Migratory Connectivity of the Chatham Albatross: Assessing Vulnerability to Longline Fishing Throughout Their Migratory Cycle

By

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Executive Summary

Unremitting population declines of migratory species have led to demands for connectivity information, generated from the recent profusion of animal tracking data, to be more effectively integrated into management. The Migratory Connectivity in the Oceans system (MiCO) was launched in August 2019 to deliver on the need for an evidence-base of actionable and synthesized knowledge on migratory connectivity, with the goal of ultimately bridging the gap between data producers and policy and management arenas. This study contributes to the open-access MiCO prototype by providing migratory connectivity knowledge on the migratory seabird, the Chatham Albatross *Thalassarche eremita*, through identifying general and core use areas for the species unique behavior nodes and migratory corridors throughout the South Pacific Ocean using Kernel Density Estimation (KDE). The Chatham Albatross has a history of longline fishery interaction, and has been recorded as bycatch in artisanal longline fisheries in both Peru and Chile's Exclusive Economic Zones (EEZs) and in demersal and pelagic longline fisheries in New Zealand, but few or no data exist for Chatham Albatross bycatch in the South Pacific. The second objective of this study is to assess Chatham Albatross vulnerabilility to longline fishing throughout it's annual cycle, with a particular interest in international waters, by performing an overlap analysis between areas used by the Chatham Albatross and the location of longline fishing effort. Results reveal that the Chatham Albatross has strong spatial connectivity throughout it's post-breeding migratory corridor from the Chatham Islands to South America, using a single narrow corridor, and strong temporal connectivity throughout it's pre-breeding corridor from South America back to the Chatham Islands, as most birds are migrating during one month of the year- August. The overlap analysis reveals that the greatest potential for interactions with longline fishing fleets is likely to be in August when the Chatham Albatross is migrating from South America back to the breeding site at The Pyramid, as significant, isolated fishing effort overlaps in three different areas throughout the migratory corridor, including a core area in the high seas. This core area overlaps with an existing proposed Ecologically or Biologically Significant Biodiversity Area (EBSA) along the Salas y Gomez and Nazca submarine ridges. The identification of this site as being a potential time and space of interaction with fisheries and the Chatham Albatross, can provide new information in revisiting EBSAs, through describing new areas, and help strengthen the existing Salas y Gomez and Nazca EBSA.

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1 Introduction

1.1 Migratory Connectivity

Migratory species spend different stages of their annual, migratory cycle in extensively separated ecological areas of the world, often migrating from one critical habitat (i.e. breeding site) to the next (i.e. non-breeding site) (Webster et al., 2002). Recently, there has been a proliferation of research about marine migratory species that has revealed that some species ranges are wider than previously thought, and that we may be able to predict migration patterns, spatially and temporally (Dunn et al., 2019). More specifically, improvements in animal tracking technology have allowed for a greater understanding of migratory connectivity, or "the geographical linking of individuals and populations throughout their annual migratory cycles," (Dunn et al., 2019).

Understanding the degree of migratory connectivity a population has throughout their life history, such as the number of sites used across the migratory cycle, can help us understand the spatial and temporal dynamics of stressors they are exposed to and the degree to which they respond to selective pressures. For instance, stressors that occur at one stage of the annual cycle or in one season, may impact the performance of the population in the next, depending on the degree of connectivity (Briedis & Bauer, 2018). Populations demonstrating weak connectivity throughout their annual cycle, which means that individuals from a breeding area might utilize many foraging sites or migratory corridors in space and time, will likely exhibit significant genetic variation in the context of migratory behavior, such as in direction or timing (Webster et al., 2002). This means that these populations may be able to respond quickly to alterations in their preferred breeding and non-breeding (or wintering) habitats. Conversely, populations demonstrating strong connectivity may not exhibit as auspicious of an evolutionary response to significant changes in climate, for instance, as the population is unlikely to contain much genetic variation (Webster et al., 2002). This is because they are likely to use similar corridors in space and time to traverse between different stages of their migratory cycle. Understanding migratory connectivity means understanding the factors that govern species abundance and population size in time and space, which are fundamental to conservation. For vulnerable species in which large

portions of a population utilize only one restricted breeding or wintering location, a well-founded understanding of their annual geographical ranges is particularly important in developing effective, long-term, and integrated conservation plans (Webster et al., 2002).

1.2 Migratory Connectivity in Management

Sustainable management of migratory species involves an understanding of their entire life history, including all stages of their critical habitats and migratory corridors, behavior, and exposure and interactions with anthropogenic stressors, such as fisheries, habitat degradation or severe weather, as these pressures can scale up to impact population abundance and distribution (Dunn et al., 2019). However, while the recent improvements in animal tracking technology have enhanced this understanding of migratory connectivity and have allowed for a deeper understanding of its implications for conservation, migratory species are declining (Dunn et al., 2019). For instance, 95% of albatross species are on the IUCN Red List, and considered Vulnerable, Endangered, or Critically Endangered (Dunn et al., 2019). The wide-ranging, circumpolar or pole-to-pole migrations of albatrosses expose them to stressors such as, predation, severe weather, habitat destruction, and fishing mortality, which can scale up to influence population abundance and distribution (Dunn et al., 2019). Moreover, migratory species can cross one or more national jurisdictional boundaries, or Exclusive Economic Zones, and pass through the high seas, or areas beyond national jurisdiction (ABNJ). Migratory seabirds, such as albatrosses and petrels, spend a significant portion of their migration in the high seas, which are increasingly understood to be the least known and most difficult to govern of marine ecosystems (BirdLife International & Global Procellariiform Tracking Workshop, 2004). Limitations in management of migratory species, especially in the high seas, have hampered the development of effective management strategies for migratory species (Dunn et al., 2019). These limitations include geographic and taxonomic gaps in management, lack of integrated management and conservation tools across sectors, lack of implementation of ecosystem-based management approaches, and conservation strategies that narrowly focus on single stages of a migratory species annual cycle with minute consideration of connectivity (Ban et al., 2014). Geographic gaps include inconsistencies in MPAs and fishing closures in the high seas, as well as between Regional Fishery Management Organizations, with large swaths of the high seas still ungoverned

(Ban et al., 2014). Taxonomic gaps includes different definitions of migratory species in science and policy. Some species that are omitted from policy definitions might suffer in management (Dunn et al., 2019). Management in the high seas is also not coordinated, and there is no transparent process for weaving together existing conservations tools, and there are many disparate interventions for migratory seabirds, such as international treaties like the Agreement on the Conservation of Albatrosses and Petrels (ACAP), national regulations, and FAO's International Plan of Action for Reducing Incidental Catch of Seabirds in Longlines, that only apply to participating States (Ban et al., 2014).

Migratory species do not observe boundaries, and as such, need to be managed with a unified approach that considers their entire life history and how it's connected. Unremitting declines in populations of migratory species have led to demands for this connectivity knowledge generated from the profusion of animal movement data to be more effectively integrated into management (Dunn et al., 2019). Connectivity hasn't been completely absent from policy, however, and has been included in international policy in the form of area-based management approaches. Birdlife International has led the charge to identify Important Bird and Biodiversity Areas (IBA), based on the proportion of a population using a specific area. While most sites identified as an IBA are usually breeding and foraging habitats, if enough of a population is aggregated during migration, a migratory corridor might also be identified as an IBA (Dunn et al., 2019). Birdlife International also developed the Global Procellariform Tracking Database, whereby over 500 tracking datasets live that can be used to identify IBAs and in fishery overlap analysis (BirdLife International & Global Procellariiform Tracking Workshop, 2004). The Convention on Biological Diversity (CBD) identifies Ecologically or Biologically Significant Marine Areas (EBSAs), and while connectivity is not overtly one of the seven criteria for identifying an EBSA in Annex I, it is one of CBD's criteria for selecting areas in identifying a representative network of marine protected areas (Dunn et al., 2019). Additionally, Annex II contains suggestions for network criteria, including connectivity, yet has not been adopted yet. The Aichi Biodiversity Targets, which are a set of conservation goals to protect global biodiversity, contain connectivity language in Target 11, which pleas for "10% of coastal and marine areas to be conserved through well-connected systems of protected areas," (Dunn et al., 2019). The Convention on Migratory Species (CMS) has Resolutions on Ecological Networks, where they encourages States to consider connectivity

between areas when describing areas of importance. However, while the concept of connectivity is omnipresent in international environmental treaties and agreements, a deficiency of easily accessible and serviceable geospatial information prevents the complete deliberation of migratory connectivity in management and planning processes (Dunn et al., 2019).

1.3 The Migratory Connectivity in the Ocean Consortium

In an effort to deliver on the need for an evidence-base of actionable and synthesized knowledge on migratory connectivity, the Migratory Connectivity in the Ocean (MiCO) consortium was launched in August 2019 at a UN Intergovernmental Conference on a new "international treaty for the conservation and sustainable use of marine biological diversity of ABNJ" (Dunn et al., 2019).The consortium is an open-access data sharing system, connecting existing global processes with usable knowledge on migratory connectivity. Led by the Marine Geospatial Ecology Lab (MGEL) at Duke University and made possible by a growing list of international partners, the MiCO system is ultimately an endeavor to bridge the gap between individuals or organizations producing the data and policymakers or management organizations. Specifically, the MiCO system synthesizes best available information about migratory connectivity for marine mammals, seabirds, sea turtles and fish species through performing a complete literature review and aggregating existing data, such as electronic tracking data, mark-recapture, observations, stable isotope ratios, population genetics and passive acoustic monitoring (Dunn et al., 2019). By combining these data, we can visualize in space and time the critical habitats that species depend on throughout their life cycles, including their global migratory corridors.

To aid the transfer of and make transparent this actionable knowledge, a prototype system was developed, whereby information on general and core-use areas for a particular species lives, categorized by behavior or activity (breeding, migrating, non-breeding, etc.). Specifically, MiCO identifies unique nodes and migratory corridors for the species and generates general and core use areas within them. Nodes are grouped areas of non-migratory behavior, such as wintering, breeding and foraging. Corridors are grouped, or aggregated areas used by birds that are migrating. Currently, the protype provides information for over 357 animals making up more than 7 species (Dunn et al., 2019). For this master's project, I contribute to the MiCO system

platform by synthesizing information for just one more species -- the IUCN-classified Vulnerable seabird, the Chatham Albatross *Thalassarche eremita*. Specifically, I aggregate two satellite tracking datasets performed over the course of three years from 1997-1999, both provided by David Nicholls, and generated general and core-use areas for the entire life history of the Chatham Albatross, including nodes and migratory corridors. In addition to identifying use areas by nodes and corridors for the Chatham Albatross using refined MiCO methods, I also identified monthly use areas. Monthly node and corridor use-areas were generated to allow for temporal precision in assessing my second objective: to assess Chatham Albatross vulnerability to longline fishing throughout its annual migratory cycle by quantifying overlap between marine areas used by Chatham Albatrosses and the location of longline fishing effort. Many seabird-fishery interaction analyses overlay density maps, or use area maps, with fishing effort derived from point locations. These studies can be disingenuous, as they represent birds and boats as static objects. I attempt to consider the spatial and temporal dynamics of birds and vessels (Torres et al., 2013).

1.4 The Chatham Albatross

The Chatham Albatross is one of the least studied of albatrosses with its entire population breeding only on The Pyramid- a nearly inaccessible rock stack in the Chatham Islands to the east of New Zealand (Deppe et al., 2014). This single extremely restricted breeding site significantly increases the vulnerability of this species to all threats and gives reason to believe that the species has strong connectivity to its non-breeding wintering area. However, only three years of tracking data are available for the Chatham Albatross to assess the population trend, connectivity and distribution. From this data, it has been estimated that there is a population of approximately 11,000 breeding individuals, up from approximately 8,000 birds in 1998, laying eggs once a year beginning in September and chicks fledging in March or April (BirdLife International & Global Procellariiform Tracking Workshop, 2004). Productivity is considered low, as Chatham Albatross only begin breeding at the age of 6 and birth one chick, if any, per year (*Chatham Albatross*, n.d.). During the breeding months, Chatham Albatross forage almost entirely in New Zealand's EEZ. Failed breeders, and then successful breeders soon after, migrate every year across the South Pacific to sojourn in South America for the winter, between January

and April. After a rapid eleven to thirty-day eastward migration across the Pacific Ocean to Chile's EEZ, the Chatham Albatross migrates northward up to Peru's coast via the Humboldt Current to their non-breeding area, and traverse in a more northerly course back across the Pacific Ocean to the breeding site at The Pyramid between April and August (Nicholls, 2007).

1.5 Threats to the Chatham Albatross

The major threat to the Chatham Albatross at the single, extremely restricted breeding area is habitat degradation. Changing climatic conditions and severe weather events have resulted in loss of soil cover and reduction of vegetation, which have implications for breeding success (*Chatham Albatross*, n.d.). The long-distance migratory behavior of the Chatham Albatross also makes it susceptible to fisheries interactions across the South Pacific Ocean. Longline fishing in particular is thought to partially govern the adverse conservation status of the bird order, Procellariforms, of which Chatham Albatross belong (BirdLife International & Global Procellariiform Tracking Workshop, 2004). During longline fishing, seabirds are caught, entangled, or drowned in fishing lines. An estimated 160,000 seabirds are killed annually from longline fisheries, with albatrosses being one of the most frequently caught species (Anderson et al., 2011). Through at-sea observations, the Chatham Albatross is considered an insistent feeder behind fishing vessels and exhibits vessel-following behavior (SPRFMO, 2007). In New Zealand's EEZ, the Chatham Albatross has been observed as bycatch in both demersal longline fisheries for Ling and pelagic longline fisheries for tuna (*REPORT OF THE EASTERN TROPICAL AND TEMPERATE PACIFIC REGIONAL WORKSHOP TO FACILITATE THE DESCRIPTION OF ECOLOGICALLY OR BIOLOGICALLY SIGNIFICANT MARINE AREAS*, 2012). The Chatham Albatross interacts and has been killed by longline fishing fleets within Peru and Chile EEZs, as well. In Peru alone, the Chatham Albatross- along with 8 or more species- has been recorded as bycatch in artisanal longline fisheries with approximately 194-544 birds killed per year (Bernal, n.d.). In high seas areas or ABNJ of the South Pacific, few or no data exist for seabird bycatch from longline fishing (*Chatham Albatross*, n.d.). Although the proportion of time spent in the high seas by the Chatham Albatross is relatively low (SPRFMO, 2007), the species small effective population size, coupled with sometimes ineffective or incomplete governance in the high seas as explained above, make them vulnerable to any level of

mortality through longline fishing interactions. Here, I attempt to assess potential areas of interaction between Chatham Albatross and longline fishing fleets both within EEZs and in ABNJ, but with a particular interest in ABNJ. In this study, Global Fishing Watch (GFW) fishing effort data was used to analyze potential areas of interaction. GFW was founded to analyze and provide information on the behavior of fishing vessels from global electronic monitoring data such as the vessel monitoring system (VMS) or the automatic identification system (AIS) (Guillermo, Ortuño Crespo, 2018). GFW assesses vessel movement and behavior through using "neural network algorithms and logistic models" to categorize the different types of fishing gear used, in addition to the locations and timing of deployment of the gear (Guillermo, Ortuño Crespo, 2018).

2. Methods and Materials

2.1 Chatham Albatross Argos Tracking Data

The Chatham Albatross tracking data was provided by David Nicholls and consists of 33 tracks from 13 birds from 1997 to 1999. In 1997, three birds were tracked using the CLS:Argos system, which connects a location, data-collection receiver aboard NOAA satellites, and platform transmitter terminals (PTT) attached to the animals (Nicholls & Robertson, 2007). The PTT regimes gave locations every 1.5 to 2.5 days until the batteries died. From 1998 to 1999, ten birds were tracked using the same system, but with a regime that provided locations daily (BirdLife International & Global Procellariiform Tracking Workshop, 2004). The data supplier cleaned the data before providing it to MiCO, retaining by location class, which is an indicator of location accuracy with 3 being the most accurate and Z being the least accurate, and a Quality Index, which rates the performance of the transmitter in terms of signal stability and frequency (Nicholls & Robertson, 2007). Only tracks with location class 0, 1, 2 and 3 were given to the MiCO system. Tracks were labeled by activity (into breeding and non-breeding behaviors) by Nicholls prior to providing data to MiCO (**Figure 1**).

Figure 1: Chatham Albatross tracks from 1997-1999, separated by behavior (breeding and non-breeding).
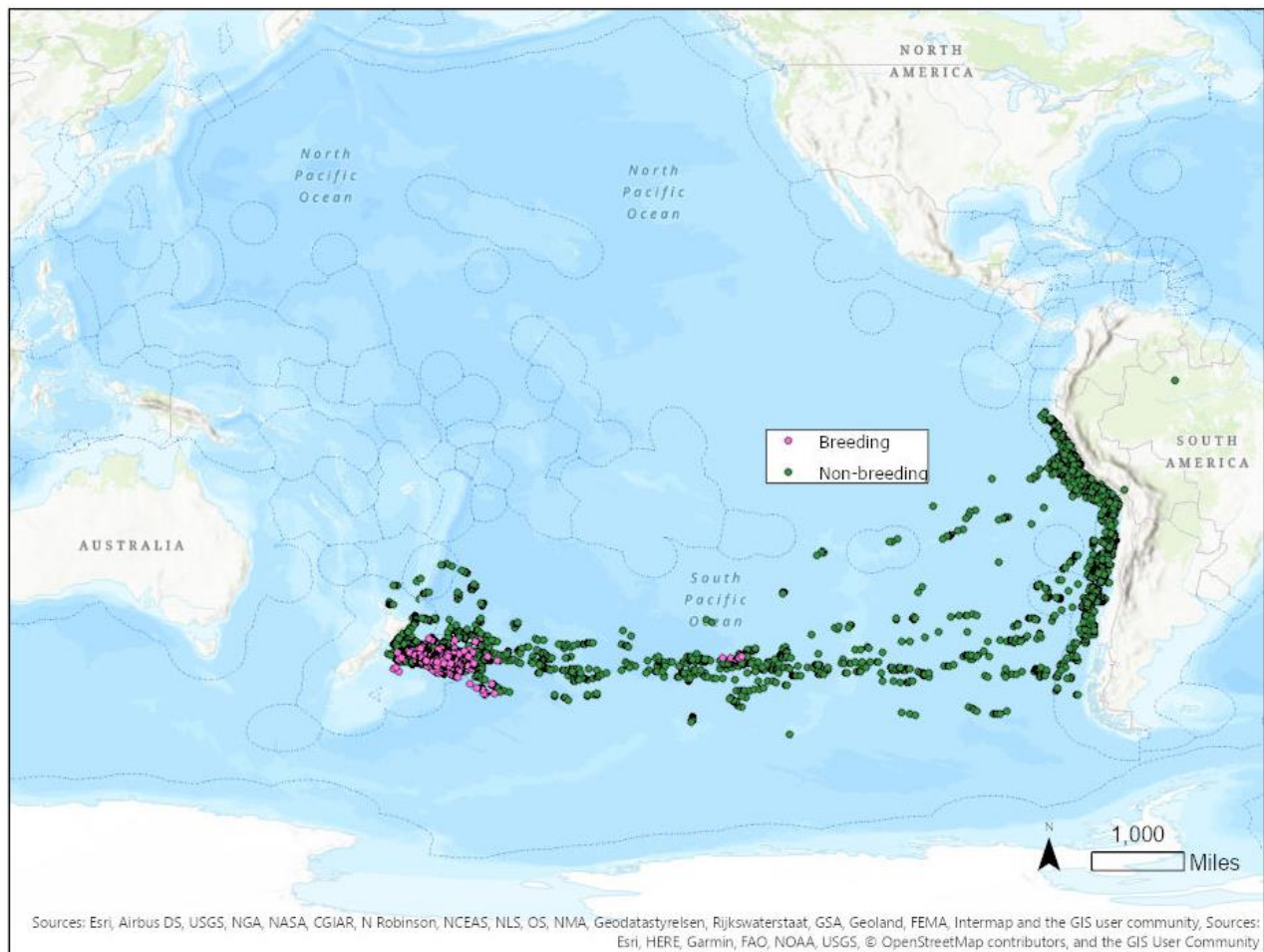
2.1.1 Identifying Use-Areas and Corridors for Chatham Albatross

Data were formatted, cleaned and standardized by the Marine Geospatial Ecology Lab at Duke University before I performed subsequent filtering, track segmentation and kernel density analysis. General and core-use areas for the Chatham Albatross nodes and corridors were identified from both the literature and the tracks, and generated via refined MiCO methods, whereby well-accepted kernel density estimation (KDE) methods were performed using R statistical software (*Methods*, 2020) (R Core Team 2018). The KDE algorithm calculates a density distribution from the tracking locations and a probability distribution of the space used (Le Bot et al., 2018). Monthly use areas for the Chatham Albatross nodes and corridors were

identified via altered MiCO methods (*see section 2.1.1.4*). Again, these monthly areas were identified to overlay monthly fishing effort data with Chatham Albatross monthly use areas to achieve a finer scale seabird-fishery interaction analysis.

2.1.1.1 Speed, Distance, Angle Filter (MiCO Methods)

Argos data, when tracking seabirds or any moving animal, may be inherently erroneous due to potential unavailability of Argos satellites during the time a transmitter provides a location. In addition to aforementioned filtering of data by Nicholls, the tracks were filtered via a speed, distance, angle algorithm from the R package *argosfilter,* in order to regularize the tracks and prevent biases in space and time in the estimation of Chatham Albatross area use. The filter takes into account the Chatham Albatross maximum flight speed taken from the peer-reviewed literature (84.5 km h-1 or 23.58 m/s) (Nicholls, 2007), the distance between successive points, and the turning angle (-1) to rid of locations in which exceed what is biologically possible for the Chatham Albatross (*Methods*, 2020) (Freitas 2012).

2.1.1.2 Track Segmentation (MiCO Methods)

In order to create general and core-use areas for Chatham Albatross nodes and corridors, the tracks needed to first be separated into breeding and non-breeding portions of the annual cycle, and then segmented into migratory and non-migratory categories. As mentioned above, the data provider already labeled the tracks by activity (breeding and non-breeding), so the data was separated and grouped by these labels. The breeding tracks were grouped as the breeding node and was set aside for later KDE analysis. The non-breeding tracks were segmented further into migratory and non-migratory categories. Net squared displacement (NSD), which is the squared distance between successive points and the initial point in the track line was computed for every non-breeding segment (*Methods*, 2020). NSD used in a behavioral change point analysis framework to separate a track line into distinct segments. All of the individual tracks were plotted to visually examine and categorize them based on destination or absence of migration. Within those categories, each individual track was then segmented using the Lavielle contrast function (Lavielle 1999;2000) through the R package *adehabitatLT* (Calenge 2006), which is

another behavioral change point analysis framework. These tracks were then manually grouped into one of these remaining three nodes and corridors that Nicholls and Robertson identified for the Chatham Albatross in 2007: (a) "eastward migration across South Pacific", or post-breeding migration corridor to the coast of Peru and Chile; (b) "localized foraging off the coast of South America", or non-breeding node off the coast of Peru and Chile, and; (c) "westward migration to breeding site", or pre-breeding migration corridor to the Chatham Islands. Nicholls and Robertson identified another stage of the Chatham Albatross flight regime, which was migration heading north up the South American West Coast from Chile to Peru. However, I included this stage in the non-breeding node off the coast of Peru as it was difficult to manually identify the difference between the two stages, while also minimizing the contrast function.

2.1.1.3 Kernel Density Estimation (MiCO Methods)

Kernel density estimates were created for each individual node and corridor (breeding node at The Pyramid, post-breeding migratory corridor to Peru and Chile, non-breeding node off the coast of Peru and Chile, and pre-breeding migratory corridor back to the breeding site) to identify general and core use areas for each, using the R package *ks* (Duong 2018). The mean integrated square error (MISE) bandwith outputted from the KDE function in the R package *ctmm* (Fleming and Calabrese 2018) was used in creating the KDEs. This bandwith was used because MiCO scientists performed exploratory work on alternative bandwith estimators and found the MISE bandwith to have the least amount of smoothing issues and MISE does not make the assumption that data is independent (*Methods*, 2020). Density estimates that were outputted for each segment were stacked and averaged to take into consideration variability in the length of a segment or tracking duration, and ultimately to generate one KDE for each node and corridor. Contour levels were then calculated for the averaged KDEs for each node and corridor. MiCO classifies the 25% contour level as the core area for the species and the 90% contour level as the distribution, or home range, of the species. In this study, I classify the contour levels in the same way, but refer to the 25% contour as the core area and the 90% contour as the general use area.

2.1.1.4 Kernel Density Estimation: Preparing Monthly KDEs for Longline Fishing Effort

   Overlay

After segmenting the tracks into nodes and corridors (*section 2.1.1.2)* and before performing kernel density analysis*,* the tracks within each node and corridor were separated by month to prepare for an overlay with the monthly longline fishing effort data. For instance, tracks within the breeding node consisted of 6 months: January, February, March, October November and December (**Table 1).** For each month within a node or corridor, a KDE was created using similar methods as in *section 2.1.1.3*. However, if only one individual was tracked during a given month in a given node or corridor- say one tracked individual in January- then a KDE was not created for that month. This was to ensure that the behavior of a single tracked individual would not produce hot spots in areas not visited or frequented by any other tracked individuals in the dataset.

*Table 1:* Nodes and corridors partitioned by month to prepare for fishing effort overlay analysis.

Node/corridor	Month(s)	Number of Segments
Breeding	January	4
	February	3
	March	3
	October	2
	November	8
	December	12
Post-breeding migration from The Pyramid to South America (New Zealand migration)	January	5
	February	6
	March	2
	April	1
	November	1
	December	3

Non-breeding area off the coast of Chile and Peru	January	1
	February	5
	March	7
	April	8
	June	5
Pre-breeding migration from South America to The Pyramid (South America migration)	January	1
	February	1
	July	1
	August	3

2.2 Global Fishing Watch AIS Longline Fishing Data

Fishing effort data used in this study were acquired from Guillermo Ortuño Crespo from the MGEL lab, and originally provided by Global Fishing Watch (GFW). The data used in this study were AIS longline fishing effort data for 2015 and 2016 - including ships from 114 countries and territories - where fishing effort is calculated as hours of fishing, and where resolution is 1x1 degree (~85 sq. miles) (**Figure 2)**. While there is an obvious temporal mismatch between the Chatham Albtross and GFW datasets, these were the *only* datasets available for the Chatham Albatross and the most *robust* fishing effort datasets available. GFW provides fishing effort data from as early as 2012, however, I chose the 2015 and 2016 datasets as there were likely a greater amount of orbiting satellites during this time compared to 2012, capturing a truer representation of longline fishing events (Guillermo, Ortuño Crespo, 2018). Data was originally provided for the entire global ocean but was clipped in ArcGIS Pro to just included data within the general South Pacific Ocean area. It is important to mention that the categorization of longline fishing effort by GFW is subject to classification error.
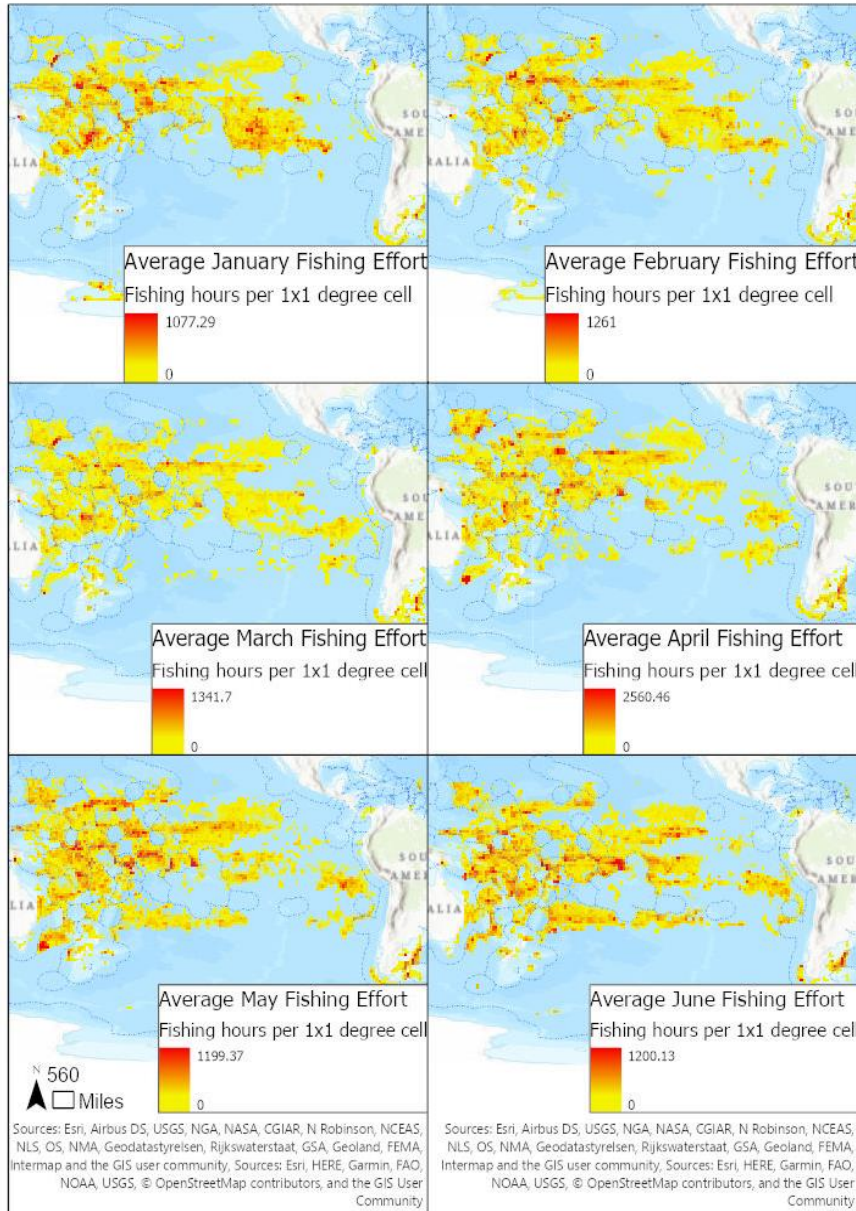
Figure 2: AIS longline fishing effort data from GFW, only including longlining events in the South Pacific Ocean.
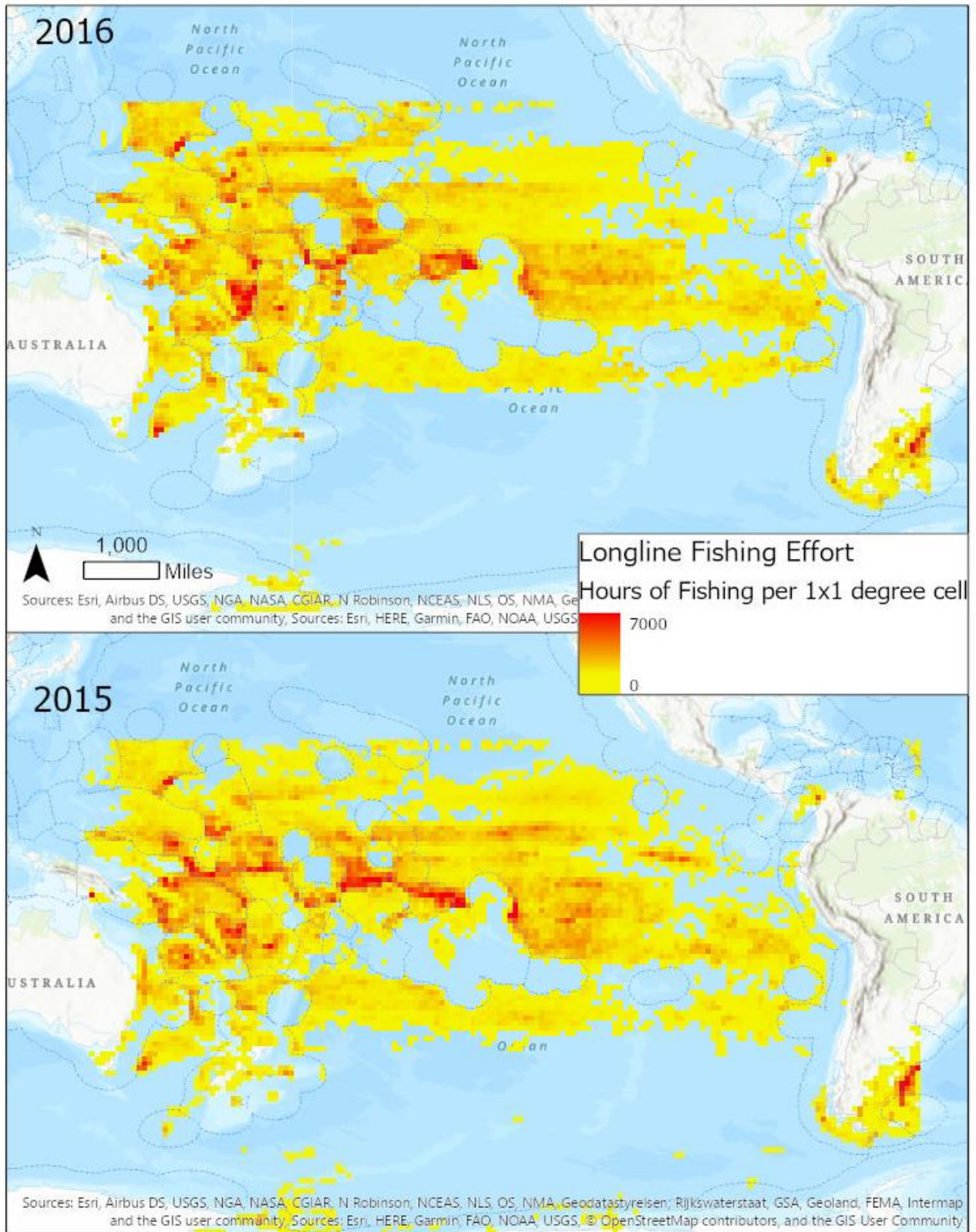
2.2.1 Generating Average Fishing Effort by Month

Both the 2015 and 2016 original point data were grouped by month using *ESRI ArcGIS Pro 2.4.3 (Esri Inc., 2019)*. This produced 24 separate point feature classes, 12 of them representing January through December for 2015, and the remaining 12 representing January through December for 2016. Each of the datasets were transformed from a point feature class, to a raster, by summing up the hours of fishing effort occurring in a 1x1 degree cell. Rasters of the same month for 2015 and 2016 were then averaged together using the Cell Statistics tool in *ESRI ArcGIS Pro 2.4.3* (Esri Inc., 2019*)*. For example, January 2015 raster was averaged with the January 2016 raster. The remaining months were averaged in the same way. This produced average monthly fishing effort for each month of the year, per 1x1 degree cell (approximately 85 square miles) (**Figure 3 & 4).**
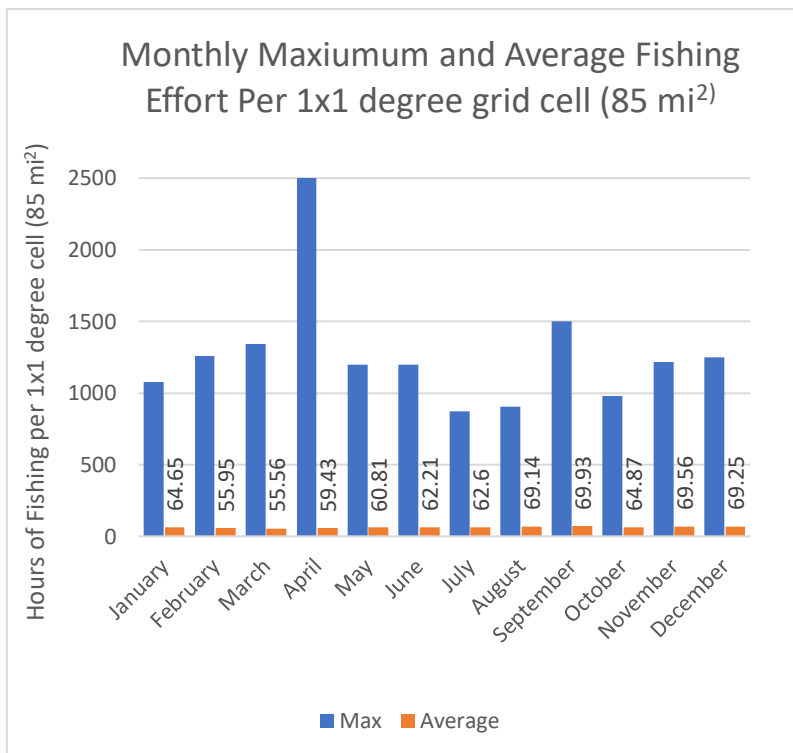

Figure 3: 2015 and 2016 average longline fishing effort for January – June, per 85 sqaure mile cells.

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Figure 4: 2015 and 2016 average longline fishing effort for July – December, per 85 sqaure mile cells.
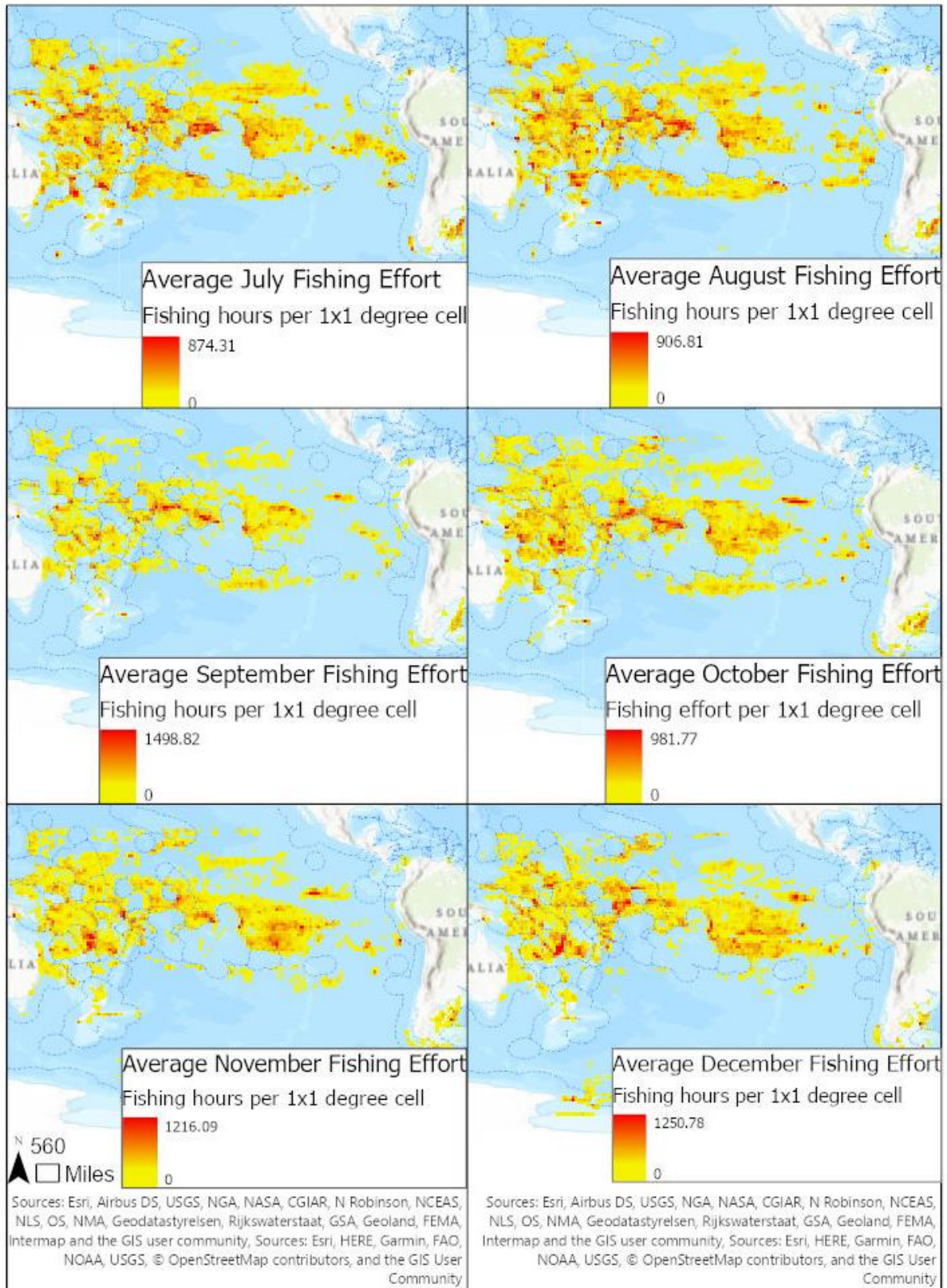
2.3 Spatial and Temporal Overlap of Chatham Albatross Use-areas and Longline Fishing Effort

Each monthly KDE for each node and corridor for the Chatham Albatross was overlain with the monthly fishing effort data using the Extract by Mask tool in *ESRI ArcGIS Pro 2.4.3*. The breeding node consisted of 6 monthly KDEs, and therefore 6 overlays were completed. The post-breeding migratory corridor consisted of 3 monthly KDEs, the non-breeding node consisted of 4 monthly KDEs and the pre-breeding migratory corridor consisted of 1 monthly KDE, and so 3, 4, and 1 overlay was completed, respectively. If a fishing effort grid cell representing fishing effort overlapped with a KDE, I determined if that grid cell of fishing effort was considered to be high fishing effort. To determine how many hours of fishing effort constituted high fishing effort, I compared the hours of fishing in the given cell that overlapped with the KDE to the average hours of fishing per grid cell occurring for the entire month. If the fishing hours occurring in an overlapping cell were higher than the monthly average fishing effort (**Figure 5**), the area of overlap was considered to be an area of concern for Chatham Albatross interaction with longline fishing. If the fishing effort grid cell overlapped with core use areas, the area of overlap was considered to be an area of high concern for the Chatham Albatross. Because the mean fishing effort between years and months were similar, the average fishing effort per month is thought to be a representative number for comparison. However, fishing effort intensity increased slightly in 2016, likely due to an increase in the amount of satellites that are orbiting and capable of detecting longline fishing events by GFW (Guillermo, Ortuño Crespo, 2018).


Figure 5: Maximum and average fishing effort per 1x1 degree cell, partitioned into months.

3. Results

### 3.1 General and Core Use Areas for the Chatham Albatross

A total of four general use areas and six core areas were identified for the Chatham Albatross (**Figure 6**). For the breeding node, the general use area was within a radius of 430 kilometers (km) from the Pyramid and the core area was within 50 km from The Pyramid. A total of 15 tracked individuals were used to generate use areas for the breeding node. These results are consistent with previous studies that state that during breeding, birds are concentrated within 260 km when laying on eggs and within 360-600 km when feeding chicks (BirdLife International & Global Procellariiform Tracking Workshop, 2004). For the post-breeding migratory corridor from New Zealand to South America, 11 tracked individuals were used to generate general and core use areas. The general use area extended as far west as 170ºE, which suggests that the birds may have backtracked before migrating to South America. Two core areas were identified for the post-breeding migratory corridor. The first is a narrow band just below The Pyramid and extending east to 1500 km. The second core area is a narrow band in the center of the South Pacific Ocean. The post-breeding distribution of birds cross two EEZs: New Zealand and Chile. For the non-breeding node, 8 tracked individuals were included, which may also include birds migrating from southern Chile to the non-breeding area in Peru. The general use area extends from 40ºS to 4ºS. There were two core areas for the non-breeding node. One core area was a vertical band extending from 8ºS to 18ºS. Previous studies have also showed concentrations of Chatham Albatrosses near these latitudes, specifically around upwellings from 6º-10ºS and around the Nazca Oceanic Ridge at 15ºS (**Figure 7**) (Guillermo, Ortuño Crespo, 2018). The second core area is between 24º-26ºS which may indicate an aggregation of birds migrating from Chile to the wintering area north of 20ºS using the Humboldt current (BirdLife International & Global Procellariiform Tracking Workshop, 2004). For the pre-breeding migratory corridor from South America to the breeding site at The Pyramid, 5 tracked individuals were included. The general use area is initially split when the birds are leaving their non-breeding area and the two narrow bands merge around 103ºW 35ºS. The core area is a narrow horizontal band hovering over The Pyramid and is 244 km wide. The pre-breeding distribution of birds cross three EEZs:

Easter Island, New Zealand, and Peru. Throughout all nodes and corridors in the migratory cycle, more than 80% of the area used is within ABNJ.

Figure 6: Density estimates for the four behavior nodes and corridors and 6 core areas for the Chatham Albatross. (a) Breeding, 15 individuals; (b) non-breeding, 8 individuals; (c) post-breeding, 11 individuals; (d) pre-breeding, 5 individuals.
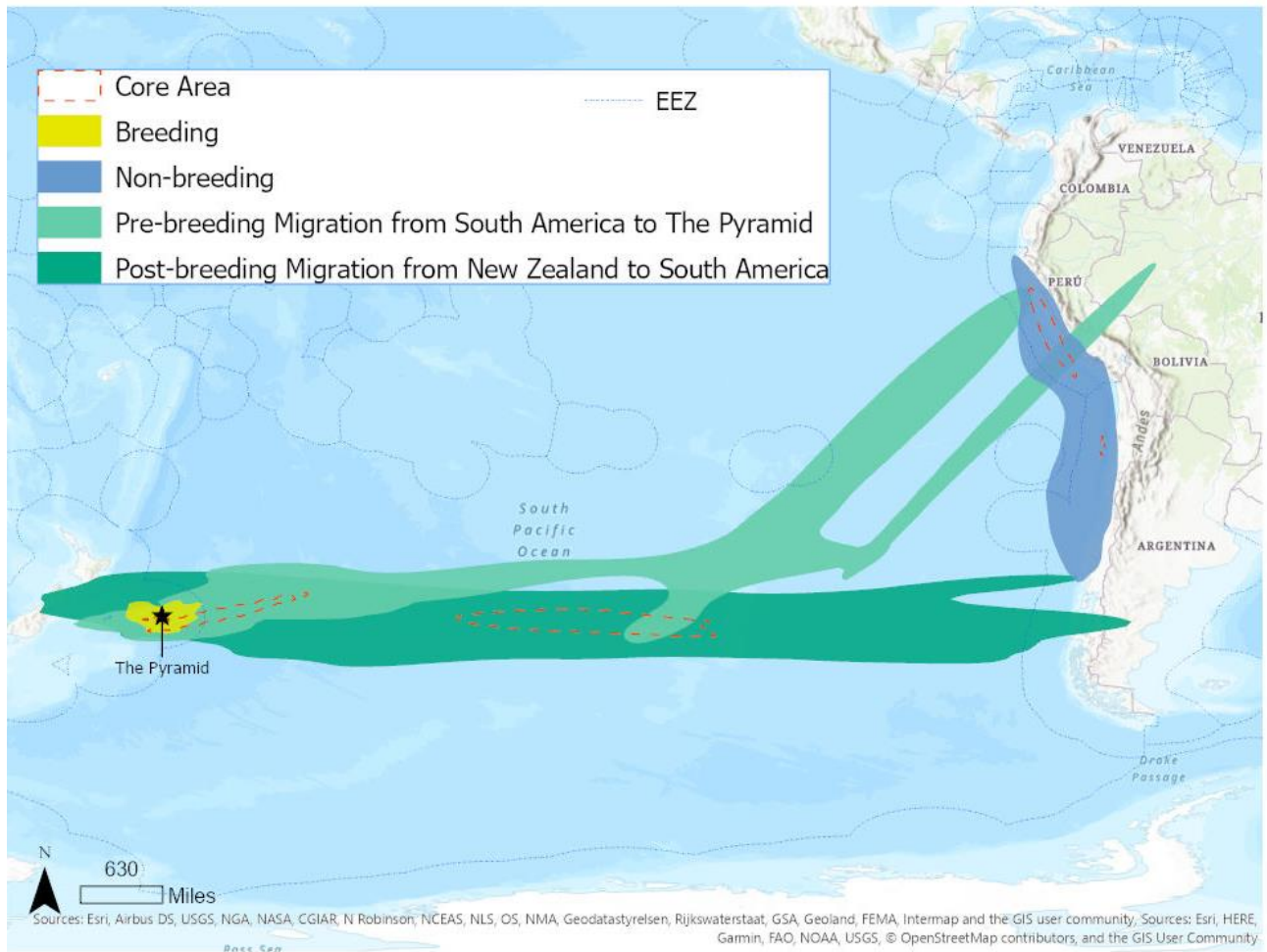
Figure 7: Utilization distribution performed by Birdlife International on the Chatham Albatross using the same datasets: (a) migration routes of 10 tracked birds moving east from January to August and 4 tracked birds moving; (b) foraging areas from January to August for 9 individuals, only including foraging locations and does not include transit locations.

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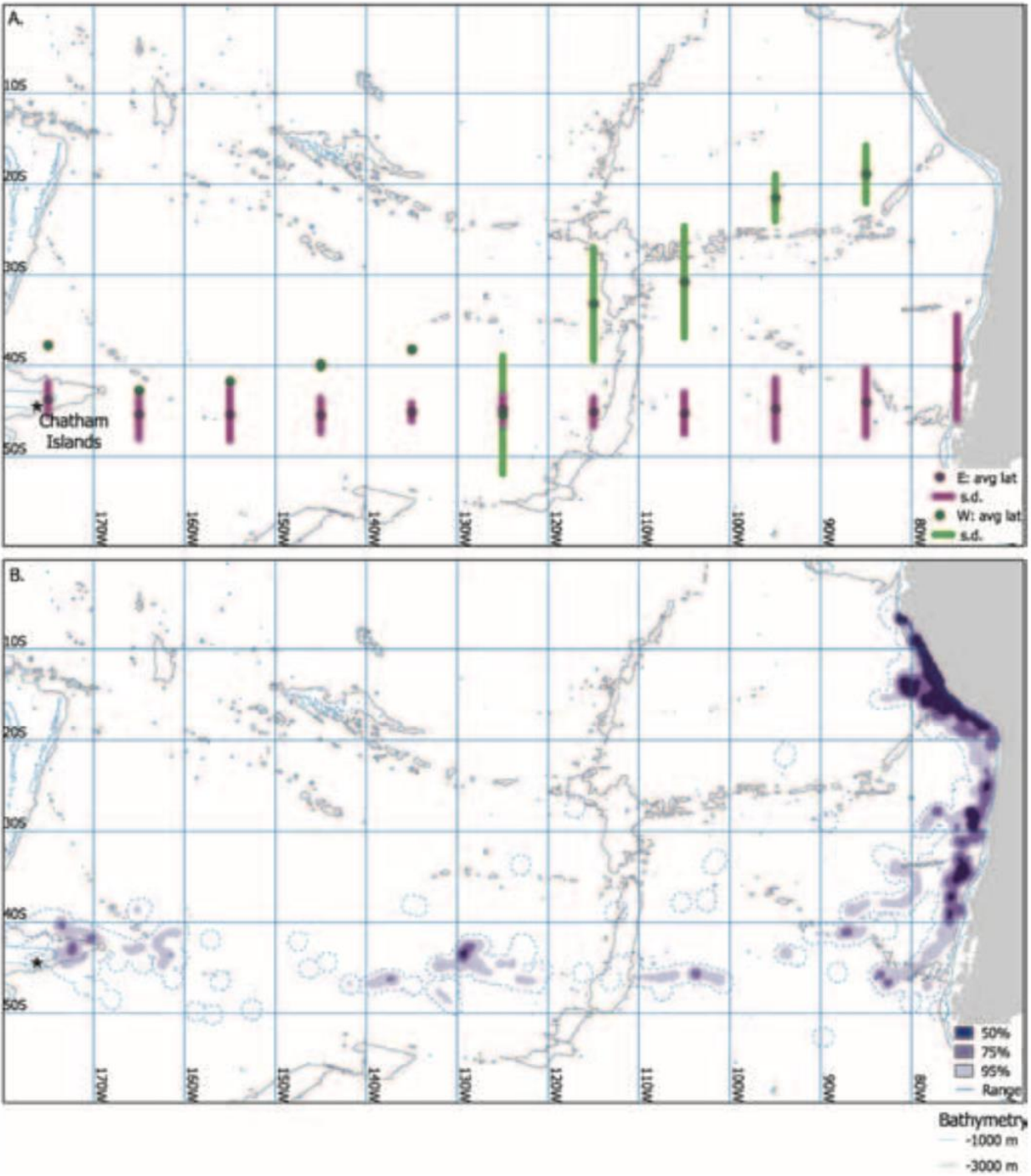
3.2 Chatham Albatross Overlap with Longline Fishing

3.2.1 Breeding

Out of the six monthly KDEs generated for the breeding node, two monthly KDEs, January and November, overlapped with fishing effort (**Figure 8**). In January, three fishing effort grid cells overlap with the 90% contour level for the Chatham Albatross in New Zealand's EEZ. Of the three grid cells, two of them exceed the average fishing effort for the month of January, which is 64.65 hours per 1x1 degree grid cell. No fishing effort overlapped with the breeding core area in January. In November, one fishing effort grid cell overlaps with the 90% contour level in New Zealand's EEZ. The fishing effort exceeds November's monthly average of 69.56 hours. No fishing effort overlapped with the breeding core area in November.
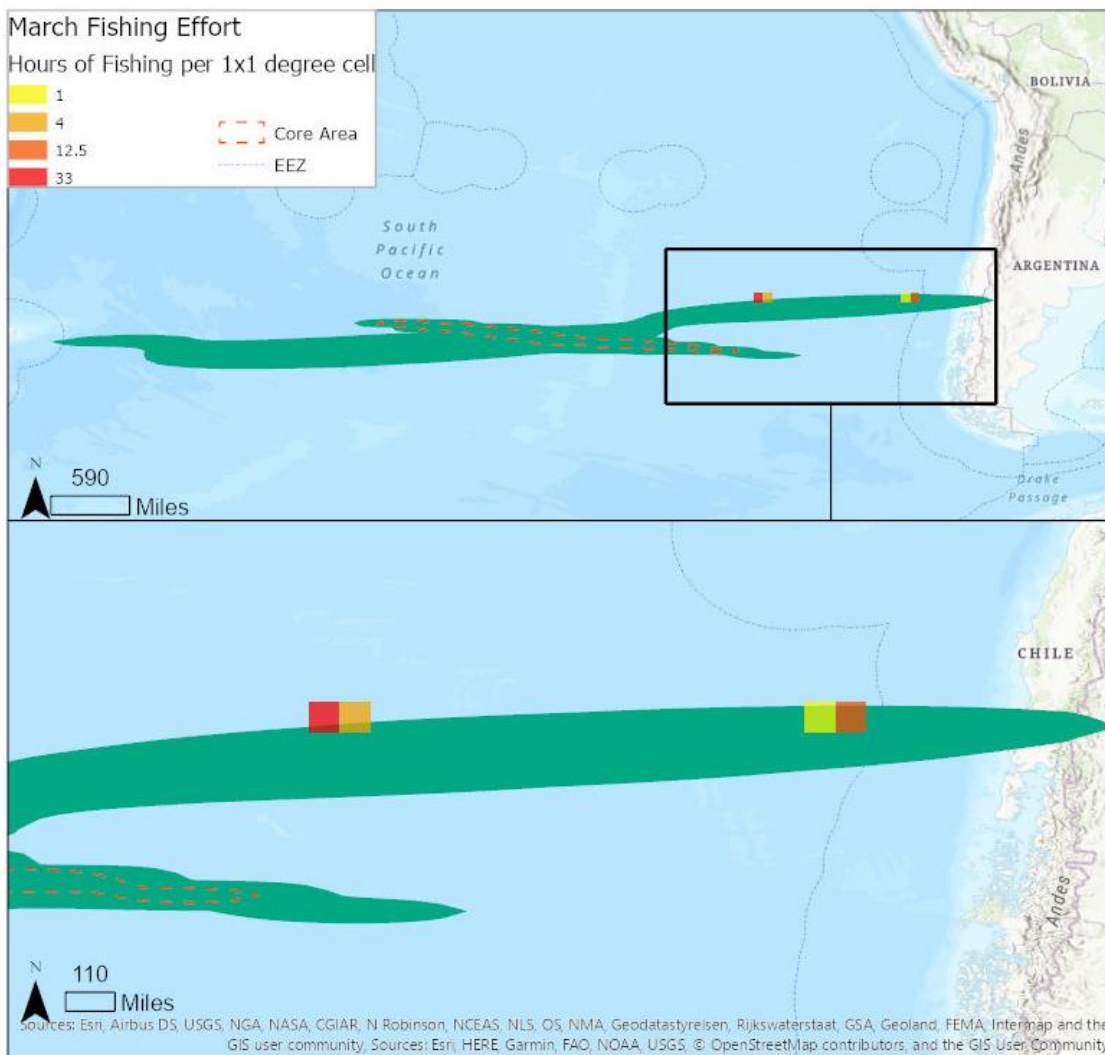
Figure 8: Breeding KDEs for January (4 tracked individuals) and November (8 tracked individuals) overlain with monthly fishing effort. Overlap occurs in New Zealand's EEZ.
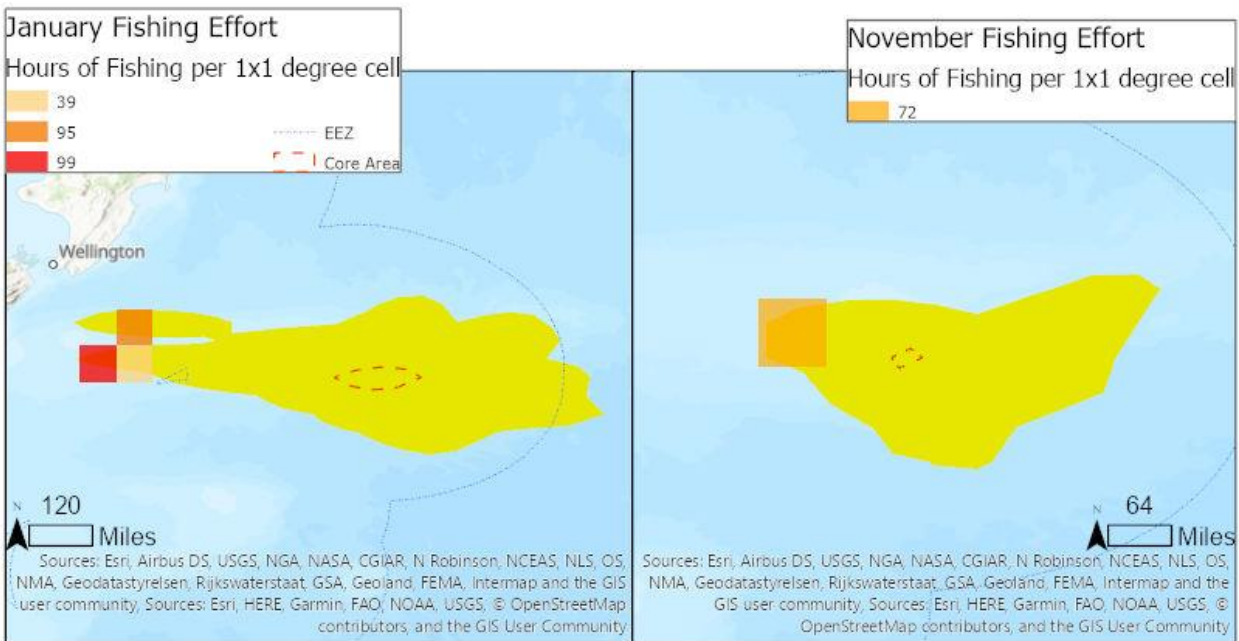
3.2.2   Post-breeding Migration from New Zealand to Chile and Peru

Of the four monthly KDEs generated for the post-breeding node, the KDE for March overlapped with fishing effort in the high seas (**Figure 9**). In March, four fishing effort grid cells overlap with the 90% contour level for the Chatham Albatross in New Zealand's EEZ. None exceed the average fishing effort for the month of March, which is 55.56 hours per 1x1 degree grid cell. No fishing effort overlapped with the post-breeding core area in March.

Figure 9: Chatham Albatross post-breeding KDE for the month of March, using 2 individuals, overlain with average March fishing effort. Overlap occurs in the high seas.

3.2.3   Non-breeding Node Off the Coast of Peru and Chile

June Fishing Effort

Hours of fishing per 1x1 degree cell

- 1
- 8
- 50

37.5

Miles

Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 10: Chatham Albatross non-breeding KDE for June, using 5 individuals, overlain with average June fishing effort. Minimal overlap occurs in core area.
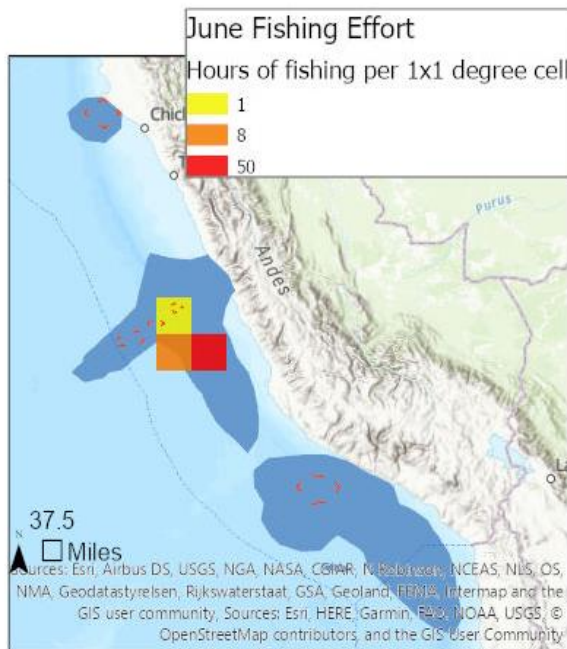
Of the five monthly KDEs generated for the non-breeding node, the KDE for June overlapped with fishing effort in Peru's EEZ (**Figure 10**). In total, three fishing effort grid cells overlap with the Chatham Albatross KDE in June. Two of the fishing effort grid cells overlap with the 90% contour level for the Chatham Albatross. However, both grid cells are below the monthly average fishing effort for June. One fishing effort grid cell partially overlaps with one of the core areas in June. However, with only 1 hour of fishing occurring there, the overlap is not considered significant.

3.2.4   Pre-breeding Migration from South America to Breeding Area at The Pyramid

Of the four months included in the pre-breeding migratory corridor, only one KDE was generated. Kernel density analysis was not performed on January, February or July, as only one tracked individual was present in each of those months. A KDE was created for August, as three individuals were present. Fishing effort overlapped with the August KDE in both the high seas and in New Zealand's EEZ (**Figure 11**). In the high seas, fishing effort as high as 205 hours in a single 85 square miles grid cell overlapped with the 90% contour, or general use area for the Chatham Albatross, nearly tripling the average fishing effort in August (69.14 hours). Within the core area, fishing effort as high as 382 hours overlapped, which is five times the average fishing

effort in August. Moreover, only 1.7% of the fishing effort grid cells for the entire South Pacific Ocean exceed 380 hours of fishing in August and 31.6% of the fishing effort grid cells that overlapped with the pre-breeding core area in August exceed average fishing effort. In New Zealand's EEZ, six fishing effort grid cells overlapped with the general use area, with two of them exceeding 500 hours of fishing. Only 0.6% of the fishing effort grid cells (85 square miles) for the entire South Pacific Ocean exceed 500 hours of fishing in August.

Figure 11: Chatham Albatross pre-breeding KDE for August, using 3 individuals, overlain with average August fishing effort. Significant overlap occurs in core area and general use area, in both the high seas and New Zealand's EEZ.
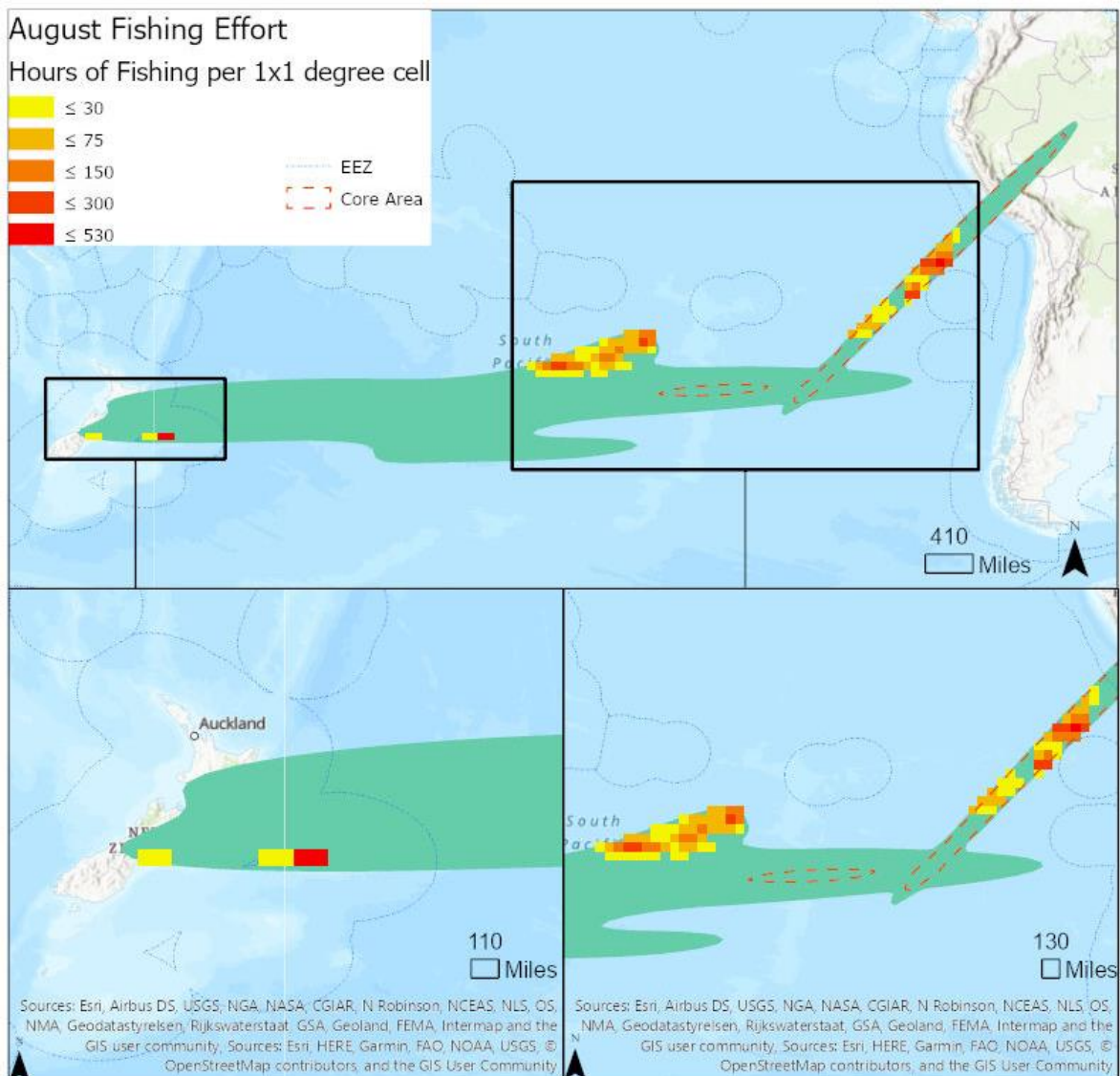
4   Discussion

4.1 Strength of Migratory Connectivity

The area use model in **Figure 6** evidences the assertion that the Chatham Albatross has strong connectivity between life history stages, as the birds are primarily using one migratory corridor to traverse between a single breeding area and non-breeding area. This suggests that the population is not migrating separately in space and rather, is migrating from the breeding site using one relatively narrow route and spending the non-breeding period in the same area, albeit a large area spanning from 40ºS to 4ºS. Although the breeding population is migrating at different times, with most birds leaving The Pyramid in November, December and January, they are using the same corridor. When considering this, in combination with their low productivity, habitat degradation at The Pyramid, and that more than 80% of the area used during their annual cycle is in ABNJ where governance is fragmented and sometimes ineffective, it becomes clear that any stressor in any magnitude is likely to scale up beyond effects on the individual and have a large impact on the population. However, rare species or species with little known about them, such as the Chatham Albatross, suffer from small sample sizes and consequently, potentially weak models. With only 33 tracks and 13 birds, the results of this study must be interpreted carefully. With a smaller sample size, it is more likely that individual birds created hotspots in areas that may not be representative of the entire dataset or population. Some solid conclusions can be made, however. The post-breeding corridor is more conclusive in terms of evidencing strong migratory connectivity in space because there are two core areas within it, demonstrating that a high probability density of birds are utilizing the corridor, and a sample size of 11 tracked individuals was used to create it. The pre-breeding corridor, however, while it only consists only of 5 birds, is more conclusive in terms of evidencing strong migratory connectivity in time, as it is only occurring in August. In any case, interactions with stressors throughout their migratory cycle, such as longline fishing, are likely to have an impact on the population given the low producitivity, habitat degradation and small population alone.

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*4.2 Degree of Overlap with Longline Fishing in the South Pacific*

Chatham Albatross and longline fishing effort overlap is small, yet important in time and space. Spatially, significant seabird-fishery overlap is occuring in ABNJ in both core areas and general areas, as well as in New Zealand's EEZs in general areas. Temporally, significant overlap is occurring during breeding in January and November, and during pre-breeding migration from Peru to the breeding site in August. The greatest potential for interactions with longline fishing fleets is likely to be in August when the Chatham Albatross is migrating from Peru back to the breeding site at The Pyramid, as significant, isolated fishing effort overlaps in three different areas throughout the migratory corridor, including a core area in the high seas. Moreover, longline fishery interactions in August are most likely to have large effects on the population, more than any other month, as most of the population migrates back to the single breeding site during August, suggesting strong temporal migratory connectivity. During this migratory stage, there is lack of segregation in both time and space, meaning that negative effects on the population from longline fishing during August can have serious consequences for population dynamics. Furthermore, while the amount of time that the Chatham Albatross uses the high seas is low (SPRFMO, 2007), more than 80% of the area they use in their annual cycle is in ABNJ. Management fragmentation and ineffectiveness in the high seas could exacerbate their vulnerability to longline fishing.

4.2.1 How does this overlap analysis fit into area-based management approaches?

Fortunately, an EBSA has been proposed in the area of highest concern for the Chatham Albatross. **Figure 12** shows that an EBSA has been proposed in the same area where significant fishing effort, namely the top 1.7% of fishing effort in August, overlaps with the Chatham Albatross core area of the pre-breeing migratory corridor. The proposed area includes pelagic waters down to the sea floor in the Salas y Gomez and Nazca submarine rigdes (*REPORT OF THE EASTERN TROPICAL AND TEMPERATE PACIFIC REGIONAL WORKSHOP TO FACILITATE THE DESCRIPTION OF ECOLOGICALLY OR BIOLOGICALLY SIGNIFICANT MARINE AREAS*, 2012). These are both chains of seamounts which, together, extend over 2,900 km. The area is ranked high in terms of special importance for life history stages of swordfish,

invertebrates, corals, sharks, leatherback turtles, blue whales, and the Chatham Petrel during it's breeding season from June to September, to name a few. This study, and the identification of this site as being a potential time and space of interaction with fisheries and the Chatham Albatross, can provide new information in revisiting EBSAs and help strengthen the existing Salas y Gomez EBSA. It is important to consider the small sample size once again, however. Only 3 individual tracks were use to create the pre-breeding migratory in August, and as such, the corridor may not be representative of the entire population. Consequently, the overlap may be disingenuous. However, fishery interaction with just those three birds, assuming strong connectivity, could scale up and impact the entire population. Moreover, the site is already identified as an important area for the Chatham Petrel during the same time frame as the Chatham Albatross pre-breeding migration. The Chatham Petrel is a highly migratory species with longline fishing one of it's biggest threats (*Chatham petrel*, n.d.).

Figure 12: Chatham Albatross and longline fishing overlap area overlain with existing EBSAs.
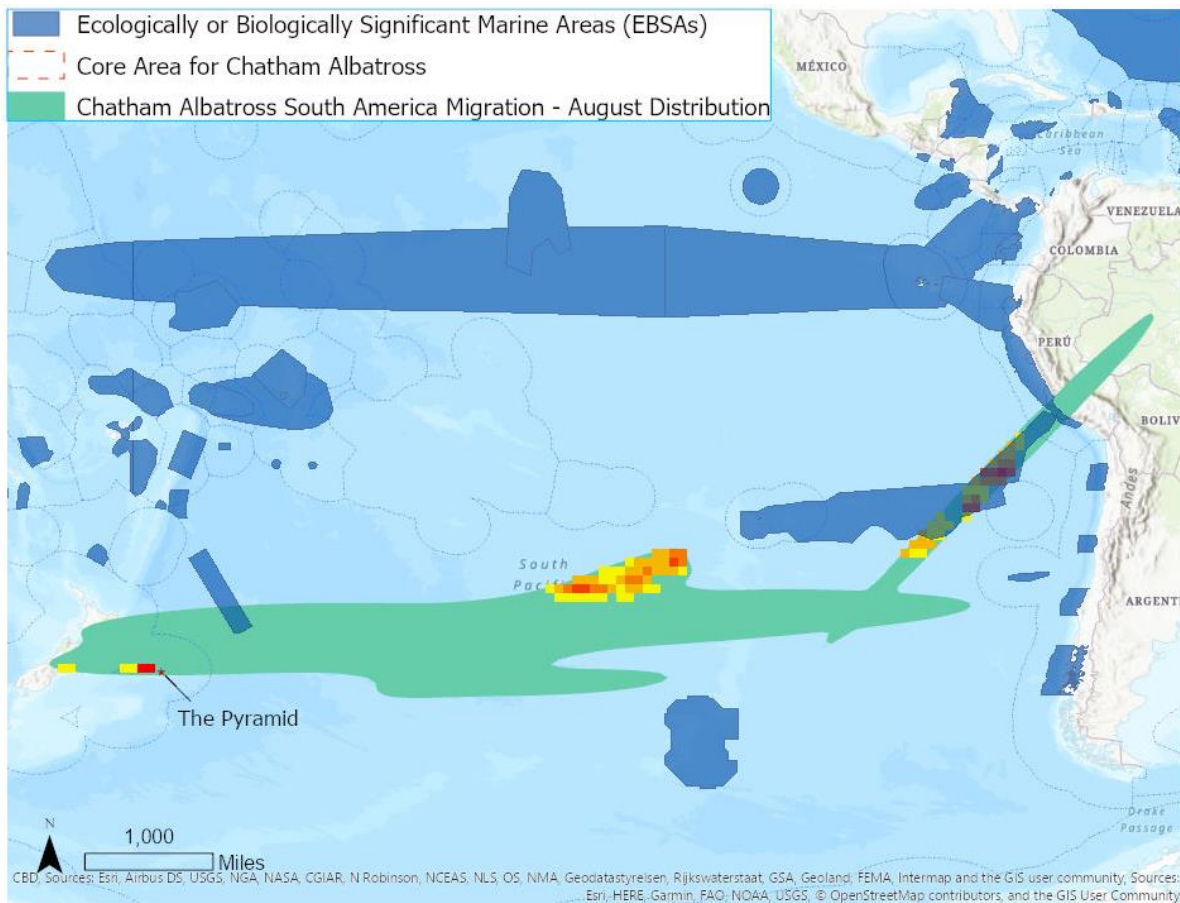
Another caveat to consider in overlap analysis is the temporal mismatch between the datasets. The Chatham Albatross tracking data was produced from 1997-1999 while the GFW fishing effort data represents 2015-2016. With a 15-year gap in the datasets, it is unlikely that the models capture decadal variablility and climatic events, such as Pacific oscillation events. Therefore, it is unclear if the Chatham Albatross migratory patterns will adapt with nature shifts or remain unwavered. Additionally, fishing behavior may be changing with a rapidly changing climate. Changing climate makes it even more important to have access to baseline information about migratory connectivity, as baseline information will allow us to have an understanding of how climate change is disrupting connectivity patterns and as a result, the effectiveness of marine protected areas (Dunn et al., 2019).

4.3 Suggestions for Future Research

Using predictive models like the models developed in Crespo et al. (2018) with more recent tracking data may allow for greater precision in assessing spatio-temporal seabird-fishery overlap, while also factoring in the effects of a changing climate on fishery and seabird behavior. Future research might also consider identifying specific fleets or specific longline gear (pelagic or demersal) that overlap with core-use and general-use areas. These identifications can be used to inform respective RFMOs of the flag states that are most likely to interact with the Chatham Albatross, and appororiate measures could be taken to minimize seabird fishery interactions. Assessing small vessel threats to the Chatham Albatross would also be insightful. Currently, as of 2004, the International Maritime Organization requires AIS devices on vessels of 300 gross tonnage or more (*Automatic Identification Systems (AIS)*, n.d.), meaning vessels smaller than 300 gross tonnage (GT) were likely left out of this analysis, unless individual states require an AIS device on a smaller GT. Therefore, this analysis does not capture the realized threat of all longline fishing effort to the Chatham Albatross.

Using this analysis in combination with density estimates for other species of seabirds with similar migratory cycles might prove useful in identifying additional EBSAs or IBAs. Birdlife International has already led the charge to combine utilization distribution maps for five different species of albatrosses in the *Tracking Ocean Wanderers* report, with the Chatham Albatross

being one of the species. While weighting the distributions by IUCN status is an interesting approach, only using foraging areas to identify intensive use areas assumes that birds will not change their non-breeding migratory behavior and forage when in proximity of longline fishing vessels. This assumption, coupled with varying sample sizes for different species, can result in missing hotspots completely. Moreover, some species might only have tracking data for non-breeding and breeding stages of their annual cycle, and not their migratory corridors, so they areas might be under-represented. Combining utilization distributions for migratory corridors and weighting the distributions by strength of connectivity could help identify areas of highest importance in terms of areas to be most likely impacted by interactions.

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