6B & Table 5).

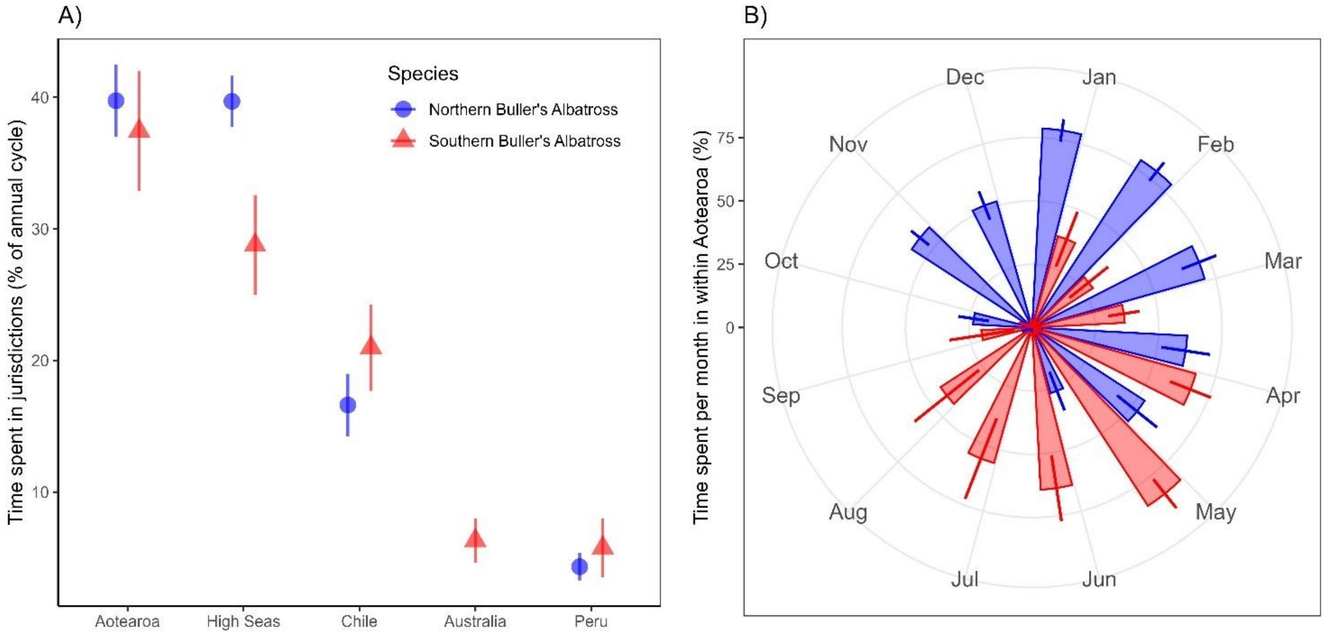

Fig. 6. Percentage (%) of time spent in EEZs and high seas of the annual cycle (A) and percentage of time spent within the Aotearoa EEZ at a monthly resolution (B) of Northern and Southern Buller's Albatross. Only jurisdictions in which birds spent >1% of their annual cycle are shown in panel A. Data are presented as means with 95% CIs.

Table 5. Percentage (%) of time spent within the Aotearoa EEZ in a monthly format, suitable for a future SEFRA (e.g., Richard *et al.* 2020). Data are presented as means (95% CIs).

Taxon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northern Buller's Albatross	79 (74-83)	79 (74-84)	71 (63-78)	61 (52-71)	53 (43-63)	27 (19-35)	1 (0-2)	0 (0-0)	3 (1-4)	23 (17-30)	57 (52-61)	52 (46-58)
Southern Buller's Albatross	37 (26-49)	29 (19-38)	37 (30-43)	67 (58-76)	84 (77-91)	64 (51-77)	56 (38-73)	43 (27-59)	20 (7-33)	2 (0-6)	0 (0-0)	2 (0-4)

Discussion

We here present the first year-round tracking of Northern Buller's Albatross, one of the least studied albatross taxa globally. As such, our study fills a major knowledge gap. Our comparison with concurrent tracking with its siter taxon, the Southern Buller's Albatross, highlighted the considerable spatiotemporal segregation between the two taxa. Specifically, the breeding phenology of Southern Buller's Albatross is delayed by approx. four months in comparison to Northern Buller's Albatross. Furthermore, during the breeding period, both species are spatially segregated, in addition to the temporal segregation. Northern Buller's Albatross core range was centred around the Chatham Rise, whereas the Southern Buller's Albatross core range was centred around the south of te Waipounamu (South Island). The only time when both taxa co-occurred in space and time was during July-September off the coast of South America.

The spatiotemporal segregation between Northern and Southern Buller's Albatross identified by our tracking study further supports the taxonomic distinction between the two taxa. Recent genetic and genomic studies (Wold *et al.* 2018, 2021) highlighted limited geneflow and some genetic differentiation between the two taxa. While these studies have provided crucial insights and present opportunities for genetic identification of bycaught individuals, no targeted studies have not yet been conducted to resolve the taxonomic status of these two taxa to date. In Aotearoa, the two taxa are treated separately in various key conservation projects such as SEFRA (Richard *et al.* 2020) and the New Zealand Threat Classification System (Robertson *et al.* 2021). However, this approach is not mirrored globally and several key conservation entities, such as IUCN (IUCN 2023) and ACAP (ACAP 2023), treat the two taxa as one in their assessments, which could have considerable consequences for the conservation for each taxon. Consequently, we recommend that an integrative taxonomic approach is used, combining genomic, phenotypic, and morphometric data with the phenological, and spatial data presented here, to holistically assess if Northern and Southern Buller's Albatross should be considered two separate species or "just" subspecies (e.g., Rodriguez *et al.* 2020, Obiol *et al.* 2023).

More importantly, however, our findings highlight the need for incorporating accurate and up-to-date spatiotemporal information at the appropriate taxonomic resolution in fisheries risk assessments, especially if those assessments are spatially explicit (e.g., SEFRA; Richard *et al.* 2020, Edwards *et al.* 2023a). We here provide the information necessary to update the spatial input layers for the next Aotearoa SEFRA. The current SEFRA inputs used a spatial probability surface across the Aotearoa EEZ to estimate the probability of a bycaught Buller's Albatross ssp. being a Northern or Southern Buller's Albatross based on genetic identifications (Roberts *et al.* 2022, Edwards *et al.* 2023a,b). The spatial probability surface developed by Roberts *et al.* (2022) is largely confirmed by our tracking efforts here. However, our results also highlight that Buller's Albatross ssp. caught off the

East Cape, in the Bay of Plenty, and off the North Cape are more likely to be Northern rather than Southern Buller's Albatross, which misaligns with the current spatial probability surface (Roberts *et al.* 2022, Edwards *et al.* 2023a,b). As such we recommend updating the current SEFRA using the data presented here to generate more accurate risk and bycatch estimates for both taxa. Additionally, as the Southern Buller's Albatross GLS deployment suffered from high failure rates, most likely due to GLS tags being attached with only one cable tie, we recommend a repeat deployment of GLS tags on Southern Buller's Albatross to generate further spatial information on this high risk taxon. Critically, this report also highlights that GLS tags should always attached using two cable ties to avoid tag loss. Additional to the data generated here for domestic bycatch risk assessment, we present information on geopolitical responsibilities across the Pacific for both taxa and we recommend further international collaboration to reduce bycatch of both taxa beyond the Aotearoa jurisdiction (Beal *et al.* 2021).

Further steps to improve insights relevant to bycatch risk estimates include high-resolution GPS/PTT tracking of both taxa to overlay high-resolution locations acquired with fishing effort layers to better assess risk (e.g., see Bose & Debski 2020, 2021) and the use of TDRs tags to understand vertical risk profiles of both taxa, as unexpected deep diving (~19 m) has been recorded in other *Thalassarche* albatrosses (Guilford *et al.* 2022). Key to understanding population level impacts of bycatch is the crucial demographic data provided by long-term studies and as such, we recommend continuation of the current long-term study on Tini Heke (Thompson & Sagar 2020, 2022) and we encourage further efforts to set up a similar long-term study on Motuhara (Bell *et al.* 2017a,b, Bell 2022). Arguably, more important than further fine scale understanding of bycatch impacts is the implementation of appropriate mitigation as per ACAP best practice advice (ACAP 2021a,b,c) and this should receive further attention domestically and internationally.

Recommendations

- Use an integrative taxonomic approach to resolve the taxonomic status of Northern and Southern Buller's Albatross.
- Update the seabird SEFRA using the spatiotemporal data presented here and reassess risk status and bycatch estimates of both taxa.
- Repeat Southern Buller's Albatross GLS tracking to increase the sample size given the high tag failure rate in this study.
- Always use two cable ties to attach GLS tags to metal bands to prevent tag wear and failure.
- Repeat tracking efforts with high-resolution GPS/PTT tags for both taxa and overlay tracking data with fishing effort to quantify risk at high spatiotemporal scales.
- Use TDRs to investigate vertical risk profiles for both taxa (see Guilfort *et al.* 2022).
- Continue long-term monitoring on of Southern Buller's Albatross on Tine Heke and further consolidate monitoring efforts of Northern Buller's Albatross on Motuhara.
- Implement best practice mitigation measures to reduce seabird bycatch domestically and internationally.

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