Antipodean albatross spatial distribution and fisheries overlap 2020

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Abstract

Bycatch in fisheries has been identified as the greatest known threat to the endangered Antipodean albatross (*Diomedea antipodensis antipodensis*), which is declining at 5% per year. Tracking birds to quantify overlap with fishing activity posing bycatch risk and identifying relevant fleets is a key conservation management task for the recovery of this population. We report on the second year of intensive satellite tracking, with 40 tags deployed on adult females and males during 2020, supplementing 63 tracked birds in 2019 (consisting of adult males, adult females, and juveniles). For each bird location obtained, we estimated the daily overlap with fishing effort, using individual vessel data derived by Global Fishing Watch from vessel monitoring systems. We made refinements to methods used to report on the 2019 tracking, including the use of updated fishing effort data sets and improved bird location filtering. Tag longevity was more consistent in 2020, providing information over the entire austral winter when most overlap with fishing activity occurs. These methods allowed us to quantify the overlap by geographic or jurisdictional area, year, season, and fishing fleet.

Over both years, overlap with fishing activity was highest for pelagic longline fishing effort, primarily in the high seas of the Western Pacific, particularly in the mid-Tasman Sea and north-east of New Zealand. Adult females had higher overlap with pelagic longline fishing effort compared to males, which corresponded to recent research showing a higher relative reduction in female survival as an important driver of the Antipodean albatross population decline. Overlap by flag-state fleet showed that the same key fleets overlapped Antipodean albatross in both years. Some individual vessels overlapped with as many as one third of tracked Antipodean albatross in either year. In 2020, foraging ranges of birds extended further north than in 2019, with birds travelling up to 21°S, where there are no mandatory requirements for seabird bycatch mitigation use by relevant Regional Fisheries Management Organisations. Individual birds may overlap with as many as 88 different pelagic longline fishing vessels per year, increasing their potential exposure to bycatch risk. A range of effective and proven seabird bycatch mitigation options are readily available, and we identified the ports used by vessels that overlapped with tracked birds to facilitate bycatch reduction outreach efforts to these vessels.

Further tracking of Antipodean albatross in 2021 and beyond will provide for an expanded dataset to further improve our understanding of interannual variation and provide greater certainty on the range of fisheries that may pose potential bycatch risk to this endangered seabird.

Introduction

Antipodean albatross (*Diomedea antipodensis antipodensis*) is classified as 'Nationally Critical' under the New Zealand Threat Classification System (Robertson et al 2017), and the Antipodes Island population is recognised as a population of priority conservation concern by the Agreement on the Conservation of Albatrosses and Petrels (ACAP). At the species level (*D. antipodensis*), it is listed as 'Endangered' on the IUCN Red List (Birdlife 2018). Antipodean albatross is essentially a breeding endemic to Antipodes Island in the New Zealand subantarctic region, but its pelagic range extends across the South Pacific, from Australia to Chile. The Antipodean albatross population is declining at 5% per year. Their current population is estimated at around 3200 breeding pairs, and under the current projected decline only about 400 pairs may remain in 2050 (Richard 2021). Antipodes Island is fully protected and free of any potential introduced predators or pests. Bycatch in fisheries, particularly in those outside New Zealand's jurisdiction, has been identified as one of the largest known threats to Antipodean albatross. At the species level, Antipodean albatross (*D. antipodensis*) was listed on Appendix 1 of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) in February 2020. The Concerted Action plan adopted by CMS (https://www.cms.int/en/document/proposal-concerted-action-antipodean-albatross-diomedea-antipodensis) focuses on the reduction of fisheries bycatch, supported by research including the deployment of tracking devices to better describe areas of fisheries overlap (Action 3.2). This report provides updated results against this action.

Objectives

The objective of this work was to use the second year (2020) of intensive satellite tracking of Antipodean albatross to describe areas of fisheries overlap. Specifically, we aimed to:

1. Quantify the overlap of Antipodean albatrosses with fishing activity.
2. Quantify overlap by age class, sex, and breeding state.
3. Identify and quantify overlap per fishing fleet that overlap with Antipodean albatross.
4. Identify ports most frequently used by vessels that overlapped with Antipodean albatross distribution.

Our analyses did not attempt to extrapolate a distribution for the entire population of Antipodean albatross (c.f. Carneiro et al 2020, Abraham et al 2019), which would provide a comprehensive and broadscale assessment of overlap with fishing effort. Instead, we aimed to summarize fine-scale individual bird-vessel overlap of tracked birds over the course of tag deployment (targeted at one year per deployment). Despite this limitation, using the overlap of fishing effort with individual birds as a proxy for potential bycatch risk at the population level, the findings can be used to target seabird bycatch reduction outreach to relevant fleets or vessels, and to identify which ports could be used to provide such outreach to vessels of interest. We built on the methods described by Bose & Debski (2020) to analyse the 2019 data, making a number of refinements to the analytical methods. We also applied the updated analyses to the 2019 dataset and provide updated summary results for the 2019 tracking year. The intensive tracking of Antipodean albatross is envisaged to continue as part of a multi-year research programme. Applying our methods to the growing dataset over time will further enhance the representativeness of the results to the entire population and better describe inter-annual variation.

Methods

We used a point-based method to assess overlap between satellite tracked seabirds and fishing effort data available from Global Fishing Watch (GFW; https://globalfishingwatch.org/). Data was sourced and analysed for both the focal year (2020) and to update the previous year of this study (2019) to provide meaningful comparisons between years. The first step of the analysis was to map fishing effort data at a 100 km x 100 km grid resolution and to produce maps of relative overlap at the same spatial scale. This allowed rapid identification of key areas of overlap with different fishing methods. We then used location and fishing activity data of individual vessels for our fine-scale analysis of overlap with pelagic longline fisheries to quantitatively describe overlap by area and vessel variable (e.g., fishing method, flag state, fishing company).

We present results by jurisdiction per Exclusive Economic Zone (EEZ) and non-EEZ portions of the two key Regional Fisheries Management Organisations (RFMOs): Western and Central Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna Commission (IATTC). We report results for the area of overlap between WCPFC and IAATC, as within IATTC only, to avoid double reporting. Because much of the overlap was in the non-EEZ part of WCPFC, we also provide results for the western and eastern parts of WCPFC separately. We separated the areas by 180° longitude, which approximates areas west or east of the New Zealand EEZ. Boundaries of EEZ and RFMO sectors are included on all map figures.

Fishing effort data

Daily fishing effort data was obtained from GFW in two resolutions. The first dataset included fishing effort and vessel presence by flag state and gear type at 100th degree resolution. This gridded dataset was used for mapping annual fishing effort and overlap with relevant fishing methods (pelagic longline, trawl, demersal longline and jig) at a 100 km x 100 km scale. The second dataset included fishing effort and vessel presence data by individual vessel Maritime Mobile Service Identity (MMSI) at 10th degree resolution. This dataset was used for quantifying overlap of Antipodean albatross with pelagic longline fishing effort in the South Pacific. MMSI information allowed us to estimate the number of vessels birds overlapped with and quantify overlap per flag state of the vessel. Data was also obtained from GFW on vessel port visits by MMSI. This allowed for identification of key ports for vessels fishing in the South Pacific.

GFW was chosen as our source of fisheries data because of its temporal match with the tracking data, its comprehensive nature, and its high temporal and spatial resolution at a global scale. The GFW algorithm uses data from Automatic Identification Systems (AIS) and Vessel Monitoring Systems (VMS) to derive fishing effort (Kroodsma et al. 2018). We used this GFW-derived measure of fishing effort directly. We did not attempt to re-analyse raw vessel position data ourselves. As data available from RFMOs is typically at a coarse 5° x 5° spatial resolution, the data we used for fishing activity is relatively precise, particularly for high seas areas. Due to limitations and data availability issues, RFMO effort data have been found to be biased low in some regions and times (Francis and Hoyle 2019), providing further arguments for the use of GFW data.

Tracking data

Data on Antipodean albatross distribution were obtained from satellite tracking devices deployed on Antipodean albatross in 2019 and 2020 (n=63 in 2019 and n=40 in 2020) as described by Elliott & Walker (2019, 2020). Full tracking data can be viewed and accessed through the web-based tracking app, Albatross Tracker (https://www.doc.govt.nz/albatrosstracker). An overview of all tracks obtained from the tracked birds is shown in Figure 1. In 2019, tags were deployed on adult males, adult females, and juveniles. In 2020, tags were deployed on adult males and adult females only. The timing of tag deployment also varied between years due to logistical constraints (Jan-Feb in 2019, vs. Mar-Apr in 2020; Elliott & Walker 2020). Type of device (GPS vs. PTT) and corresponding sample sizes varied by age, sex, and breeding status (Elliott & Walker 2019, 2020), resulting in varying sample sizes over time (as devices failed or were lost, or the bird died before the end of the year; Figure 2). The most consistent sample was obtained for juveniles in 2019 (20 operational tags reducing to seven by the end of the year). The largest adult sample was obtained for females (29 in 2019 and 26 in 2020). Due to this large sample size and comparable number of breeding and non-breeding females, we further subdivided the female cohort into breeding females and non-breeding females (which included failed breeders and pre-breeders). We obtained a smaller sample size for adult males (n=14 in each year). In 2019, the male sample size was reduced rapidly due to tag failure (from 14 operational tags down to only one from mid-June onwards).

The initial step for our point-based overlap analyses was to clean and groom bird location data, from which we estimated the amount of time a bird spent at a location. Bird location data consisted of both GPS fixes and PTT locations derived by ARGOS. Any PTT-derived location with ARGOS accuracy LC A, B, and Z were first discarded from the data set (Douglas et al 2012). We retained the low-quality LC 0 locations conditionally to fill in the temporal gaps in the data, especially in the central southern Pacific. We only retained LC 0 locations with semi-major axis error of less than 50 km in the dataset to avoid introduction of potentially aberrant locations. We then calculated the time difference between two retained consecutive locations for each bird. Low-quality LC 0 locations were removed if they were received within 12 hours of a high-quality location (GPS, LC 1, 2, or 3) to avoid dilution of the track quality. After removal, speed between remaining locations were computed and if consecutive bird locations were too far apart (having required over 50m/s of sustained flight speed to cover the distance between the locations) they were also discarded. The time difference (ΔT) between two clean consecutive locations for each bird were then calculated. If a GPS location was followed by a PTT location and had time difference less than the frequency of acquisition of GPS fixes of the tag (between 1-6 hours depending on the programming of the tags), then the PTT location was discarded to avoid introduction of noise into GPS accuracy dataset. PTT locations for GPS tags were only included (subject to filtering) when there were missing GPS fixes.

Time difference between retained consecutive locations was then recalculated. The final time for each location (hence forth birdhour) was derived as the sum of half the time of time difference between the preceding location and half the time difference with the successive location;

$$T_p = \frac{\Delta T_{(p-1)} + \Delta T_{(p+1)}}{2}$$

where, T_p is birdhour or time spent at p^{th} location, $\Delta T_{(p-1)}$ is the time difference between the p^{th} location and preceding location and $\Delta T_{(p+1)}$ is the time difference of the p^{th} location with the successive location.

The derived birdhour (T_p) was weighted by the inverse of the number of individuals of the same cohort (i.e., all birds, adult male, adult female or juvenile) actively tracked (i.e., with working tags) on that day to correct for difference in sample size (progressively smaller) over time;

$$Tw_{i,p} = {}^{T_p}/_{n_p} \ for \ i \in C$$

in which $Tw_{i,p}$ is the weighted birdhour for the p^{th} location of the i^{th} individual and n_p is total number of birds tracked on that day in the cohort C. Whilst this accounted for potential bias in changing sample size over time, the data obtained later in the year was still based on a smaller samples and hence should still be viewed as less representative of the total cohort population.

Point-based fishing effort overlap estimation

To quantify overlap with fishing effort per bird location, a radius of 100 km was used to sum the fishing effort for each location on that calendar day. A 100 km threshold was used based on typical distances between sequential bird locations and the scale of pelagic longline fishing operations (an individual industrial tuna longline is typically in the order of 100 km in length; FAO 2021).

Fishing effort data from GFW were first overlaid with the final bird location dataset. We then used a spatial join to identify all fishing effort within a radius of 100 km of a bird location on that day. All fishing effort within 100 km distance of a bird location on that day were then summed to assign total fishing effort against the location.

$$FE_{i,p} = \sum_{j=0}^{n} f_j$$

where, $FE_{i,p}$ is the sum of fishing effort for the p^{th} location of the i^{th} individual and f_j is the fishing effort *j* of all n points within the radius of 100 km of p^{th} location on that day.

The total fishing effort against a location was divided by 24 to provide an hourly fishing effort ($HFE_{i,p}$) for the location and then multiplied by the weighted birdhour for that location ($Tw_{i,p}$) to give an estimate of overlap at that location (O).

$$O_{i,p} = HFE_{i,p} \times Tw_{i,p}$$

Mapping of fishing effort and cumulative annual overlap

A 100 km x 100 km grid was used to map annual fishing effort and overlap for all relevant fishing methods: pelagic longline (drifting longline in the GFW data), trawl, demersal longline (set longline in the GFW data) and jig methods. To map fishing effort, we summed fishing effort (in hours) per grid cell for the entire year and then converted the grid to annual fishing effort raster layer. To map annual overlap for different fishing methods, we used the point-based overlap value derived from overlaying bird locations with fishing effort and vessel presence by flag state and gear type at 100th degree resolution. We summed all estimated overlap within a grid cell for the entire year and then converted the grid to produce cumulative annual overlap raster layer.

Quantifying overlap by vessels and area

We used the point-based overlap value derived from overlaying bird locations with fishing effort and vessel presence data by individual vessel MMSI at 10th degree resolution to quantify overlap by area and vessel variables. The estimated overlap against each bird location was divided by the number of unique vessel locations within the defined 100km radius to assign an average overlap value to a vessel location. The averaged overlap for vessel locations was then summed by area and vessel variables to estimate overlap in a particular area or with a particular fleet.

Identifying port use of overlapped vessels

A slight variation of the above-mentioned point-based analysis was used to identify port use of vessels. For this purpose, we identified vessels with fishing activity within 100 km and within 24 hours either side of each bird location. This slightly different approach was used to better account for all vessels that potentially overlapped with birds and identified 16 additional vessels. We obtained port visit history from GFW for identified vessels per calendar year to assess the ports most frequently used. Eight port visits could not be assigned to a valid port or port state and were excluded from the analysis.

Differences from the 2019 analyses

A number of improvements were made to the input data and methods used by Bose & Debski (2020) to analyse the 2019 tracking data.

Firstly, analyses in 2019 were conducted and reported against a different set of cohorts. Bose & Debski (2020) used cohorts defined by age and sex class (adult male, adult female, and juvenile). To capture the variability of behaviour between different breeding classes, we redefined cohorts by age, sex, and breeding status. Consequently, there were potentially five different cohorts: juvenile, breeding male, non-breeding male, breeding female and non-breeding female. However, given the small sample size of males in both the years and the poor performance of tags in 2019, we do not report results for the adult male cohort by breeding and non-breeding male. Thus, our current analyses use four different cohorts: juvenile, adult male, breeding female and non-breeding. The non-breeding female cohort includes pre-breeders and failed breeders.

Secondly, we updated our data grooming procedure for the tracking data. Bose & Debski (2020) discarded any PTT-derived location with Argos accuracy LC 0, A, B, and Z from the dataset based on Douglas et al (2012), before applying a speed filter. Visual inspection of raw vs. groomed datasets indicated several gaps in the processed tracks when consecutive low accuracy locations were obtained, particularly in the mid-Pacific where ARGOS coverage was relatively poor. To retain maximum data for our current analyses, we groomed the data slightly differently. We only discarded PTT-derived location with ARGOS accuracy LC A, B, and Z from the data set. We retained the low-quality LC 0 conditionally to fill in the temporal gaps in the data, mostly in the central southern Pacific. We then applied the speed filter and processed the data as described above.

Thirdly, we used updated GFW fishing effort data extracts, released in March 2021 (Version 2.0). The new version used the latest AIS algorithms, neural network models, and vessel registry database and estimated vessel presence and fishing effort more accurately. As well as using the new version to estimate overlap from our 2020 tracking data, we also reanalysed the 2019 tracking data to make the results between the two years comparable.

Fourthly, to make the cumulative annual overlap maps for different fishing methods comparable with our fine-scale overlap analysis, we replaced the rapid mapping method with point-based analysis.

Lastly, we improved our estimation of overlap by region. Bose & Debski (2020) reported overlap by region based on the location of the bird. So, if a bird was at the very edge of an EEZ was within a 100 km radius of a vessel fishing in the high seas, the overlap was assigned to the EEZ based on the location of the bird. In our current analyses, we used the location of vessel to sum overlap by region. So, in the previous example, if a bird was at the very edge of the EEZ and within a 100 km radius of a vessel fishing in high seas, the overlap is assigned to the high seas area.

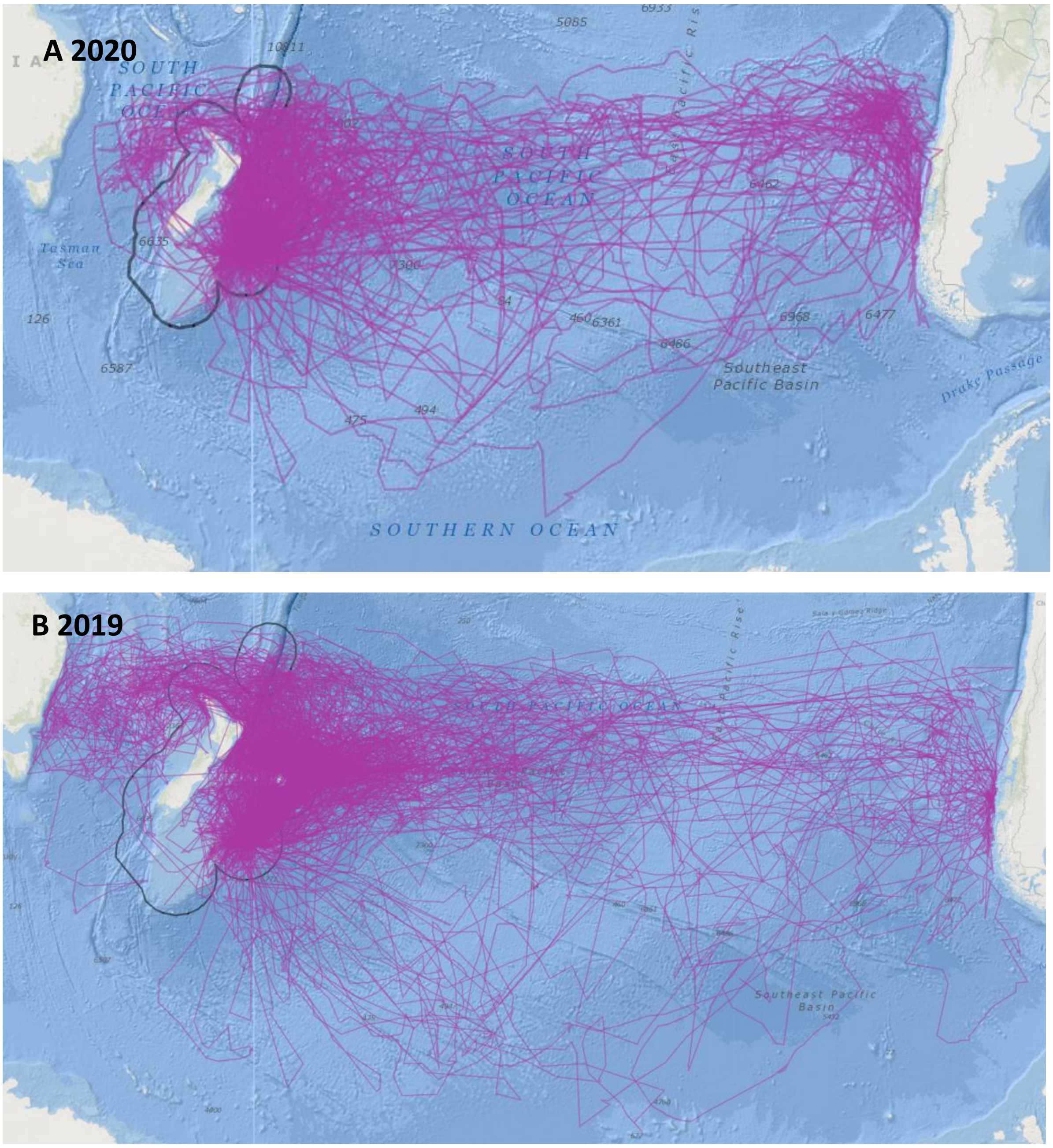

Figure 1. All tracks obtained from Antipodean albatross in a) 2020, and b) 2019.

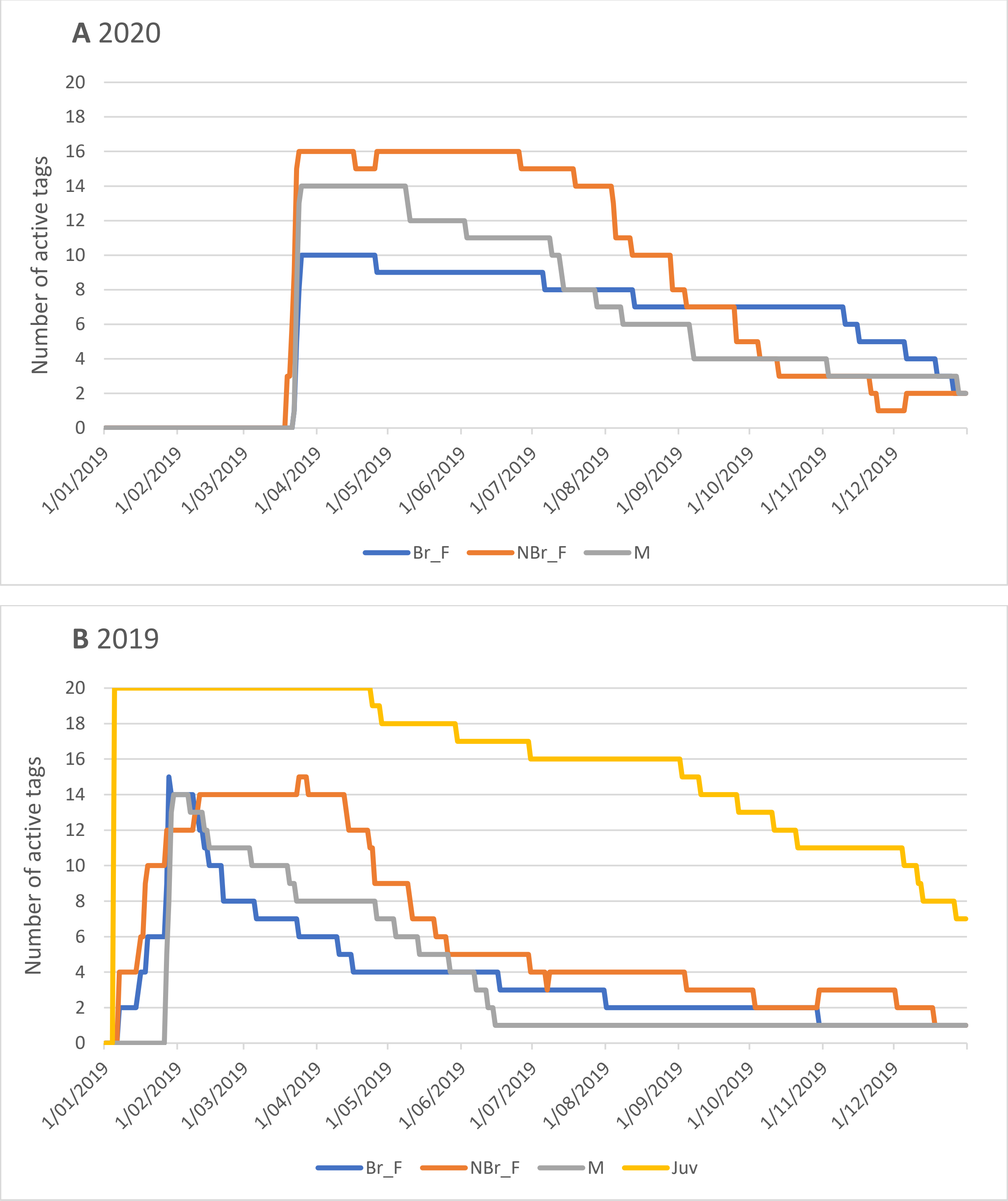

Figure 2. Sample size of working tags for breeding female (Br_F), non-breeding female (NBr_F), male (M) and juvenile (Juv) Antipodean albatross over a) 2020 and b) 2019.

Results

Spatial distribution of tracked Antipodean albatross

The spatial distribution of all tracked Antipodean albatross is shown in Figure 3. The core distribution extends from the east coast of Australia across the Pacific to the coast of Chile, from approximately 25°S to 60°S. Highest occurrence was recorded in the vicinity of Antipodes Island (the breeding site south-east of New Zealand), in an area to the east of New Zealand straddling the edge of the New Zealand EEZ, the mid-Tasman Sea, and areas off the southern Chile coast. These broad patterns match earlier tracking efforts of this population (Walker & Elliott 2006; Elliott & Walker 2018). Whilst the broad pattern was consistent between years, there are some differences between 2019 and 2020. Notably, there was higher occurrence in Australian waters in 2019, due to the inclusion of a juvenile cohort in 2019 (see Bose & Debski 2020) and inter-annual variation of non-breeding females (see below). There was also higher occurrence in the central eastern Pacific in 2020 and birds travelled further north, up to 21°S, which we explore further by cohort below.

The distribution of each comparable cohort between years is shown in Figures 4-6. Breeding females (Figure 4) had the most constrained distribution, as expected by the nature of the cohort having to return regularly to the colony to incubate an egg or feed a chick. A slightly more northerly distribution was recorded in 2020 compared to 2019, extending to 25°S, close to the EEZ boundaries of various Pacific Island States. Non-breeding females (Figure 5) travelled further from New Zealand, with a pronounced more northerly distribution in the eastern Pacific in 2020, north to 21°S. In 2019 this cohort had relatively higher occurrence in the Australian EEZ. Male distribution (Figure 6) is more difficult to compare given the smaller effective sample sizes. However, greater occurrence in the more northerly part of their eastern Pacific distribution is notable in 2020. In both years, males travelled further south than females, with some birds approaching the Antarctic ice shelf, as far south as 69°S.

When summed by geographical jurisdiction (Figure 7) the occurrence of breeding females was very similar between years, mainly in the New Zealand EEZ. Non-breeding females had relatively higher occurrence in the IATTC and the Chile EEZ in 2020 compared to 2019. Males showed higher occurrence in the New Zealand EEZ in 2020 compared to 2019, which is likely a more representative sample in 2020 due to improved tag longevity.

Overview of overlap with fishing effort

Mapping of the overlap of all tracked birds with demersal longline, trawl and jig fishing effort during 2020 is shown in Figures 8-10 (each figure provides a plot of total fishing effort and the overlap with the tracked birds). Overlap with trawl fishing effort was mainly within the New Zealand EEZ, where estimated bycatch of Antipodean albatross in trawl fisheries is low compared to pelagic longline (FNZ 2020). Very little overlap was found with demersal longline fishing effort and virtually no overlap with jig fishing effort. Given the limited overlap with these fishing methods the rest of our analyses focussed only on overlap with pelagic longline fishing effort.

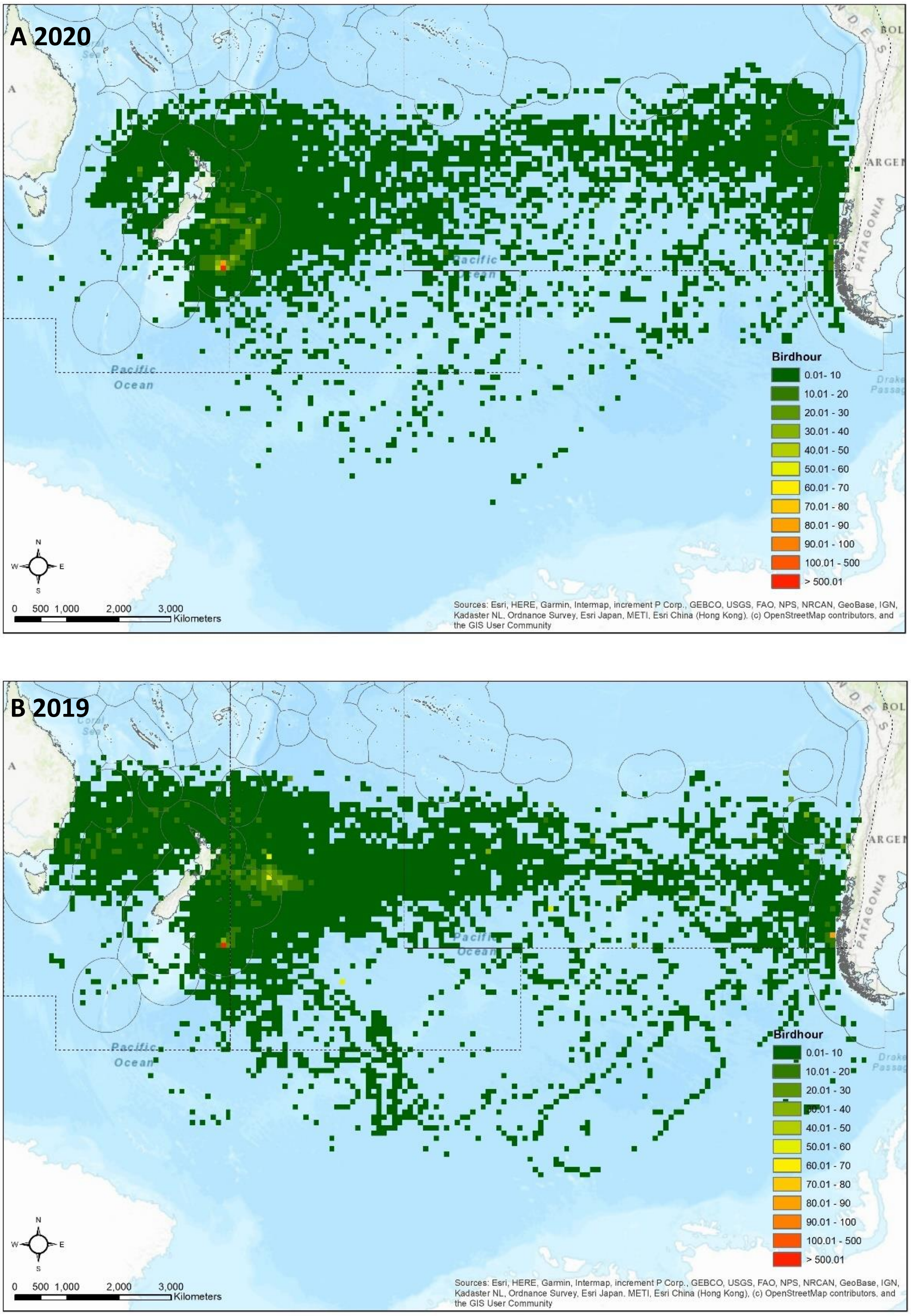

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Figure 3. Spatial distribution of all tracked Antipodean albatross in a) 2020 and b) 2019 (average number of bird hours per 100 km x 100 km grid cell). Red is highest occurrence, dark green lowest. Dashed lines indicate RFMO boundaries.

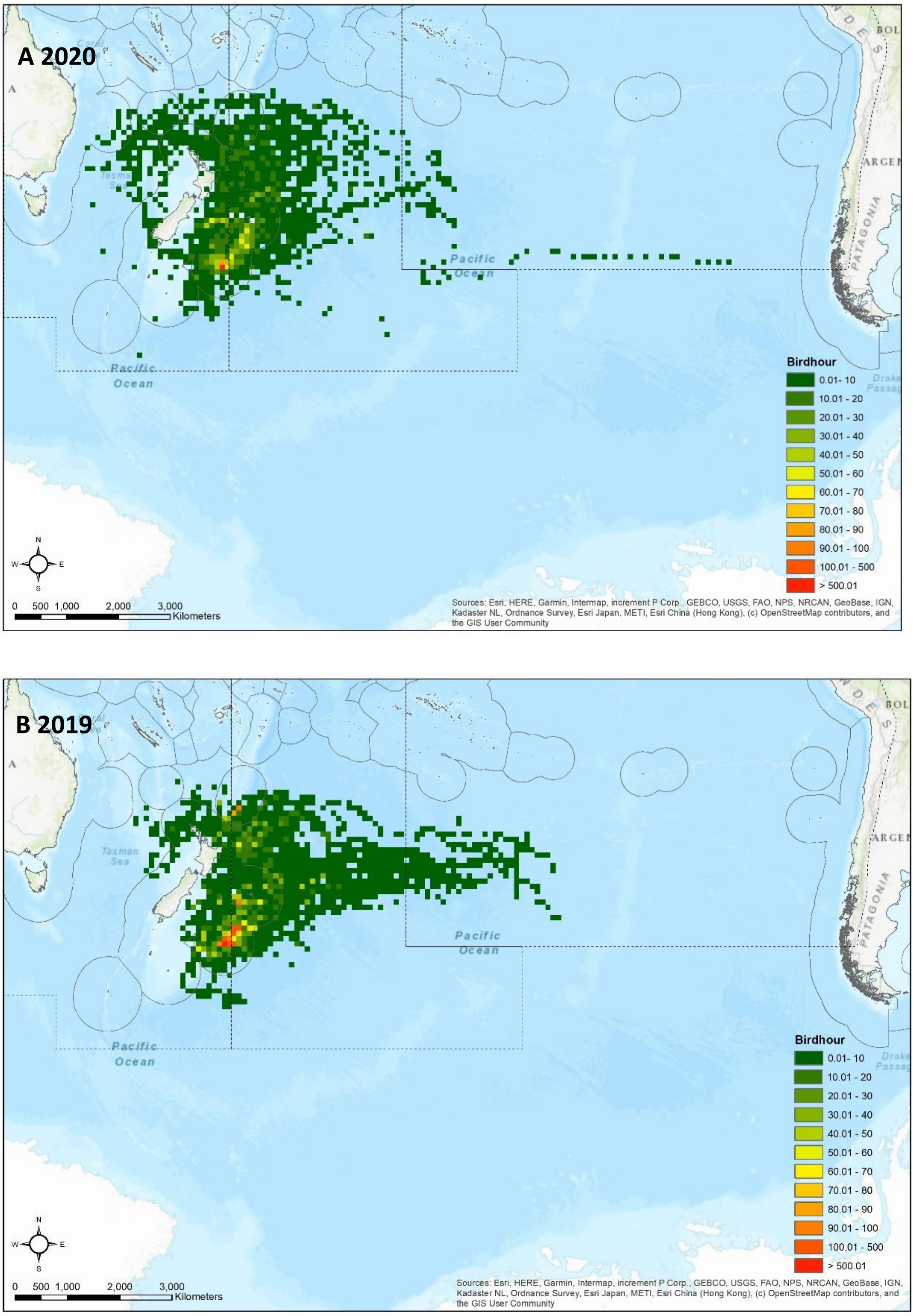

Figure 4. Spatial distribution of tracked breeding female Antipodean albatross in a) 2020 and b) 2019 (average number of bird hours per 100 km x 100 km grid cell). Red is highest occurrence, dark green lowest. Dashed lines indicate RFMO boundaries.

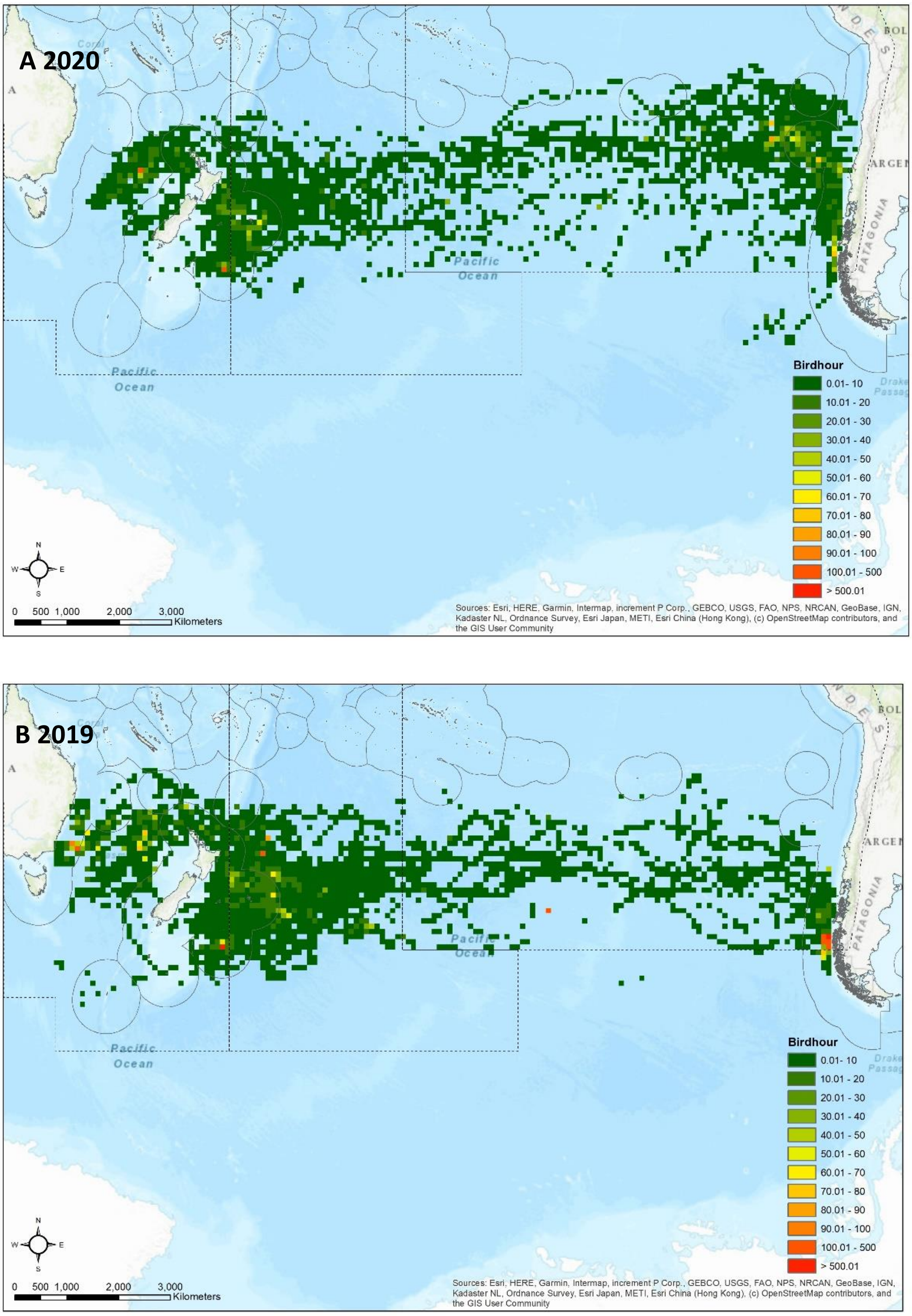

Figure 5. Spatial distribution of tracked non-breeding female Antipodean albatross in a) 2020 and b) 2019 (average number of bird hours per 100 km x 100 km grid cell). Red is highest occurrence, dark green lowest. Dashed lines indicate RFMO boundaries.

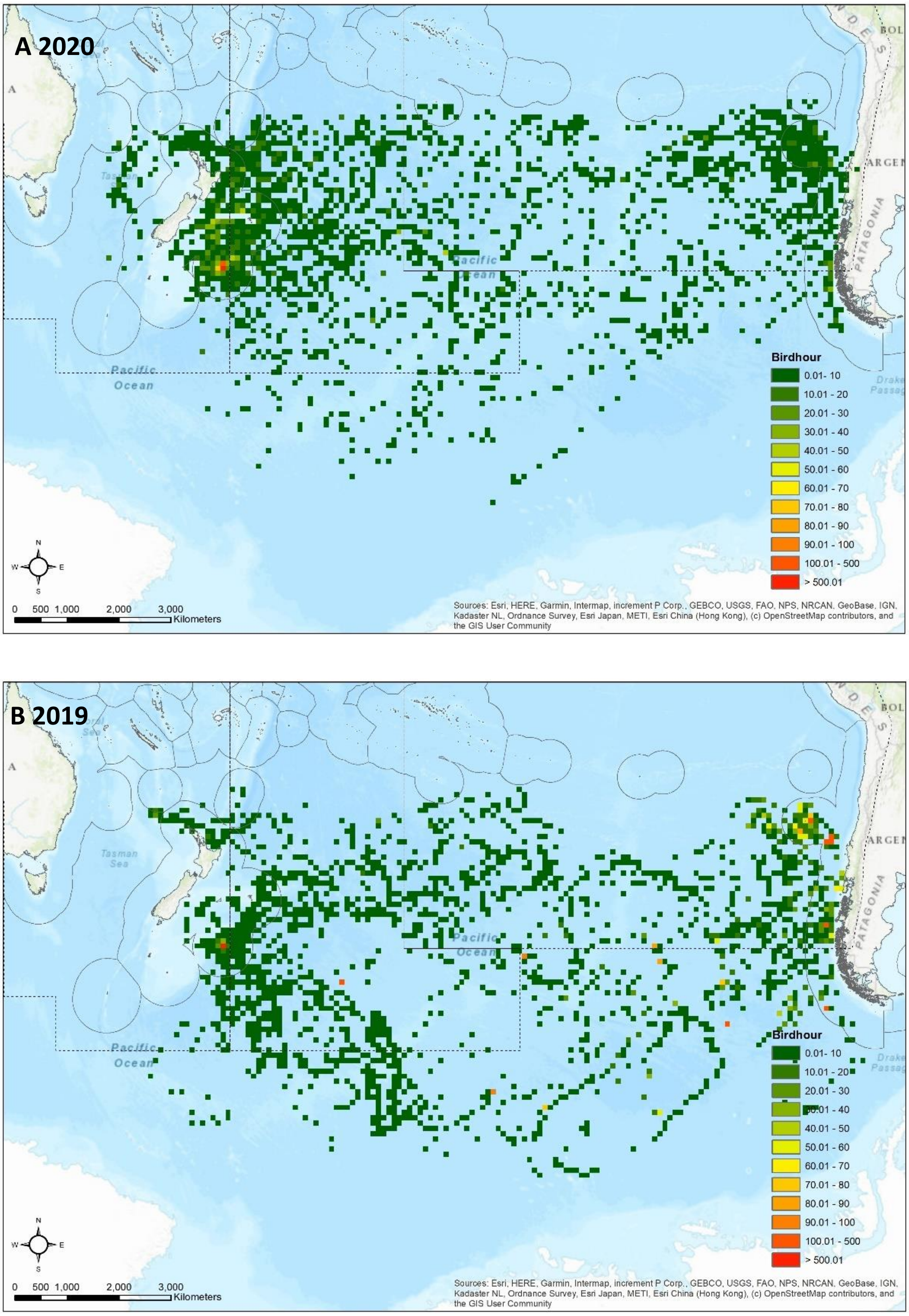

Figure 6. Spatial distribution of tracked male Antipodean albatross in a) 2020 and b) 2019 (average number of bird hours per 100 km x 100 km grid cell). Red is highest occurrence, dark green lowest. Dashed lines indicate RFMO boundaries.

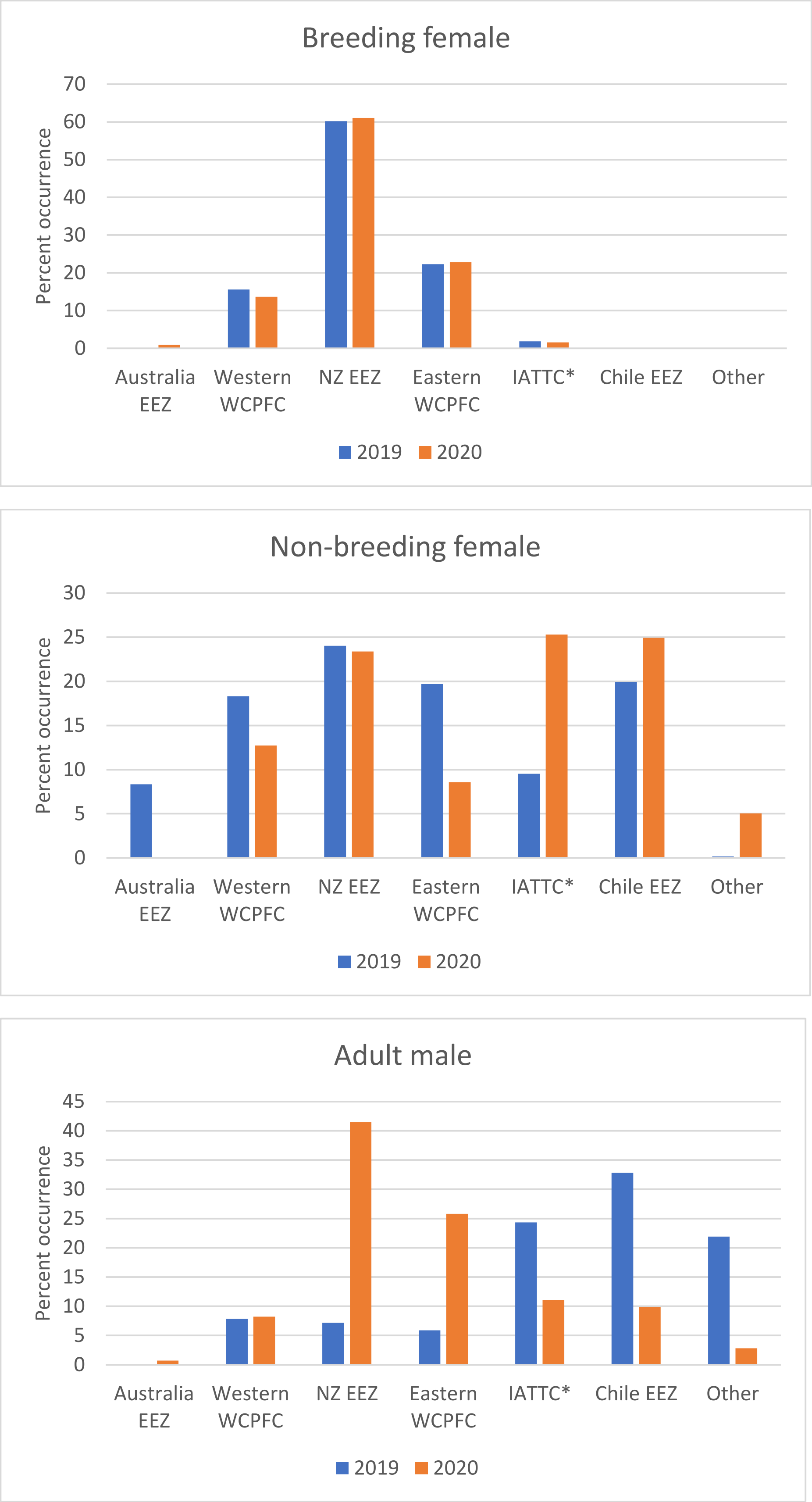

Figure 7. Distribution of bird occurrence (% total bird hours) by Jurisdiction, for breeding female, non-breeding female and male Antipodean albatross in 2019 and 2020. RFMO areas are for high seas only. *IATTC includes the overlap area with WCPFC.

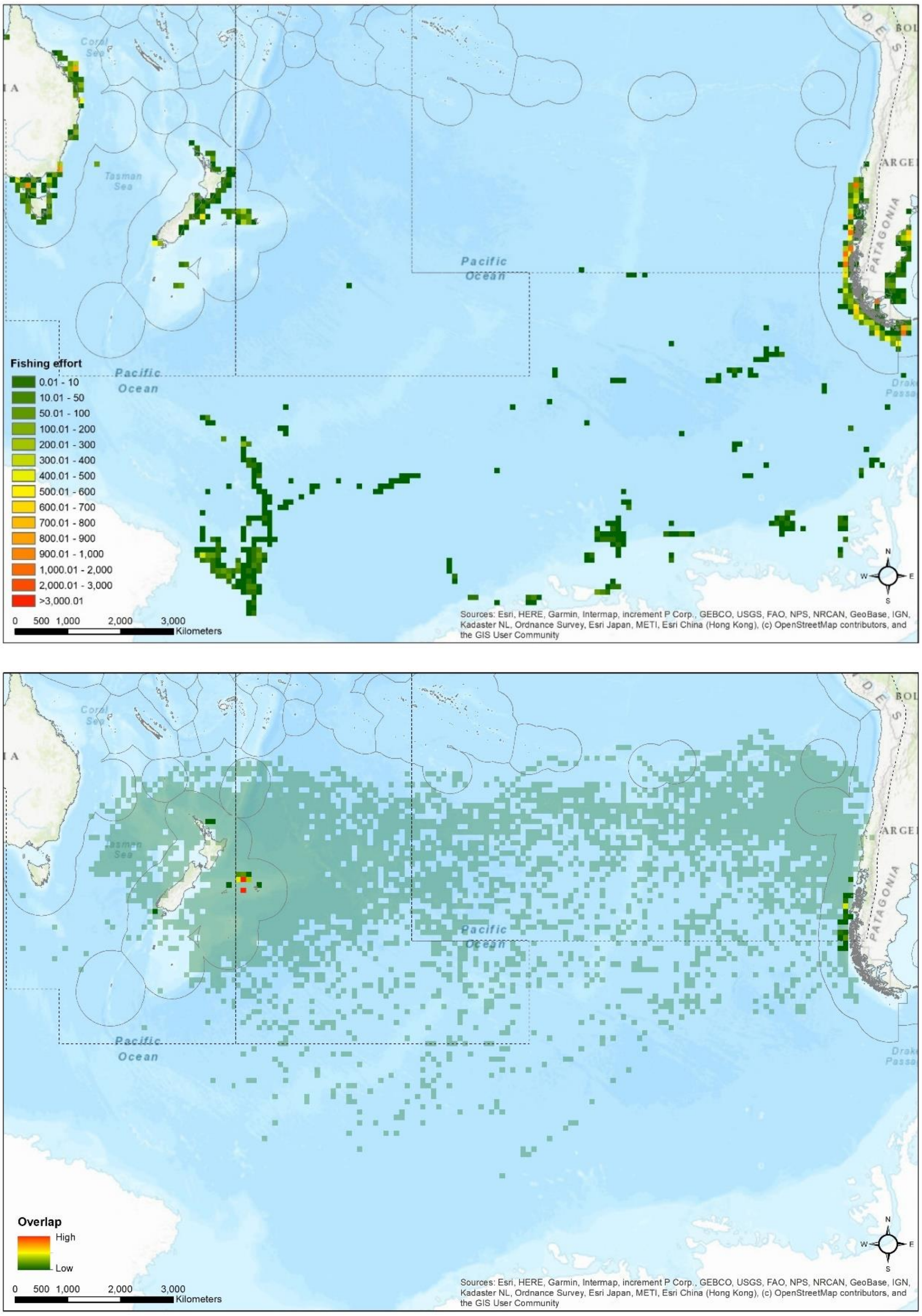

Figure 8. a) Demersal longline fishing effort (hours) in 2020 (red is highest effort, dark green is lowest effort) and b) year-round cumulative daily overlap of tracked Antipodean albatross with demersal longline fishing effort in 2020 at 100 km by 100 km grid scale (red is highest overlap, dark green is lowest overlap, and translucent green cells represent bird occurrence with no overlap). Dashed lines indicate RFMO boundaries. Fishing effort data obtained from GFW (see methods).

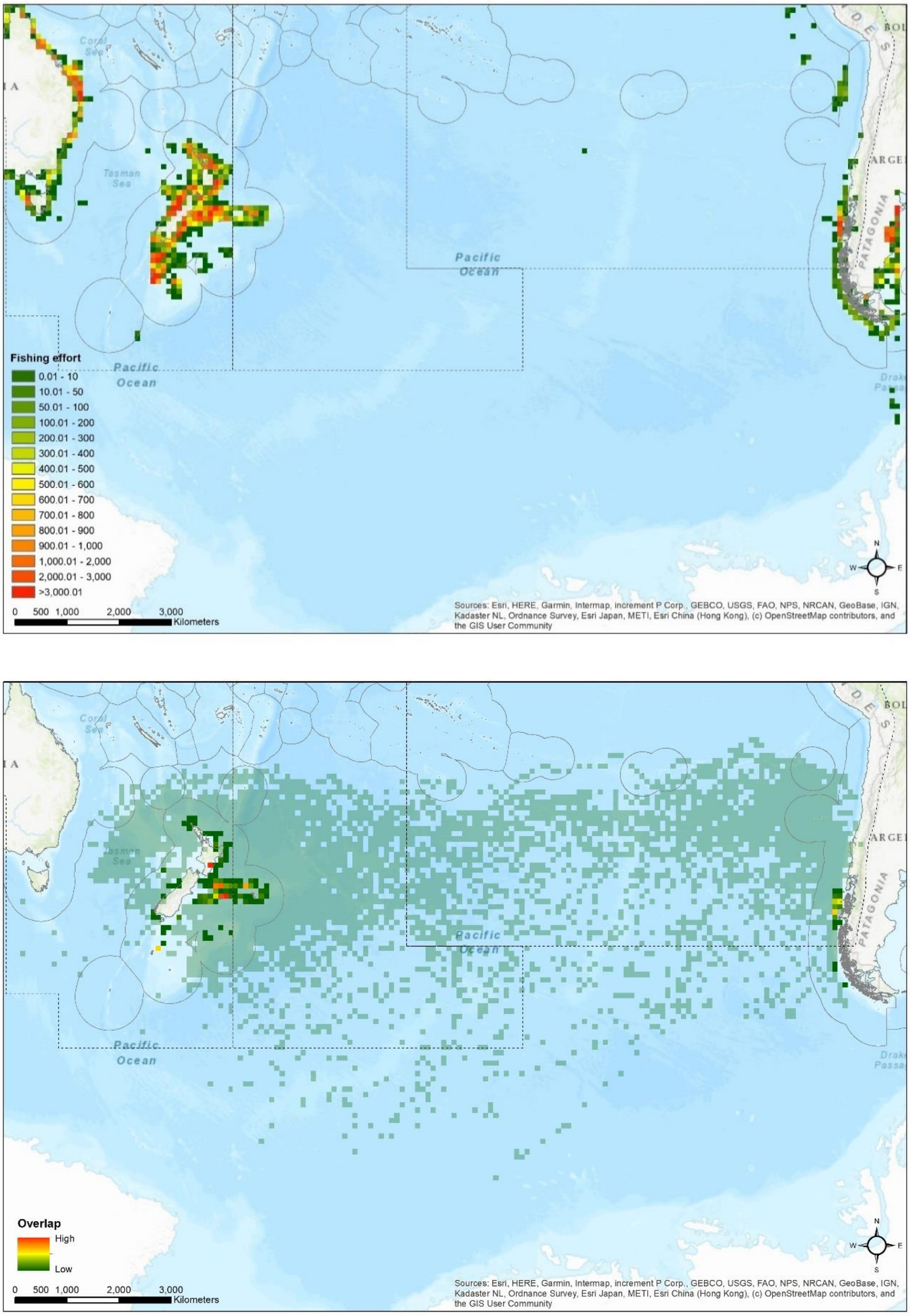

Figure 9. a) Trawl fishing effort (hours) in 2020 (red is highest effort, dark green is lowest effort) and b) year-round cumulative daily overlap of tracked Antipodean albatross with trawl fishing effort in 2020 at 100 km by 100 km grid scale (red is highest overlap, dark green is lowest overlap, and translucent green cells represent bird occurrence with no overlap). Dashed lines indicate RFMO boundaries. Fishing effort data obtained from GFW (see methods).

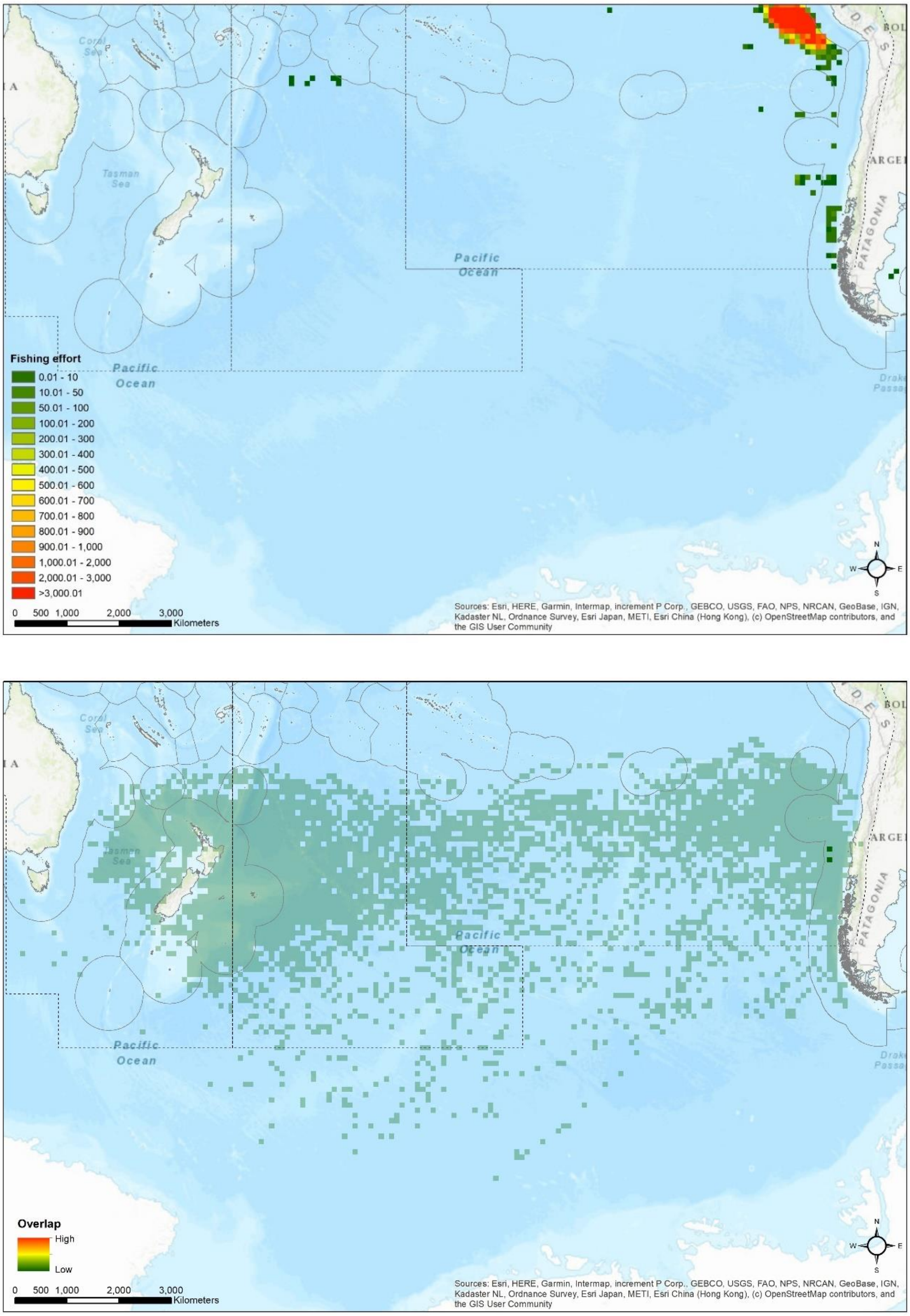

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Figure 10. a) Jig fishing effort (hours) in 2020 (red is highest effort, dark green is lowest effort) and b) year-round cumulative daily overlap of tracked Antipodean albatross with jig fishing effort in 2020 at 100 km by 100 km grid scale (red is highest overlap, dark green is lowest overlap, and translucent green cells represent bird occurrence with no overlap). Dashed lines indicate RFMO boundaries. Fishing effort data obtained from GFW (see methods).

Spatial and temporal overlap with pelagic longline fishing effort

The distribution of pelagic longline fishing effort is shown in Figure 11. The broad distribution of fishing effort was similar between 2019 and 2020. However, fishing effort was higher in the central and eastern South Pacific in 2020, with increased intensity in the WCPFC areas north and north-east of New Zealand. The increased effort in the eastern WCPFC and IATTC areas occurred mainly in the late austral winter period July-September (Figure 12).

The overlap of all tracked birds with pelagic longline fishing effort (Figure 13) showed overlap is greatest in the western (mid-Tasman sea) and the eastern (adjacent to the New Zealand EEZ) WCPFC areas, in the northerly parts of the Antipodean albatross distribution. Given the more northerly distribution of Antipodean albatross in 2020 compared to 2019 it not surprising that there was overlap further north in the eastern WCPFC area in 2020, along with more overlap in the IATTC area. There was also an area of particularly high overlap in the more southerly part of the mid-Tasman sea in 2020.

For breeding female Antipodean albatross, the area of highest overlap with pelagic longline fishing in both years was in the eastern WCPFC area adjacent to the New Zealand EEZ (Figure 14). The year-round cumulative daily overlap was very similar between years over areas (Figure 17) and months (Figure 18).

Non-breeding females overlapped with pelagic longline fishing effort in both the western and eastern WCPFC areas in both years. However, the expanded distribution of this cohort into the more northern IATTC areas in 2020 gave rise to higher overlap with pelagic longline fishing effort in this area (Figure 15), which also had higher fishing effort in 2020 (Figure 11). The year-round cumulative daily overlap of non-breeding females was much higher in 2019 than in 2020 (Figure 17). This high cumulative overlap, however, was due largely to a single spike of high overlap in May 2019 (Figure 18). Further investigation of this spike, by comparing overlap of this cohort in May 2019 with May 2020, showed the overlap restricted to a handful of grid cells in the eastern and western WCPFC areas (Figure 19). Such spikes are inherent to our methodology where a substantial proportion of a modest sample of tracked birds may by chance overlap with multiple vessels at the same time. These spikes were unlikely to represent any meaningful difference in overlap patterns between the years.

Figure 16 shows the overlap of male Antipodean albatross with pelagic longline fishing effort, with much greater overlap in 2020 across all northern parts of their distribution, as clearly shown by their year-round cumulative daily overlap (Figures 17-18). This difference is mainly due to a better sample size over the 2020 winter period (Figure 2), when there is highest overlap with pelagic longline fishing effort.

For all cohorts in both years, overlap with pelagic longline fishing effort occurred almost exclusively during the austral winter period May-October (Figure 18).

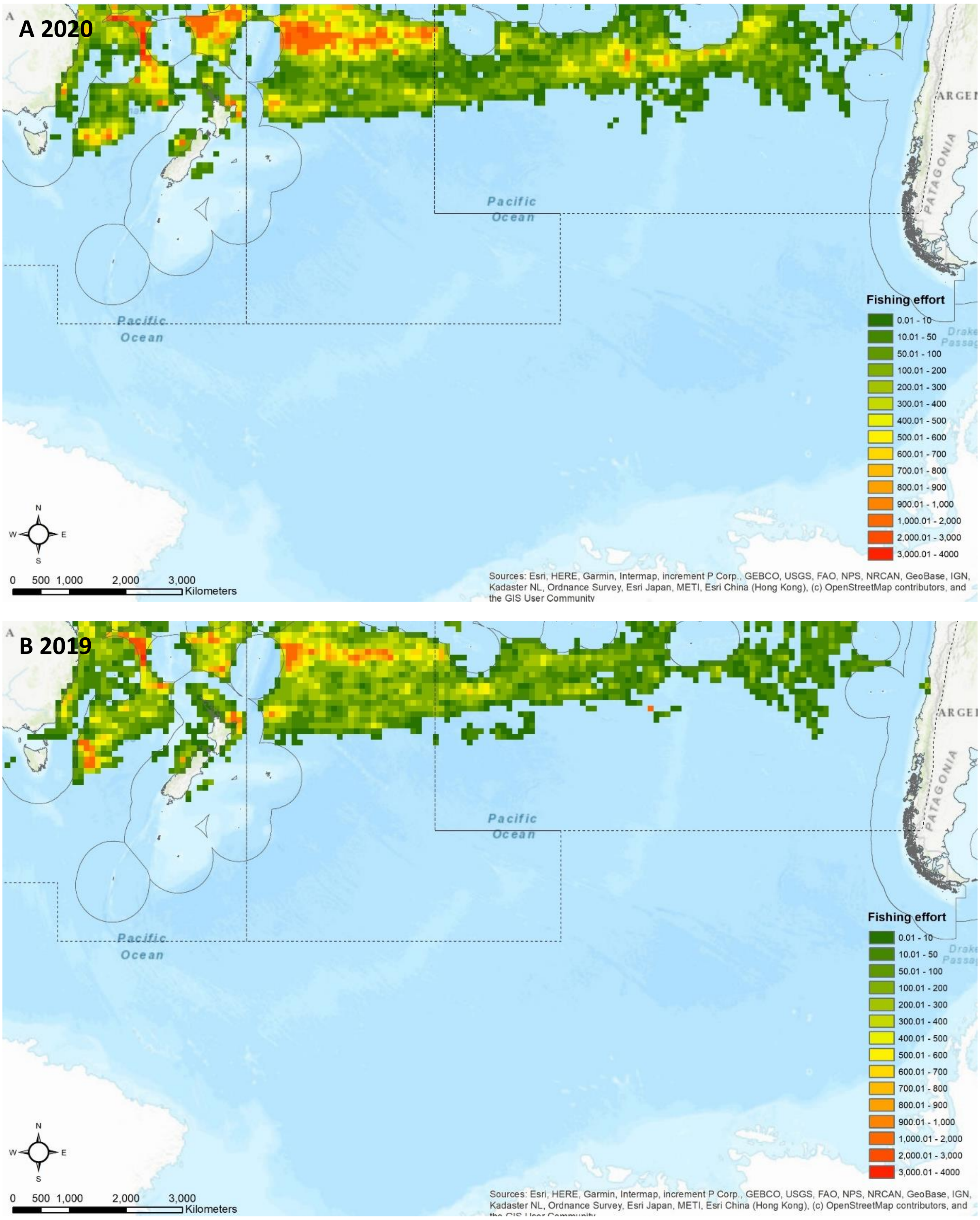

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Figure 11. Pelagic longline fishing effort (hours). Red is highest effort, dark green is lowest effort. Dashed lines indicate RFMO boundaries. Fishing effort data obtained from GFW (see methods).

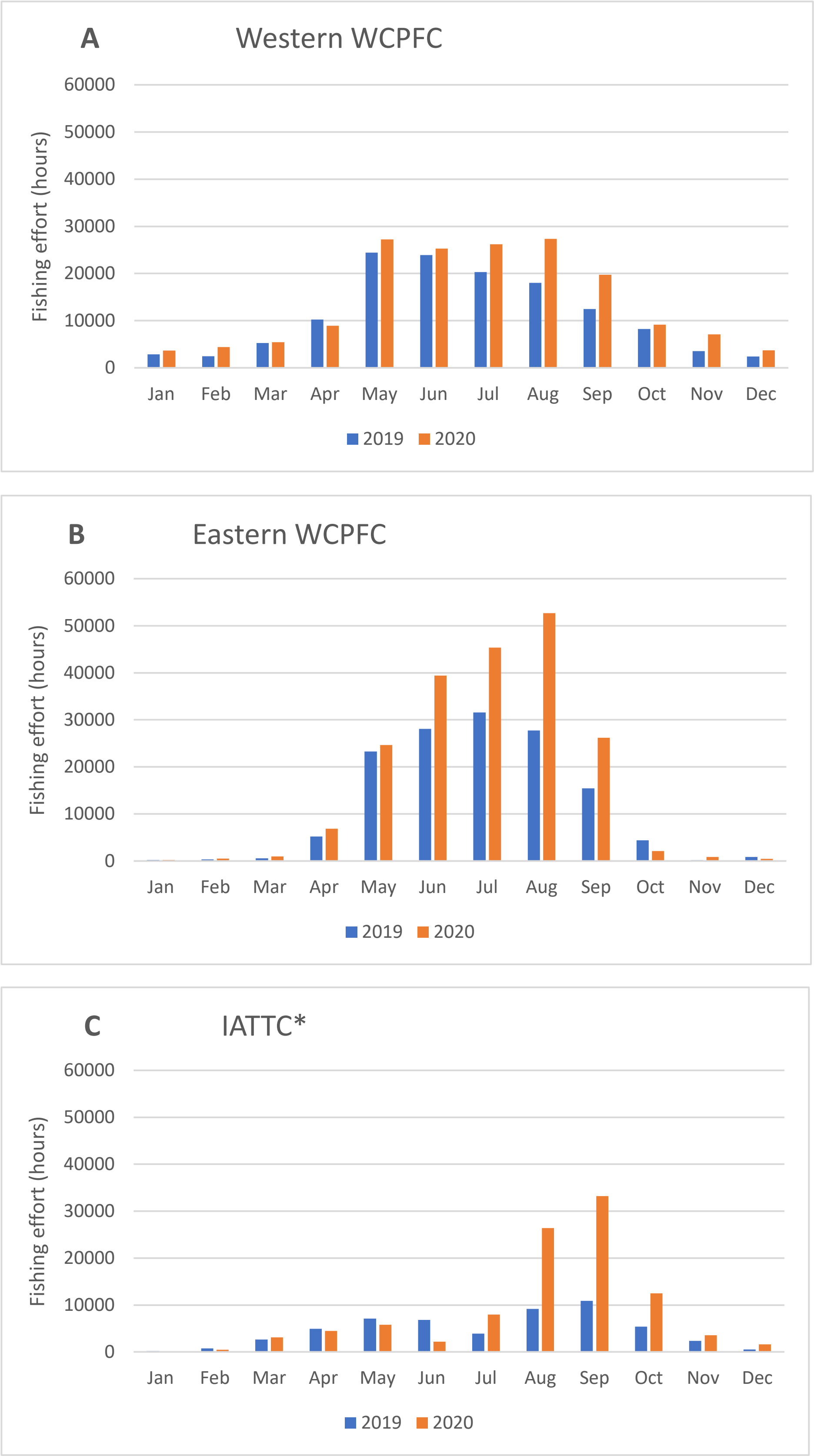
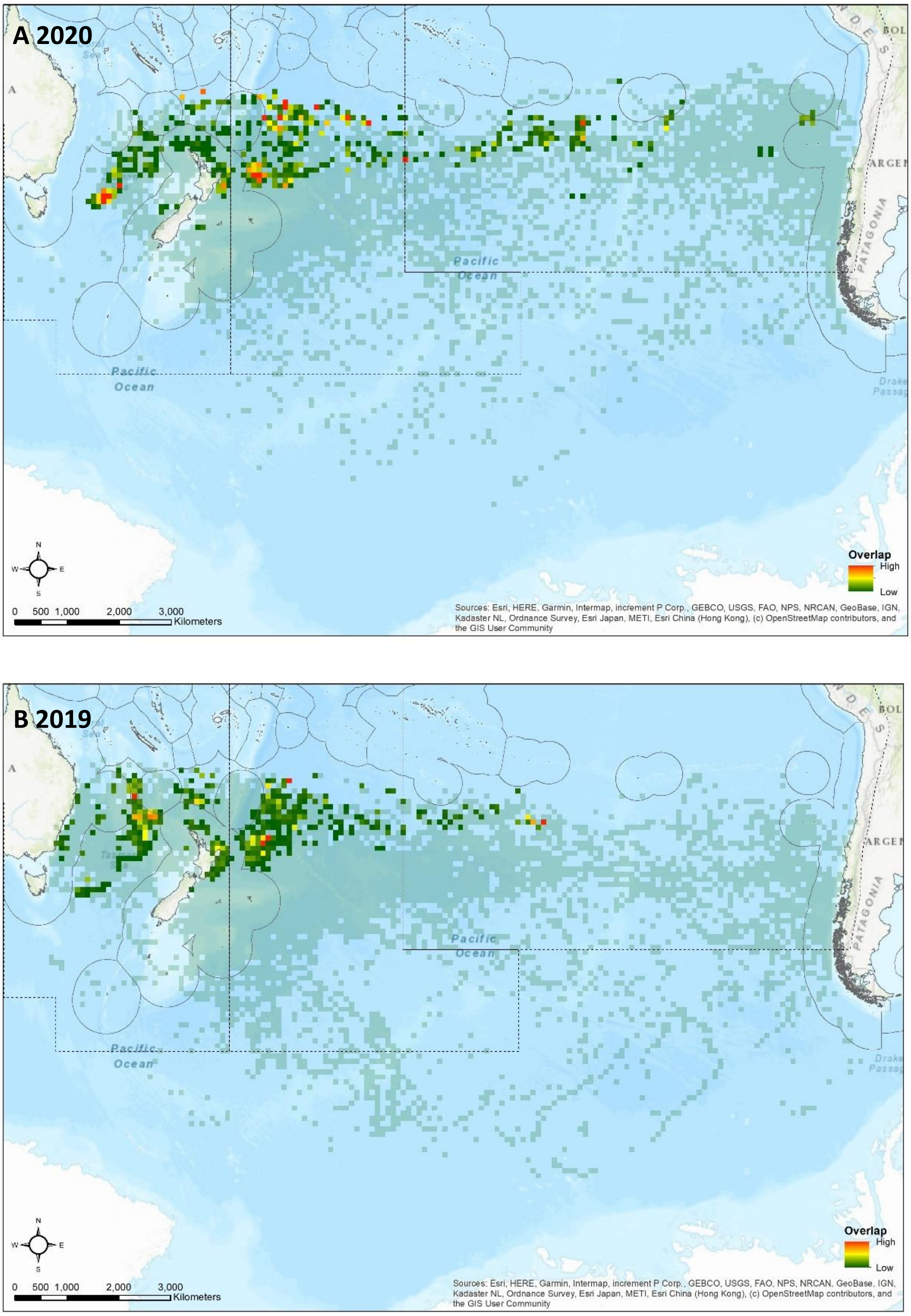


Figure 12. Pelagic longline fishing effort (hours) by month for 2019 (blue) and 2020 (orange) for three high-seas areas; a) Western WCPFC, b) Eastern WCPFC and c) IATTC. Fishing effort data obtained from GFW (see methods). *IATTC includes the overlap area with WCPFC.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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Figure 13. Year-round cumulative daily overlap of all tracked Antipodean albatross with pelagic longline fishing effort in a) 2020 and b) 2019 at 100 km by 100 km grid scale. Red is highest overlap, dark green is lowest overlap, and translucent green cells represent bird occurrence with no overlap. Dashed lines indicate RFMO boundaries.

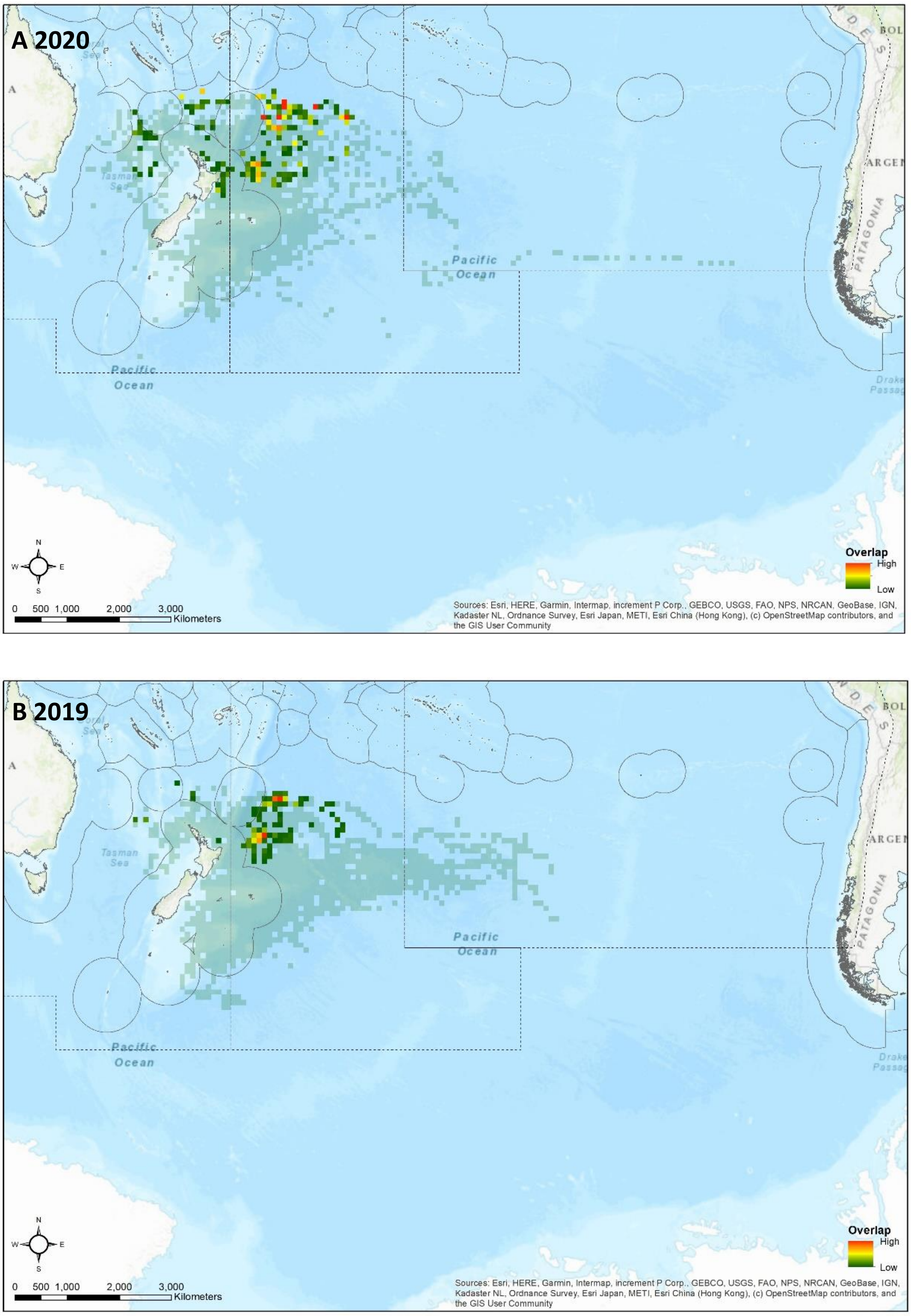
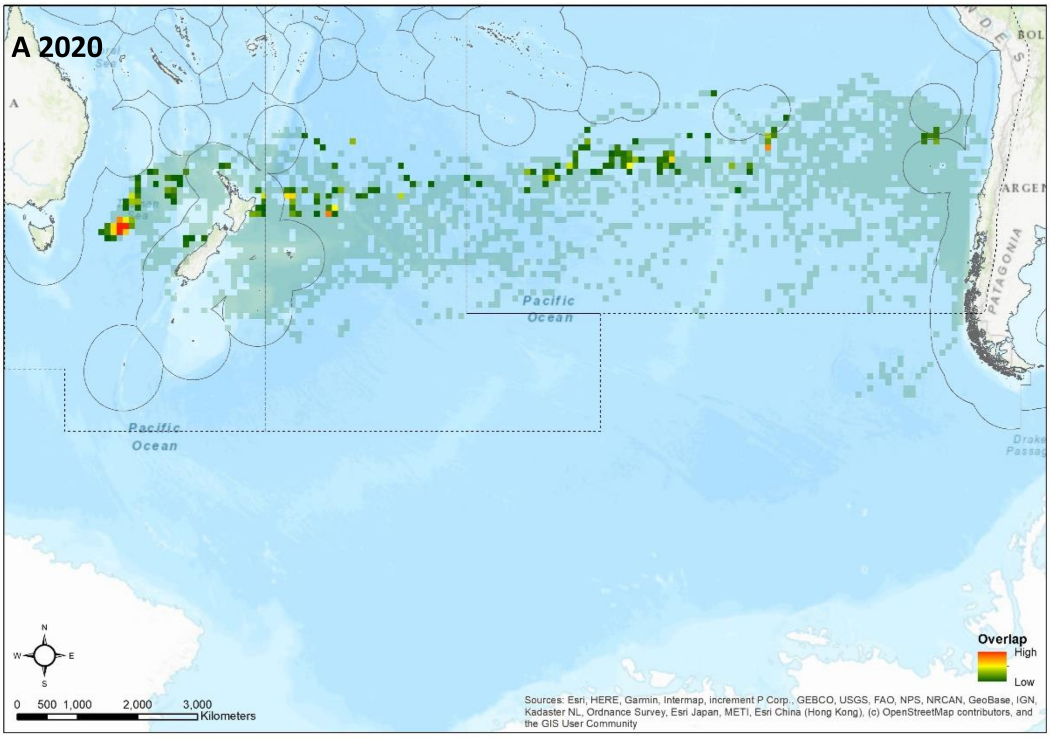


Figure 14. Year-round cumulative daily overlap of tracked breeding female Antipodean albatross with pelagic longline fishing effort in a) 2020 and b) 2019 at 100 km by 100 km grid scale. Red is highest overlap, dark green is lowest overlap, and translucent green cells represent bird occurrence with no overlap. Dashed lines indicate RFMO boundaries.



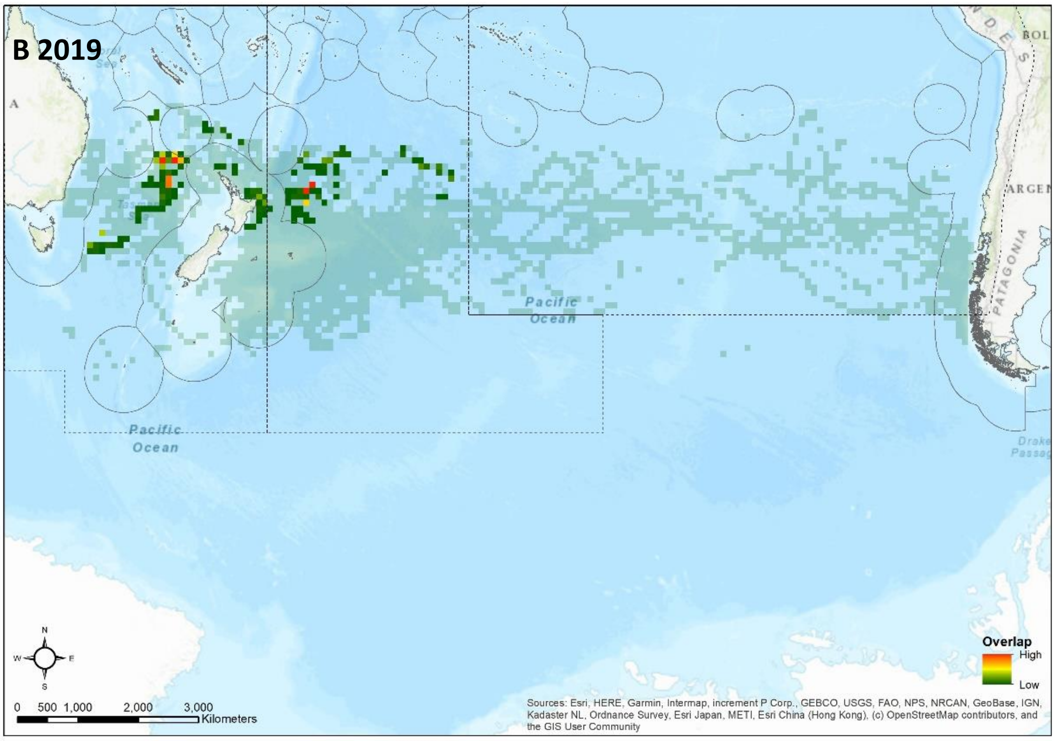
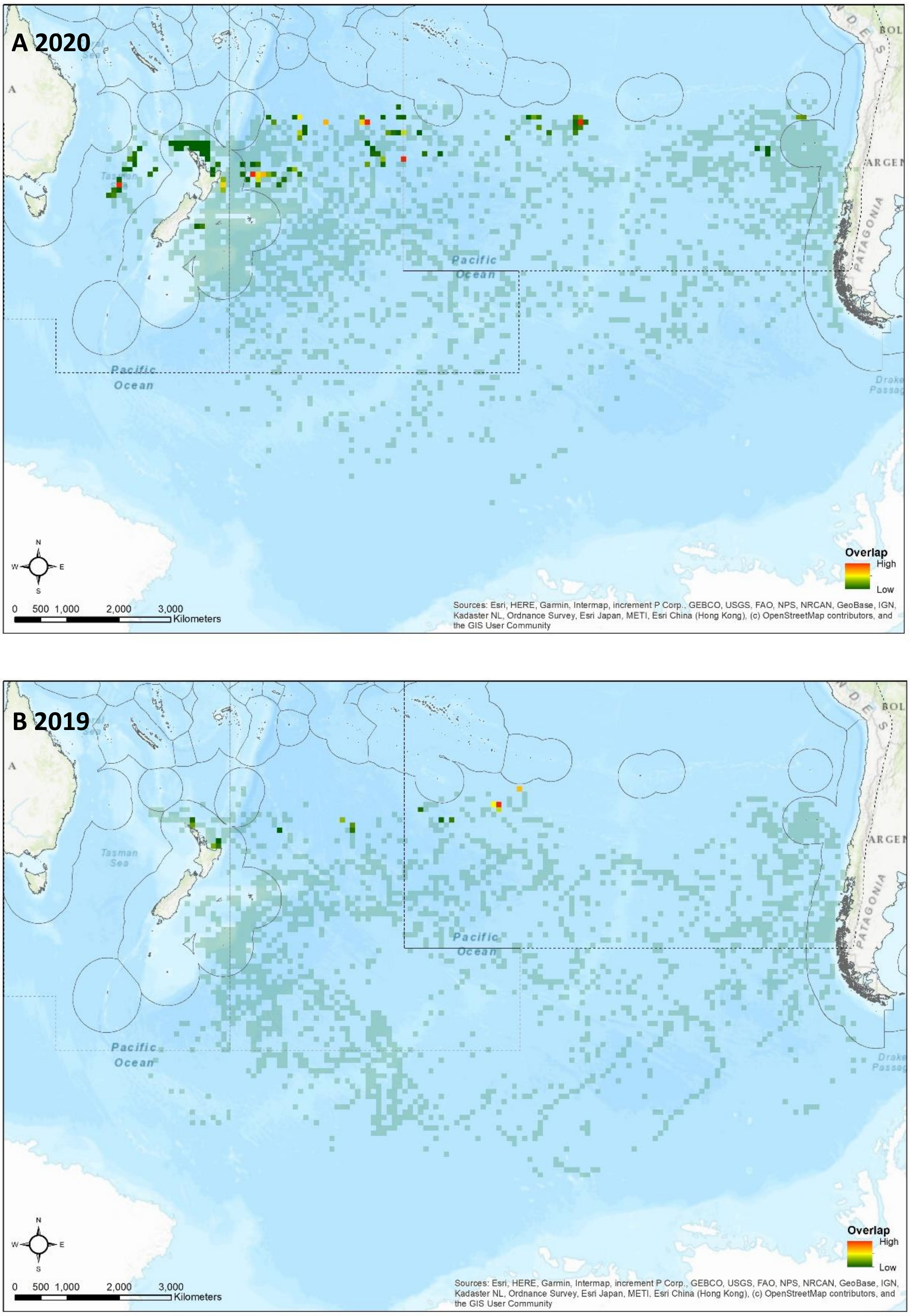


Figure 15. Year-round cumulative daily overlap of tracked non-breeding female Antipodean albatross with pelagic longline fishing effort in a) 2020 and b) 2019 at 100 km by 100 km grid scale. Red is highest overlap, dark green is lowest overlap, and translucent green cells represent bird occurrence with no overlap. Dashed lines indicate RFMO boundaries.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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Figure 16. Year-round cumulative daily overlap of tracked adult male Antipodean albatross with pelagic longline fishing effort in a) 2020 and b) 2019 at 100 km by 100 km grid scale. Red is highest overlap, dark green is lowest overlap, and translucent green cells represent bird occurrence with no overlap. Dashed lines indicate RFMO boundaries.

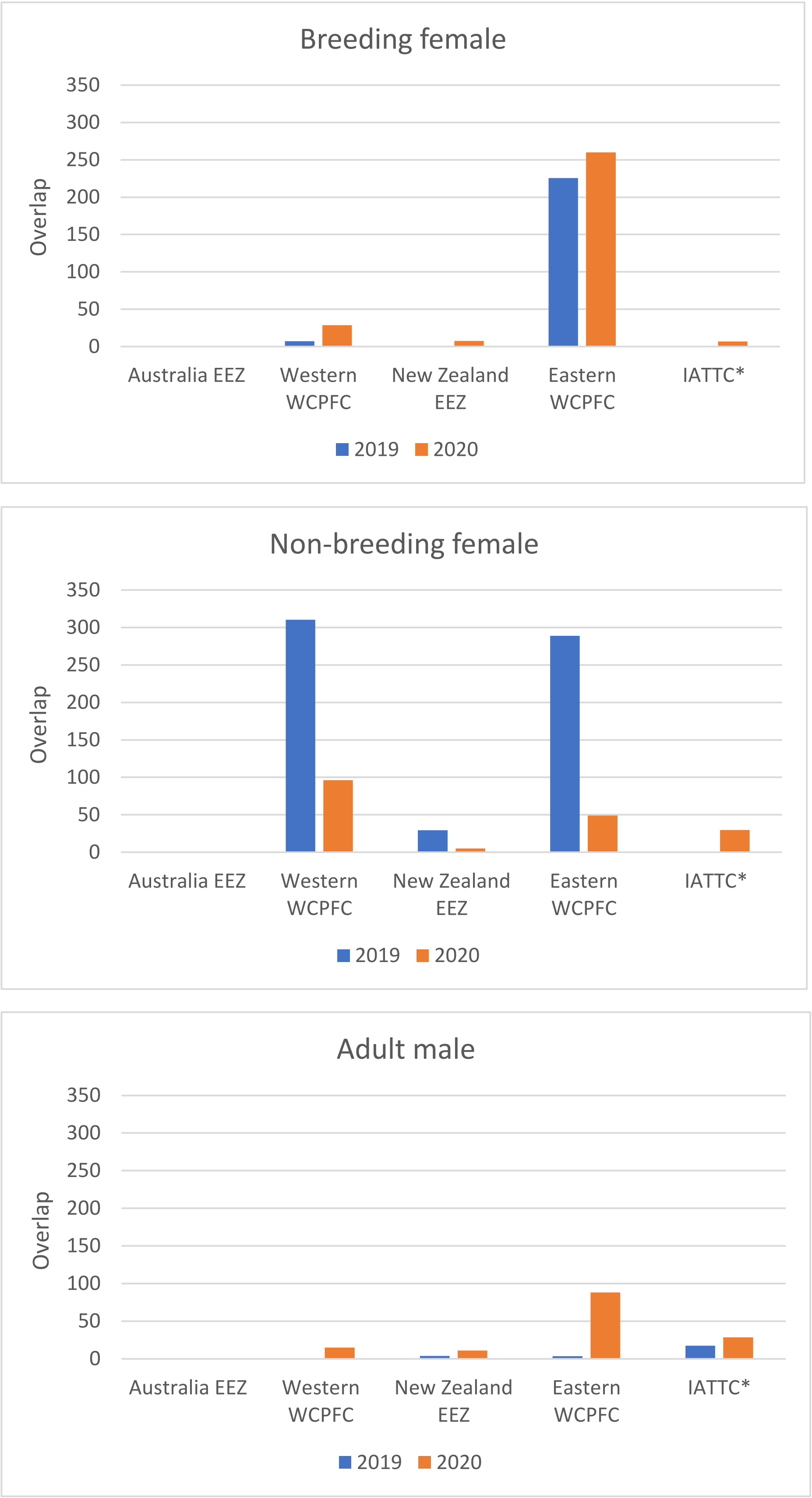


Figure 17. Year-round cumulative daily overlap of tracked breeding female, non-breeding female and adult male Antipodean albatross with pelagic longline fishing effort by Jurisdiction in 2019 and 2020. RFMO areas are for high seas only. *IATTC includes the overlap area with WCPFC.

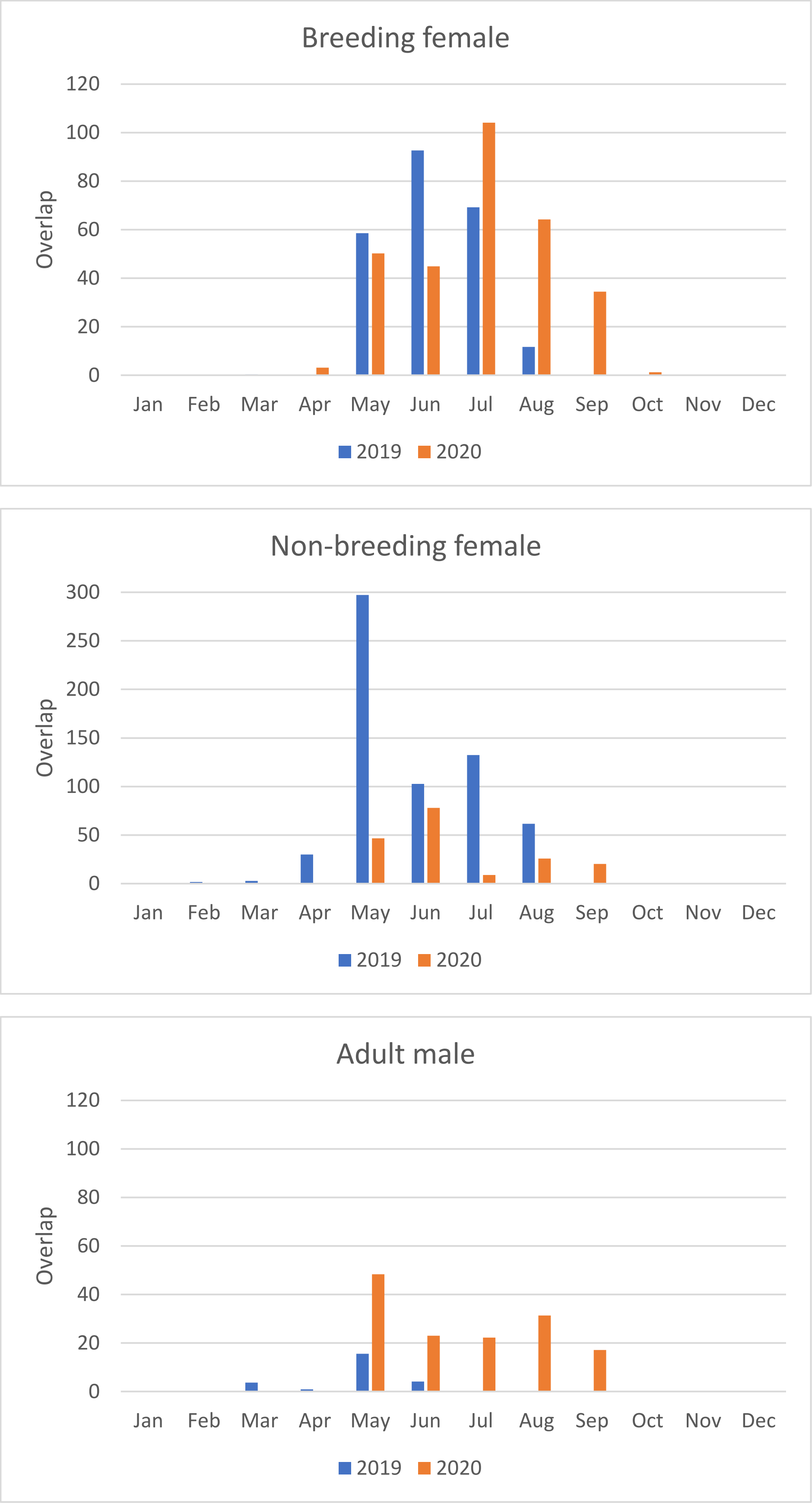


Figure 18. Year-round cumulative daily overlap of tracked breeding female, non-breeding female and adult male Antipodean albatross with pelagic longline fishing effort by Month in 2019 and 2020.

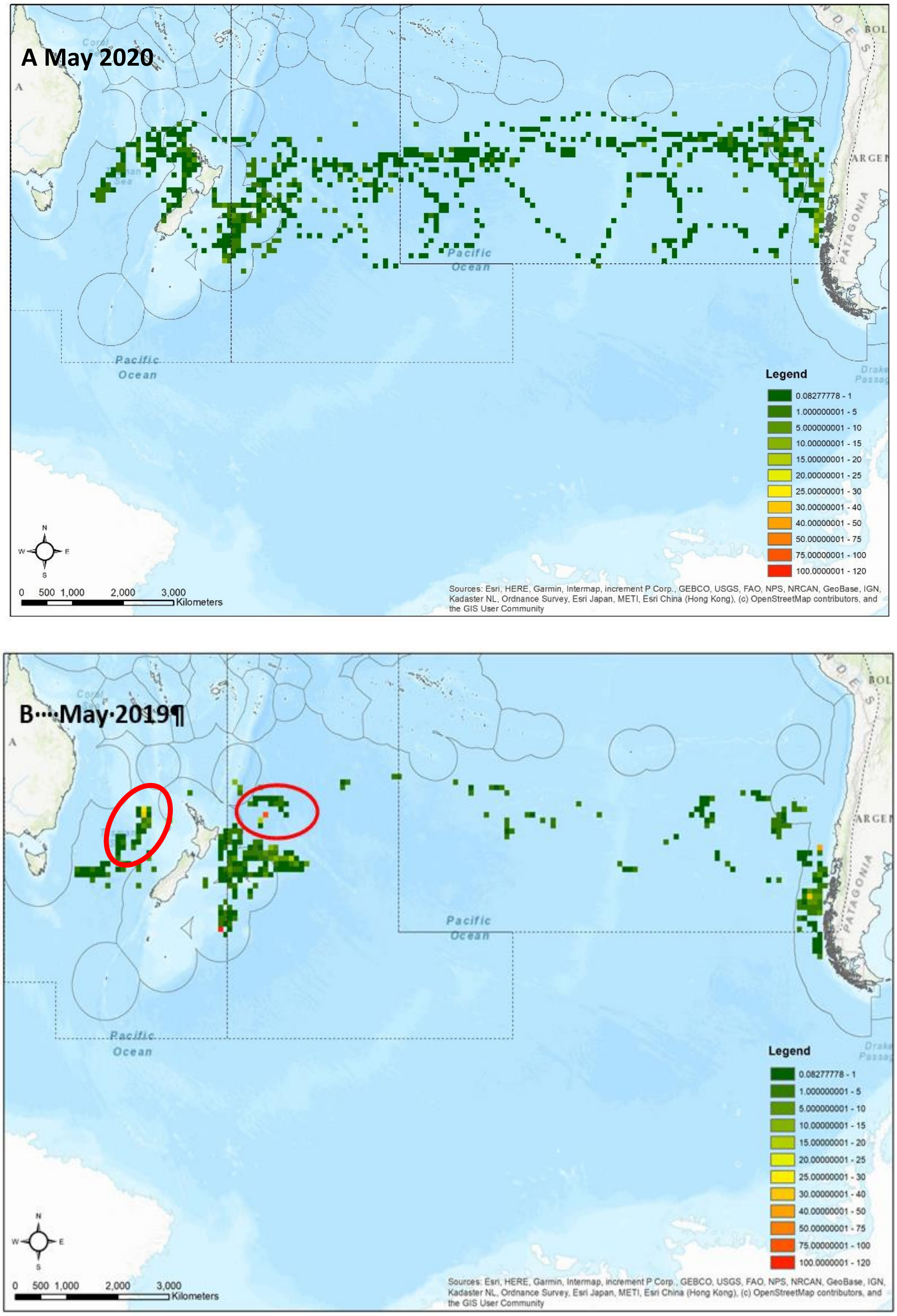


Figure 19. Spatial distribution of tracked non-breeding female Antipodean albatross in a) May 2020 and b) May 2019 (average number of bird hours per 100 km x 100 km grid cell). Red is highest occurrence, dark green lowest. Dashed lines indicate RFMO boundaries. Red eclipses in b) indicate high occurrence leading to the relatively high overlap with pelagic longline fishing effort.

Overlap with pelagic longline fishing effort by vessel and flag state

During 2020, tracked Antipodean albatrosses overlapped with 188 pelagic longline fishing vessels of eight flag states, the greatest number being flagged to Chinese Taipei, China, Vanuatu, and Japan, the remaining vessels being flagged to New Zealand, Fiji, Spain, and Cook Islands (Table 1). These fleets are broadly similar between 2019 and 2020 with most overlap being with Chinese Taipei and Vanuatu flagged vessels in both years (Figure 20), followed by China, Spain, Japan, and New Zealand flagged vessels, with the proportion of overlap varying between cohort and year.

Some individual vessels were found to overlap with numerous tracked birds. In 2019 26 pelagic longline fishing vessels overlapped with ten or more tracked birds, with one vessel overlapping 21 of 63 tracked birds. In 2020, 13 vessels overlapped with 10 or more birds, with one vessel overlapping 13 of 40 tracked birds (Figure 21). These figures do not correct for tag failure over the year; if all tags continued to transmit through the tracking year even higher proportions of tagged birds would likely overlap with each vessel. There was consistency between years in the individual vessels overlapping with most birds, with all but one of vessels overlapping with ten or more birds in either year also overlapping with birds in the other year (Figure 21).

When considering birds that were tracked until at least 1 September each year, i.e. over the main period of pelagic longline fishing effort overlap, all 22 birds in 2020 overlapped with at least one vessel, and one bird overlapped with 88 different vessels (Figure 22). A similar pattern occurred in 2019 with all but one of 23 birds overlapping at least one vessel, and one bird overlapping with 54 different vessels.

The 188 vessels that overlapped with Antipodean albatross in 2020 collectively visited ports in 19 port states with Fiji, Chinese Taipei, New Zealand, Japan and Solomon Islands accounting for the greatest number of unique vessel visits in 2020 (Figure 23, Table 1).

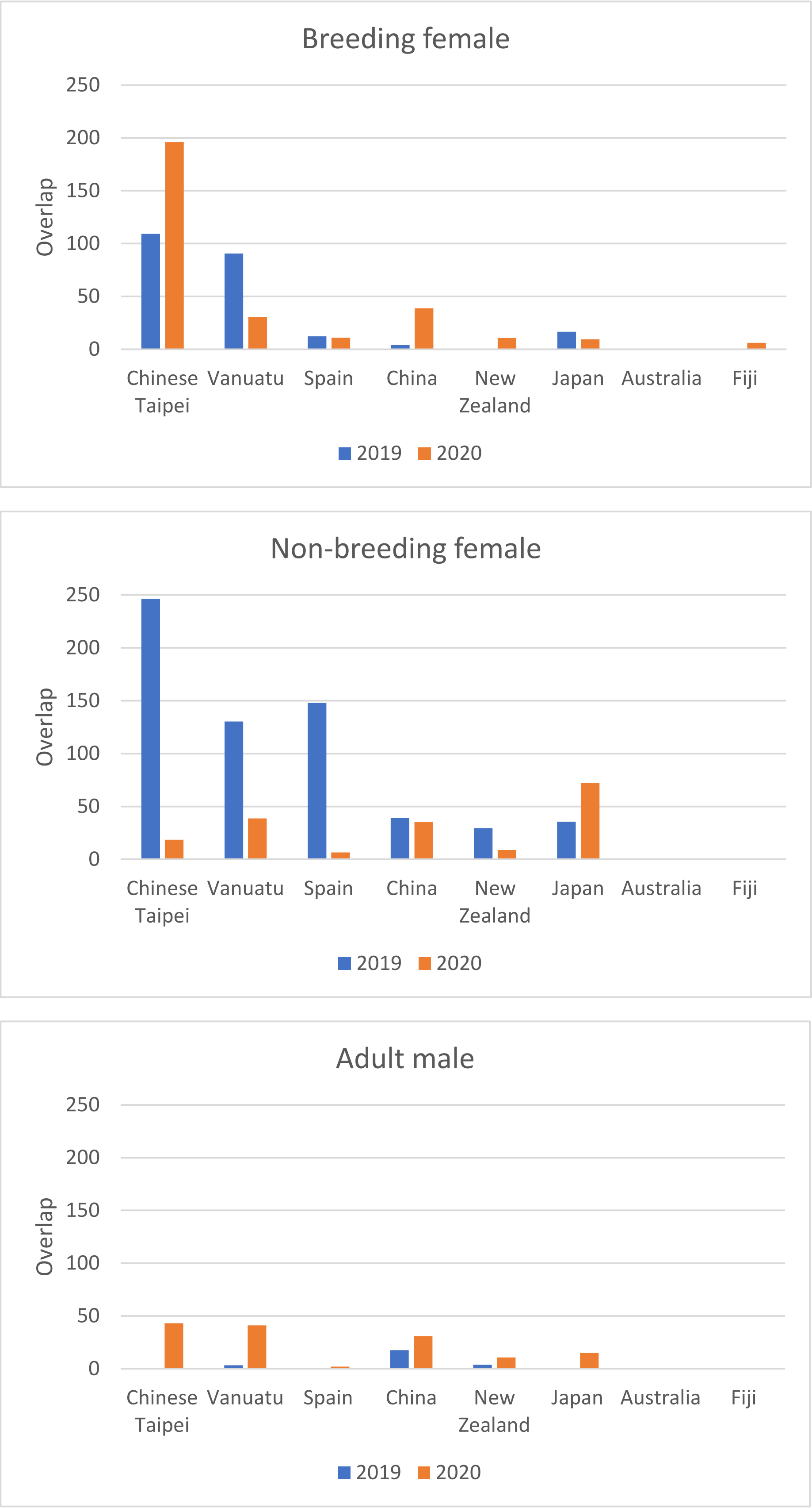


Figure 20. Year-round cumulative daily overlap of tracked breeding female, non-breeding female and male Antipodean albatross with pelagic longline fishing effort by flag state of overlapping vessels in 2019 and 2020.

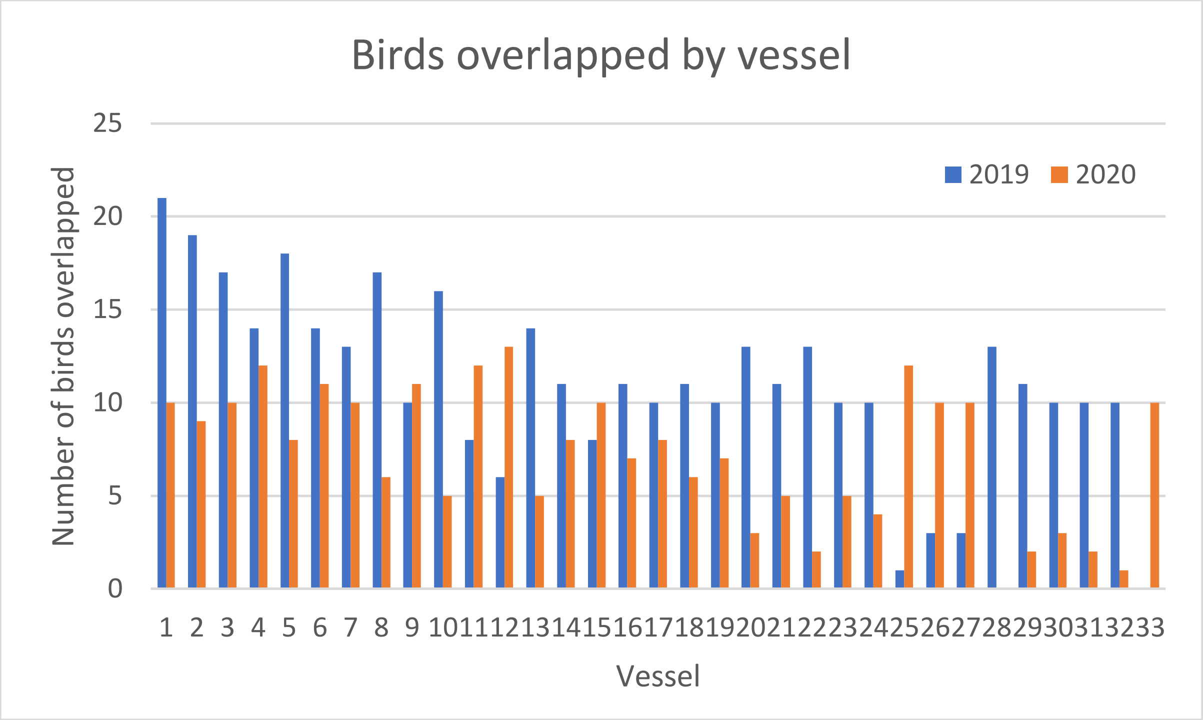


Figure 21. Number of Antipodean albatross (birds) overlapped by vessel for all vessels that overlapped with 10 or more Antipodean albatross in either 2019 or 2020.

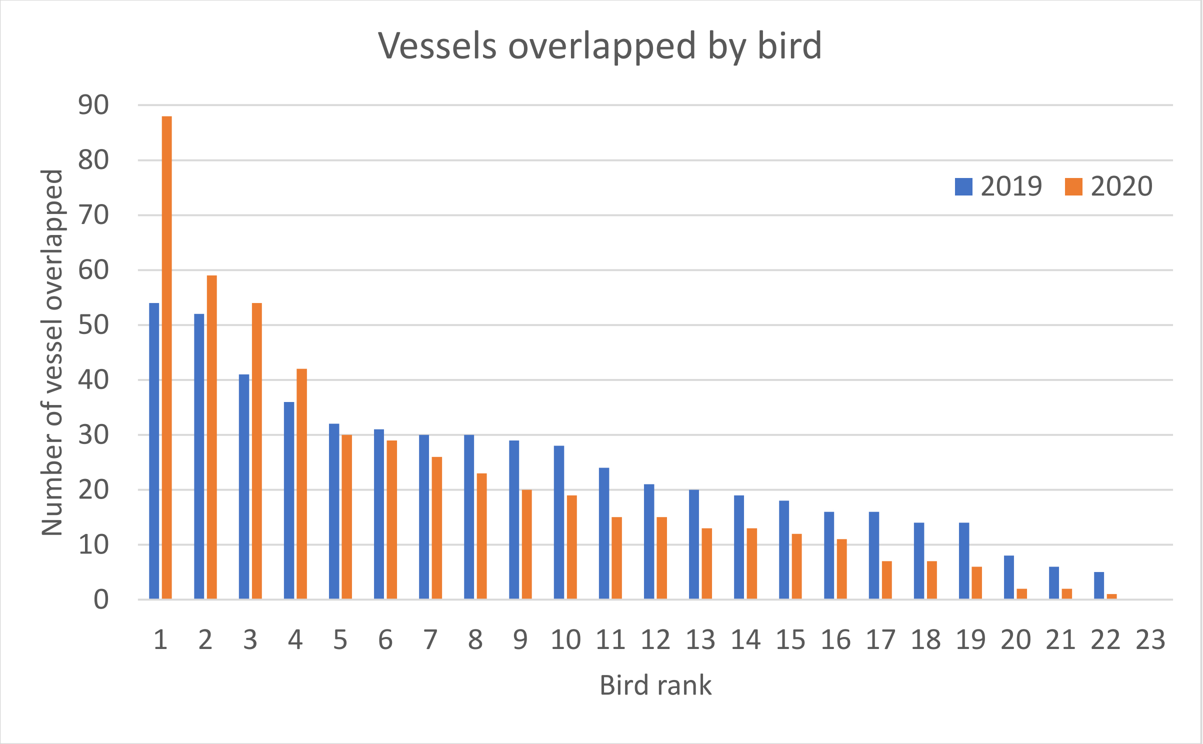
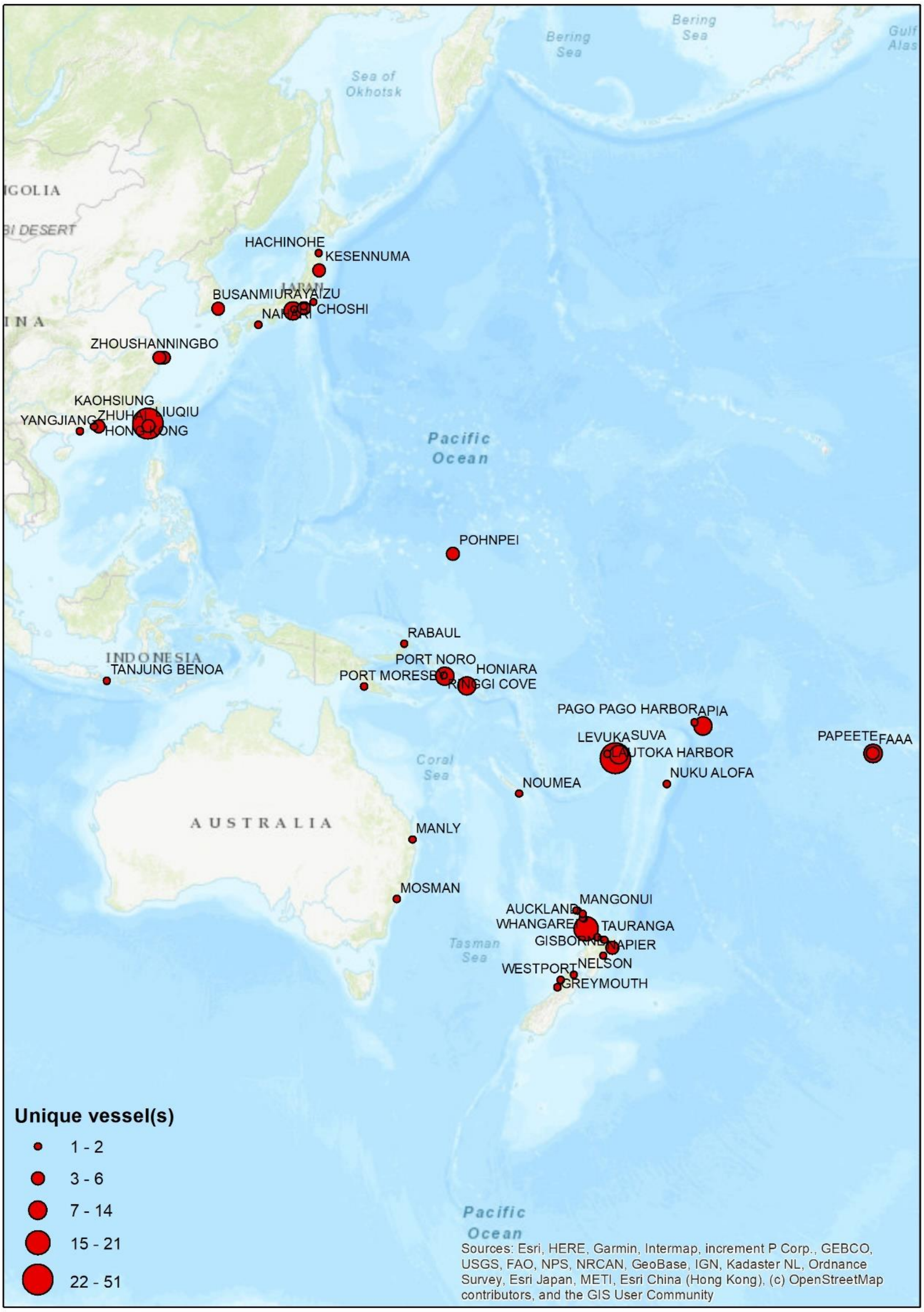


Figure 22. Number of vessels overlapped by each Antipodean albatross (bird) tracked through until at least 1 September in 2019 or 2020. Individual birds ranked each year by number of vessels overlapped.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 23. Western Pacific ports used by vessels that had fishing effort overlap (using the adjusted point-based method) with Antipodean albatross in 2020. The size of the circle is proportional to the number of unique vessel visits to these ports in 2020.

Table 1. Number of vessels that had fishing effort overlap with Antipodean albatross (within 100 km and within 24 h of a bird location) and the number of unique vessel port visits in 2020, by flag state and port state. FSM = Federated States of Micronesia

Number of vessels/ Port state	Flag state								
	China	Cook Islands	Spain	Fiji	Japan	New Zealand	Chinese Taipei	Vanuatu	Total
Number of vessels	49	1	4	6	21	7	77	23	188
American Samoa							12		12
Australia					2				2
China	11						1	2	14
Spain			1						1
Fiji	25	1		9			18	8	61
FSM					4				4
Indonesia					1				1
Japan					30				30
Korea	2							4	6
New Caledonia					1				1
New Zealand			2		19	19			40
Panama			5						5
Peru					2				2
Papua New Guinea					3				3
French Polynesia	4		6		1			3	14
Solomon Islands							21		21
Tonga				1			1		2
Chinese Taipei							35	16	51
Western Samoa							1		1

Conclusion

Like many quantitative distribution or fisheries overlap studies we faced limitations with our data inputs and methods. One of the major limitations of this study has been the tracked cohort sample size and the longevity of tags over each year-long study period. 2020 was the second year of intensive satellite tracking of Antipodean albatross, and whilst there were new challenges faced in this second year due to delayed and restricted field work (Elliott & Walker 2020), the overall performance of tags was improved compared to 2019. For comparable cohorts we have seen consistent patterns between years (in particular for breeding females; Figure 7) which corresponded well with historic tracking data (Elliott and Walker 2018). This provides confidence that our results are likely to be representative of long-term foraging patterns of the cohorts, despite being based solely on a limited number of tracked birds. As the tracking programme is extended into 2021 and beyond, the application of the methods we have developed here will provide even greater understanding of fishing effort overlap and will allow us to better examine year to year variation. Another key uncertainty in our fishing effort overlap assessment is that we had to rely on fishing effort data derived by GFW from AIS and VMS data sources. Our preference would have been to describe fishing effort using data on the number of hooks set at each location by each vessel. However, such data is not publicly available, and the effort data that is available is at such coarse spatial resolution is subject to various availability limitations (Francis & Hoyle 2019), meaning that we would have been unable to estimate overlap at a scale corresponding to the resolution of our tracking data.

Despite these limitations, our analyses from this second year of intensive satellite tracking of Antipodean albatross have provided greater certainty on with which fleets, and even with which vessels, birds overlap. We have improved our understanding of different cohorts, in particular adult males for which tracking data were particularly poor in 2019 due to tag failures. We have found differences in year-to-year distribution and overlap with fishing effort between 2019 and 2020, but the major findings from 2019 (reported by Bose & Debski 2020) have been reiterated and further refined. The greatest overlap between Antipodean albatross and fishing effort is with pelagic longline fishing and most overlap is in the high seas, particularly in the WCPFC north-east of New Zealand and in the mid-Tasman Sea. We have found consistency in the pelagic longline fleets overlapping with Antipodean albatross, with Chinese Taipei and Vanuatu flagged vessels having the highest relative overlap, with many of the same fishing vessels overlapping with birds in both years.

We have shown that over the course of a year the chance of an Antipodean albatross overlapping pelagic longline fishing effort is high. Almost every bird that was successfully tracked over the entire austral winter overlapped with pelagic longline fishing effort (Figure 22). Many birds overlapped with multiple vessels, up to 88 vessels by one bird. Likewise, individual pelagic longline vessels were found to overlap with multiple birds, with up to a third of all tagged birds in any one year overlapping individual vessels (Figure 21). Each time an Antipodean albatross encounters pelagic longline fishing activity there is a risk of bycatch. This risk can be greatly reduced through use of effective seabird bycatch mitigation (ACAP 2021), but the more vessels a bird encounters, the more likely birds may encounter fishing operations that use poor or no seabird bycatch mitigation. Indeed, we have found birds travelling as far north as 21°S, where there are no mandatory requirements for seabird bycatch mitigation use in either the WCPFC or IATTC areas.

Recent population modelling (Richard 2021) has shown reduced adult survival to be a major driver of the population decline seen since 2005 and found a greater reduction in survival for females compared to males. Fisheries bycatch of seabirds affects population dynamics through reduction in survival. The more northerly distribution of adult female birds compared to males (Figures 4-6) overlaps with more pelagic longline fishing effort which intensifies in more northerly areas of the South Pacific (Figure 11). Indeed, we have found adult females had greater overlap with pelagic longline fishing effort compared to males (Figure 17), likely putting them at higher risk of bycatch, particularly in more northerly areas where there are less stringent or no mandatory requirements for seabird bycatch mitigation use.

A great advantage of using the GFW derived fishing effort data has been that we have been able to identify individual vessels and investigate overlap at a vessel and fleet level. Further, we were able to identify where these vessels visited ports. This level of detail in our results is of great importance in helping to inform where seabird bycatch reduction outreach efforts should be focussed to ensure this threat to Antipodean albatross is minimised or avoided.

Acknowledgements

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