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Fisheries Training Programme

MOVEMENT OF SKIPJACK (*KATSUWONUS PELAMIS*) TUNA IN THE ARCHIPELAGIC WATERS AND EXCLUSIVE ECONOMIC ZONE OF PAPUA NEW GUINEA.

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ABSTRACT

Skipjack tuna dominates the purse-seine catch in Papua New Guinea. The fisheries in the archipelagic waters and exclusive economic zone are currently managed as a single entity. However, because of the huge land mass and abundance of food sources provided by the large river deltas that flow into the Bismarck Sea, the question of whether there is a larger resident population of skipjack that occurs in archipelagic seas has arisen. Therefore, the movement of skipjack tuna in the Archipelagic Waters (AW) and the Exclusive Economic Zone (EEZ) of PNG is explored to deduce whether a considerable amount of stock resides in the Archipelagic waters. Conventional tagging data from the PTTP and observer sampling data were used to study 1) the extent of skipjack tuna movement between Archipelagic Waters and Exclusive Economic Zone, 2) to analyze any size difference of skipjack tuna from AW and EEZ waters. This study showed results where most fish released from central part of the PNG AW were recaptured close by within 0 -250 days at liberty. It is evident that based on where the fish are tagged and released the proportion recaptured in the AW versus the EEZ can differ however, this study only analyzes locations of release and recapture and does not track the path of individual fish. Therefore, it is difficult to conclude that these fish reside in the AW during their entire days at liberty. Given the high migration speed of tuna, fish could be travelling out to the EEZ in the interim period and migrating back to AW. It is recommended that a home range analysis can be done to delineate the home range or habitat of the species and the use of archival tags for further studies is also recommended for better understanding of movement patterns. Finally, to better the residence times of fish, advection-diffusion reaction models can be applied for future work.

Keywords: Skipjack tuna, tuna movement patterns, tagging, recapture, Papua New Guinea.

This paper should be cited as: Kwapena, A. O. 2022. *Movement of skipjack (Katsuwonus pelamis) tuna in the archipelagic waters and exclusive economic zone of Papua New Guinea.* GRÓ Fisheries Training Programme under the auspices of UNESCO, Iceland. Final project. https://www.grocentre.is/static/gro/publication/1823/document/Kwapena21prf.pdf

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1 INTRODUCTION

1.1 Tuna Fisheries

Papua New Guinea (PNG) is made up of the eastern half of the enormous island of New Guinea, as well as the smaller islands of New Britain, New Ireland, Bougainville, and Manus. In terms of both size and population, Papua New Guinea is by far the largest Pacific Island country. It has a population of roughly 7 million people and a landmass of just over 462 000 km^2. From the highlands and its steep cordillera to the lowland rainforests, savannahs, swamps, and mangrove forests of the coastal lowlands, out to the many islands, atolls, and huge fringing and barrier coral reefs, PNG features a varied range of ecosystems. The whole length of PNG's coastline is believed to be around 17 110 km, with an estimated coral reef area of 40 000 km^2 (FAO, 2018).

PNG’s Exclusive Economic Zone (EEZ) of 2.4 million km^2 in extent, is one of the largest and more productive in the Western and Central Pacific Ocean. Industrial scale fisheries for tuna and associated species have operated since the 1950’s, and in certain years, around 10% of the global catch of the main market species of tuna has been taken within the PNG EEZ. The tuna fishery is the largest of PNG’s fisheries and represents a balance of both domestic industry development and foreign (DWFN)[1] access arrangements (Kumoru, 2004 unpublished). The purse-seine and longline sectors of the tuna fishery are both active. Domestic longline vessels fish entirely in PNG seas, and just recently, PNG reopened its waters to foreign longline vessels after more than two decades. The purse-seine sector is made up of domestic and international access vessels. The domestic sector includes PNG flag vessels and PNG locally based foreign (LBFV) vessels that are chartered on a domestic basis to service PNG's onshore processing facilities. The entire estimated catch of target tuna species caught by PNG purse seine vessels in 2020 was 180,513 mt (NFA, 2020 unpublished).

1.2 Management of Tuna Fishery

The Fisheries Management Act of 1998[2] and the Fisheries Management Regulation of 2000 are two government measures that manage and regulate the fisheries sector. These programs need PNG's fisheries resources to be managed in a way that is both sustainable and equitable for current and future generations. The National Fisheries Authority[3] (NFA) oversees the fisheries sector's management and development under the 1998 Act. The National Tuna Management Plan (NTMP), which drives PNG policy, governs tuna fisheries. The plan, which was enacted in 1999, takes a precautionary approach and emphasizes PNG's obligations in the context of regional management (ie, WCPFC, FFA and SPC). Number of permits; total allowable catch

[1] ‘DWFN’ – Distance Water Fishing Nation means any State whose flagged vessels fish in the PNG fishery management area under the terms of an access agreement as stated in the National Tuna Fishery Management and Development Plan 2014.

[2] Fisheries Management Act 1998 is the legislation that provides for and give effect to the National Goals and Directive Principles and to promote the management and sustainable development of fisheries, and for related purposes.

[3] National Fisheries Authority (NFA) of Papua New Guinea is a semi-commercial statutory authority established and operating under the Fisheries Management Act 1998 mandated to manage the Fisheries of PNG.

(TAC); restriction of fishing effort (i.e., number of boats/days, fishing days); season closures; species length-weight limits; gear type limits; and designated fishing regions or zones are all part of the NTMP (Bailey et al, 2012).

1.3 Fishing Waters

The EEZ is the primary fishing ground for industrial tuna fleet and these are managed under Total Allowable Effort (TAE) through a Vessel Day Scheme (VDS), a system controlled by the Parties to the Nauru Agreement (PNA). Foreign and domestic fishing vessels operate here under strict licensing conditions. The purse seiners that are based at processing facilities in PNG tend to fish more in PNG waters[4] than outside. The locally based longline vessels fish exclusively in PNG waters (FAO, 2018). Purse seiners operate on free-swimming (or unassociated) skipjack and medium-large yellowfin schools, and schools associated with floating objects such as drifting logs and anchored or drifting fish aggregation devices (FADs) (SPC, 2006 unpublished). The Archipelagic Waters (AW) of Papua New Guinea are classified as internal waters, granting the country full sovereignty over their management.

1.4 Rationale of study

Within the archipelagic waters lies the Bismarck Sea, where tuna fishing is primarily conducted by the domestic fleet and locally-based foreign vessels (LBFVs). Most large fleet maintain rather high levels of effort in Bismarck Sea archipelagic waters, which overlaps with these FADs (Kumasi et al, 2010 unpublished). The Bismarck Sea, which is one of the most diverse and important tropical marine habitats in the Western Equatorial Pacific Ocean is located between Latitude 2- and 5-degrees South of the Equator, 146-152 degrees East (Cheshire, 2010). It is PNG's largest sea, and is where most of the fishing takes place (Pilling et al, 2014). Due to the vast landmass and the rich food supply from large river deltas flowing into the Bismarck Sea, speculation has emerged regarding the possibility of a larger resident population of skipjack tuna within these archipelagic waters (Authority, 2021 unpublished).

In 2010, a preliminary analysis of length frequency for FAD associated catch was carried out using port sampling data. With the installation of associated fads in archipelagic waters, the port sampling program in that year detected a significant difference in the mean lengths of skipjack and yellowfin caught in the archipelagic waters of PNG compared to the PNG EEZ. The study suggested that the skipjack and yellowfin in the archipelagic waters of PNG grow at a faster rate than those occurring in the rest of the PNG EEZ (Kumasi, et al 2010 unpublished). Therefore, the purpose of this paper is to explore the movement of skipjack tuna in the Archipelagic Waters and the Exclusive Economic Zone of PNG to deduce whether a considerable amount of stock resides in the Archipelagic waters.

[4] PNG waters refers to the fishing waters of Papua New Guinea which comprises of territorial waters, archipelagic waters and the EEZ as described in the National Seas Act 1977.

1.5 Objectives

The objectives of this study are as follows:

- To study the extent of skipjack tuna movement between Archipelagic Waters and Exclusive Economic Zone using conventional tagging data
- To analyze any size difference of skipjack tuna from AW and EEZ waters.

Specific Objectives:

- Map the tagging data to understand the movement patterns of the tuna in the Archipelagic waters and Exclusive Economic Zone.
- Plot and compare length frequency distribution of fish in AW and EEZ of PNG using length data from the tagged fish and observer sampling programme.

2 LITERATURE REVIEW

2.1 Biology

2.1.1 Distinctive Features

The skipjack tuna like other tunas, has a spindle-shaped body. These strong, torpedo-shaped fish are built for speed and agility and has two dorsal fins. The first fin with spines and the second without. The second dorsal fin are followed by 7 to 9 finlets with separate rays useful in decreasing turbulence and retaining directional control when swimming at elevated speeds. Followed by 7 or 8 finlets, the anal fin placement starts under the second dorsal fin. At the far end of the fish is the caudal peduncle. The caudal peduncle has three sets of keels; a large one on the base of the peduncle inserted between two smaller pairs. Keels are ridges that also help the fish keep its position in the water when moving quickly. The mouth of the skipjack expands to the middle of its eye with a single row of miniature pointed teeth. All skipjack do not have swim bladders. These tuna species is unique as it has a system for partly regulating the body temperature, known as counter, making them partially 'warm-blooded' (Gardieff, 2021).

On average the skipjack is 80 centimeter's long and weighs 8-10 kilograms. It is a dark blue or purple on top, dwindling to silver below. There are several dark lines along its sides and the belly (Gardieff, 2021). These stripes differentiate this tuna from other scrombrids inhabiting the same waters.

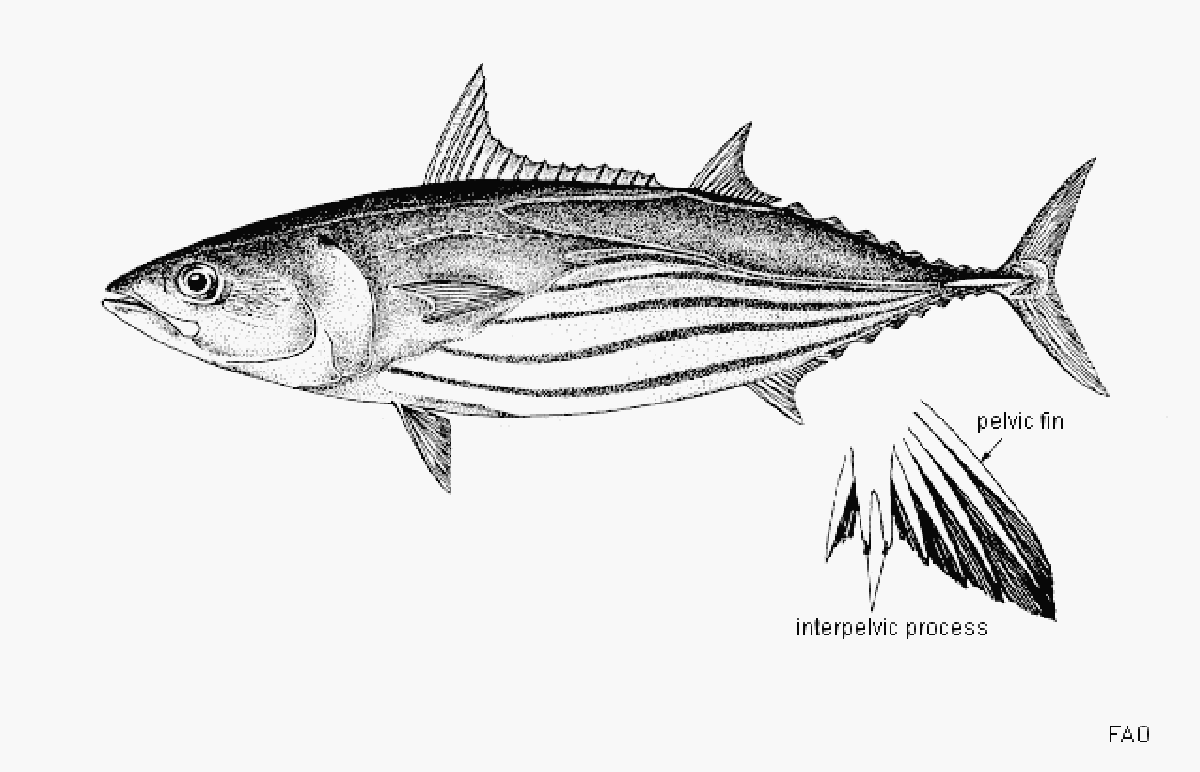

Figure 1*: Showing the body shape and fins of Skipjack tuna. Source: (Colette, 1995).*

2.1.2 Food Habits

Small fishes, crustaceans, and mollusks are the main diet of skipjacks. Its prey consists of fishes such as herrings, anchovies, and sardines. Since cannibalism is a trait; the diet appears to be highly distinct suggesting an opportunistic technique of feeding. Around dawn and dusk are the peaks of foraging and this could be in response to the diurnal and vertical migrations of another organism. Other suggestions may mean, skipjack sate their food drive mid-day. Furthermore, since skipjack seem to depend on vision when feeding, it is harder for them to look for food during the night. Groups of skipjack are always discovered near convergences and upwellings. This is where distinct bodies of water, often with different temperature, meet with one another. When foraging for food, they compete with other organisms such as the whale shark, yellowfin, albacore, frigate tuna, dolphin fish, rainbow runner and seabirds (Gardieff, 2021).

2.1.3 Reproduction

Known to be oviparous; spawning is year-round but limited to the warmer months. Most fish appear to mature at larger sizes but on average, sexual maturity may occur as small as 40 centimeters in length. An average female adult produces 80, 000 to 2 million eggs per year. It is seen that the larger the female, the more eggs. Approximately these eggs are 0.94 mm in diameter, with a transparent shell. Hatching of larvae is at a size of 3.0 mm. The larvae have large heads and jaws and lack body pigmentation and are often distinguished from closely related larvae by their pigmented forebrains (Gardieff, 2021).

2.1.4 Tagging Work in the region

Migration is a typical feature of marine and freshwater fish populations, and it involves traveling between different habitats. They have a wide geographical scale when compared to their travels within the aquatic species' home range. In aquatic systems, migration is an important and integral part of the life history of many fish species. The necessity of obtaining resources such as food, shelter, or partners is often linked to the way fish move. Tagging studies have recently become more prevalent as a source of information about long-distance animal movements (Rattankul et al, 2019). Several dedicated, large-scale conventional tagging programs have been done in both the WCPO and the EPO with the major focus on skipjack, yellowfin and bigeye tuna. These investigations began in the 1970s at the WCPO, with the skipjack Survey and Assessment Programme (SSAP: 1977-1981). The Regional Tuna Tagging Programme (RTTP:1990-1996), which operated in waters between the Philippines and the Pheonix islands of Kiribati, including off the east coast of Australia, and the Pacific Tuna Tagging Programme (PTTP: 2006-present), which operated in waters 10°N-10°S, 120°E - 130°W, have tagged large numbers of skipjack tuna. These three programs combined have tagged over 469000 skipjack tuna, with over 65,000 recoveries reported by June 2018, including about 47,000 skipjack tuna tagged through the PTTP alone (Moore, et al., 2020).

3 MATERIALS AND METHODS

3.1 Study Area

This study focused on the Exclusive Economic Zone of Papua New Guinea including the Archipelagic waters. The EEZ of PNG lies between latitudes 2° N and 15° S and longitude 140°E and 164° E and the Archipelagic waters lies between latitudes -1° S and – 11° S and longitude 140°E and 157° E (Figure 2).

Figure 2*: Area of study. The dark blue shaded area is the exclusive economic zone (EEZ), and the archipelagic waters is the light blue shaded area inside the EEZ.*

3.2 Description of Data

To conduct this study, tagging data and length frequency data were used.

The data used in the analysis were:

- release and recapture data of skipjack from conventional tags to understand the movement patterns of the tuna in the Archipelagic waters and Exclusive Economic Zone collected during the Pacific Tuna Tagging Program (PTTP).

- Release and recapture lengths of tagged fish in AW and EEZ from the tagging programme to compare the difference in length frequency distributions.
- length frequency data of skipjack from observer spill sampling programme to compare the length distribution of fish in the EEZ with AW.

3.2.1 Tagging Data

In this study the tagging data used is from the Pacific Tuna Tagging Program (PTTP) which was a joint research project implemented by the Oceanic Fisheries Programme (OFP) of the Secretariate of the Pacific Community (SPC)[5] and the PNG National Fisheries Authority (NFA). The major objectives of that project were:

1. To obtain information on the large-scale movement of tuna in, and from the PNG EEZ
2. To obtain information on the current exploitation rates of tuna in the PNG EEZ
3. To obtain information on the dynamics of tuna associations with FADs, in particular species-specific information on residence times, vertical and horizontal movements, and FAD interactions
4. To obtain data that will contribute to regional tuna stock assessment
5. To obtain information on the trophic status of free-swimming schools of tuna, and tuna associated with FADs, other floating objects and seamounts.
6. To characterize the variability and extent of catches of by-catch species from purse seine catches in PNG.

The tagging data was collected from sonic tags deployed in skipjack tuna during that exercise. Because of the nature of the objectives of that program, most of the tagging took place within close vicinity of monitored FADs. These monitored FADs were equipped with receivers and all receivers picked up at the end of each cruise. The PTTP had two cruises inside the Bismarck Sea located in the AW waters. In cruise one (1) of that program, a total of 13, 946 skipjack tuna were tagged and released and during cruise two (2), a total of 26,212 skipjacks were tagged and released. Sonic tags were surgically implanted within the peritoneal cavity of selected tuna. The relatively small tag sizes allowed sonic tagging of tuna as small as 40 cm Fork length (SPC, 2007 unpublished).

Data for years 2006, 2007, 2011, 2012, 2013 and 2016 were analyzed. This data frame consisted of year, cruise name, release length (the length of fish at release), release latitude and longitude (the location of fish released), release EEZ (region fish was released), release date, recapture length (length of recaptured fish), recapture latitude and longitude (location of recaptured fish), recapture date, and recapture EEZ.

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[5] Secretariate of the Pacific Community (SPC) is the principal scientific and technical organisation in the Pacific region. It is an international development organisation owned and governed by 27 member countries and territories with PNG been one. https://www.spc.int/

3.2.2 Length Frequency data

These data were from two (2) sources. Length frequency data from the released and recaptured fish and from the tagging programme.

Additionally, length frequency data from observer spill sampling onboard the fishing vessels were used. This included data for years 2010 to 2020. Observations were grouped into caught in AW or outside AW. Frequency of lengths were available by months and quarters for the observer sampling data.

4 ANALYSIS

4.1 Tagging data

All data analyses were conducted in R statistical software (R version 4.1.2 ©2021) which was downloaded from the website: https://cran.r-project.org/bin/windows/base/. The release and recapture latitude and longitude were converted from degrees decimal minutes to decimal degrees. The 'tidyverse' and stringr' package was used for data manipulation.

The AW region was divided into six (6) study areas; Bismarck Sea - East and Central, 147.5° E, 152° E, -6°S, -2.5°S. Bismarck Sea -Northeast, 147.5°E, 152°E, -2.5° S, 0°. Bismarck Sea Northwest, 140°E, 147.5°E, -2.5°S, 0°. Bismarck Sea West, 140°E, 147°E, -6°S, -2.5°S. Bismarck Sea East, 152°E and Bismarck Sea South, -6°S. This was done to study whether the movement of the fish differed according to where it was released from. Summary tables were generated to calculate how many fish were released and recaptured by each cruise, year, and study area. Only fish tagged and released within the AW of PNG were used. Further, days at liberty was calculated ie, number of days that passed between when the fish was released and when it was recaptured. The recapture points were color-coded by days at liberty. The proportion of fish that stayed within the AW was also calculated.

The map of the study area was plotted together with demarcations for EEZ and AW. The release locations were overlaid on the map to create separate maps for release data by the six study areas defined within the AW. Recapture maps were then created in a similar manner for the six areas. The recapture points were colour-coded by days at liberty.

To study in which direction the fish migrated, displacement maps were plotted by each study area. These maps plot a straight line between the release and recapture location to indicate the possible direction in which the fish travelled. These were also colour-coded by days at liberty.

To visualize the proportion of recaptures by areas, pie charts were plotted and overlaid on the map of the study area.

The following R packages were used for mapping the data 'ggmap', 'sf', rgdal', 'sp', 'maptools', 'maps'. An important feature recommended to have for better plotted fisheries boundaries whilst plotting maps are the shapefiles of the exclusive economic zone and the archipelagic waters. These shapefiles were taken from the marineregions.org website (https://www.marineregions.org/). The following function: 'readOGR' from library 'rgdal' was used to read the shapefiles into R. The function reads an OGR data source and layer into a suitable spatial vector object. It can only handle layers with conformable geometry features (not mixtures of points, lines, or polygons in a single layer). It will set the spatial reference system if the layer has such metadata. Release and recapture maps by cruises can be found in the appendix of this report (Appendix).

4.2 Length Frequency data from Port Sampling

Length distribution of recaptured fish in AW were compared against length distribution of recaptured fish in the EEZ and represented in plots by the six study areas defined within the AW.

5 RESULTS

5.1 Tagging data

It was seen that more than 90% of the recaptures were within 0-250 days (Figure 3). Bar plot in Figure 3 shows a rug at the x-axis indicating where most of the data is aggregated. This is observed to be in the category of days at liberty between 0-250. Therefore, analyses was focused on these data. It was also observed that there were a few fish seen to be recaptured after 1000 days at liberty or more (Figure 3). However, due to the very few numbers observed, these were considered outliers. When looking at the proportion of fish caught within 0-250 days, it is observed that 50 % are caught withing 50 days (Figure 4).

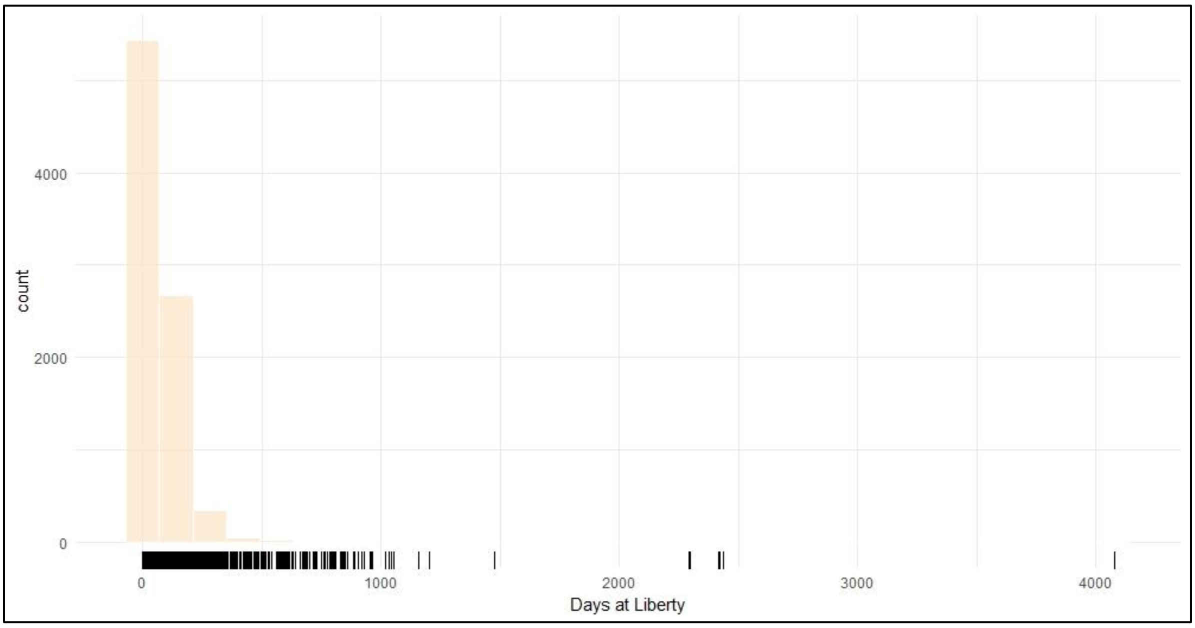


***Figure 3:** Bar plot showing the frequency of days at liberty with a rug at the bottom showing where the observations are. Most of the fish are recaptured withing 250 days and the analysis was focused on these data.*

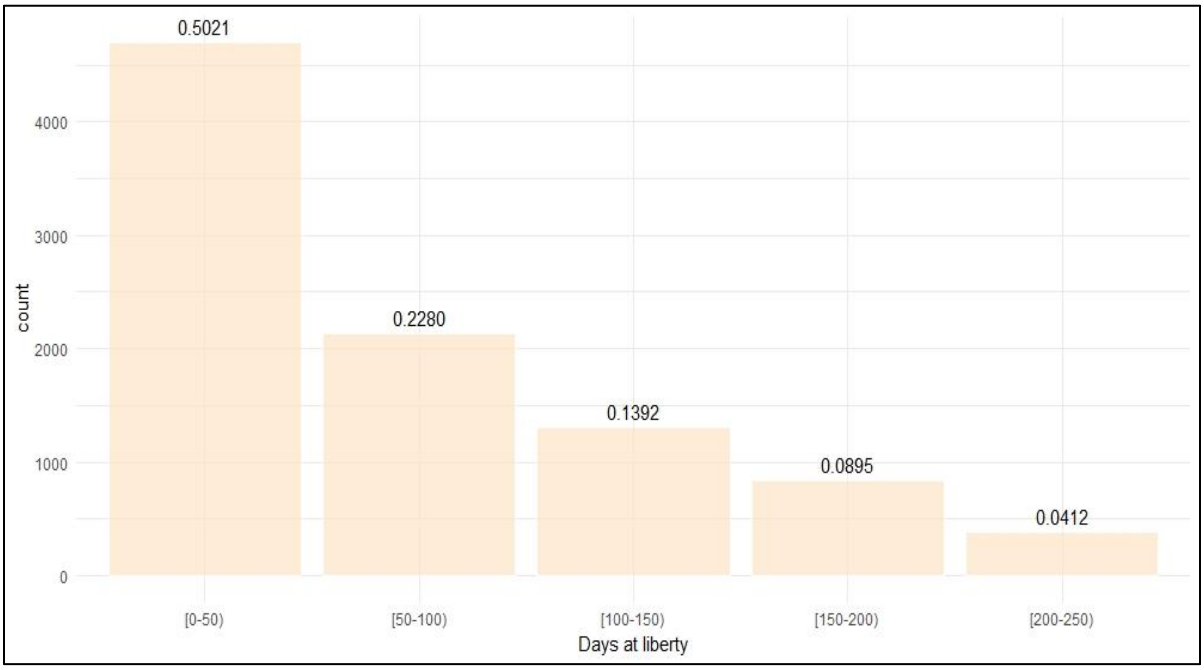


***Figure 4:** Proportion of days at liberty by 50-day intervals showing that 50 % of the fish within 0-250 days are caught in the first 50 days.*

Total number of fish released in the East and Central of Bismarck Sea was 29, 624. This was the largest in all areas. Total fish recaptured was from this area at 3946. From the total number of recaptured fish, 3274 fish were captured inside the AW which was 80% of all fish recaptured. Median displacement was 160km and median days was 60. In Bismarck Sea (North East) area, a total of 2136 fish were released and 208 recaptured. From the 208 fish recaptured, 101 were from the AW forming approximately 49% of the total fish recaptured. Median displacement was 356 km and median days was 56.6. A total of 7549 fish were released from the Bismarck Sea, North-West area. 1071 fish were recaptured from the total released. 764 fish or 70% were recaptured in the AW from the total number of recaptured fish. Median displacement was 186 km and median days were 22 (Table 1).

In Bismarck Sea West, a total of 10 662 fish were released in this area and 937 were recaptured. A total of 755 were recaptured in the AW which was 80% of all fish recaptured. Median displacement was 89.6 km and median days were 16. East of Bismarck Sea had 10 365 fish released and 672 recaptured. From the recaptured fish, 233 were captured in the AW which was approximately 35% of the proportion of fish caught. Median displacement was 617 km and median days were 78. In Area, South of Bismarck Sea, 1920 fish were released and a total of 119 recaptured. From the recaptured fish, 94 were captured in the AW which was 79% of proportion of fish caught. Median displacement was 528 km and median days were 148 (Table 1).

Table 1: *Total number of fish released and recaptured, and Proportion of recaptured fish in AW by the six study areas.*

Area	Total Released	Total recaptured	Total recaptured in AW	Proportion in AW	Median Displacement(km)	Median Days
Bismarck Sea (East and Central)	29624	3946	3274	0.830	196	60
Bismarck Sea (North East)	2136	208	101	0.486	356	56.5
Bismarck Sea (North West)	7549	1071	764	0.713	186	22
Bismarck Sea (West)	10662	937	755	0.806	89.6	16
East of Bismarck Sea	10365	672	233	0.347	617	78
South of Bismarck Sea	1920	119	94	0.790	528	148

The frequency distribution of days at liberty shows areas; Bismarck Sea (East and Central), Bismarck Sea (North West) and Bismarck Sea (West) had most of the fish recaptured within 0 – 50 days (Figure 5). Areas East of Bismarck, Bismarck Sea (North East) and South of Bismarck has most recaptured within 0 - 100 days.

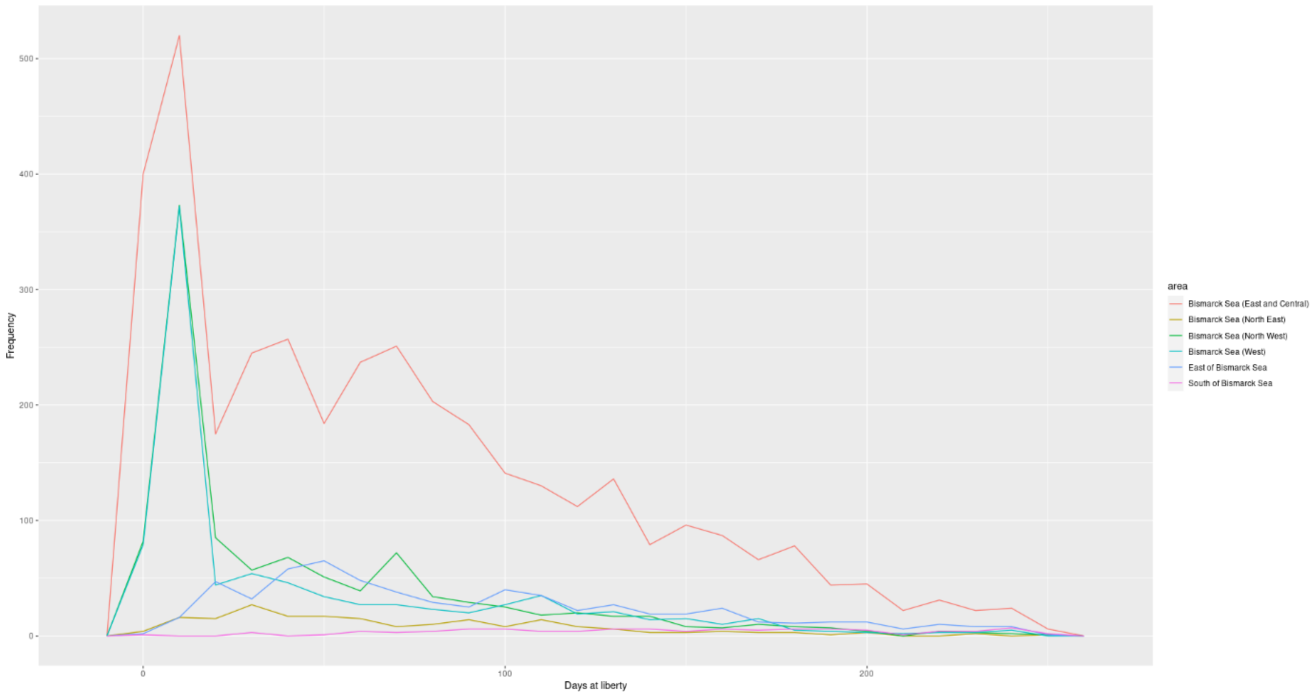


Figure 5: *Frequency distribution of days at liberty by Areas.*

5.1.1 Spatial Mapping

Spatial maps of release and recapture of skipjack tuna were generated to visually illustrate individual locations of release and recapture. All fish in this study were released inside the AW waters (Figure 6A, 8A, 10A, 12A, 14A and 15A). Recapture maps show most fish were recaptured between 0-250 days (Figure 6B, 8B, 10B, 12B, 14B and 15B). Some fish are observed to be recaptured in the neighboring EEZ's and high Seas.

Observations from the displacement maps show fish travel in all directions after release but most are recaptured within the AW close to their area of release. Fish tagged and released from the east and central area travel in all directions (Figure 7A). Some are seen to travel to the high seas and into the Indonesian EEZ to the West. Some travel far to the southeast into the EEZ of Solomon Islands. However, the proportion of recapture is the highest in the AW (Figure 7B) as indicated by the size of the pie graph. The pie distribution maps are a representation of the distribution of proportion of recaptured fish in the AW versus EEZ. The size of the pie represents the number of recaptures and the segments. Within each pie proportion caught by days at liberty are represented where (A) represents days at liberty of 0 -50 (B) represents days at liberty of 50 – 100, (C) represents days at liberty of 100 -150, (D) represents days at liberty of 150 – 200, and (E) represents days at liberty of 200 – 250 days. A much smaller proportion is caught in the EEZ and beyond. The proportion travelling to the southeast and to the west is very small and hence does not appear on the map. It should be noted that the proportion recaptured is calculated as within AW and outside of AW, therefore EEZ and high seas are represented together.

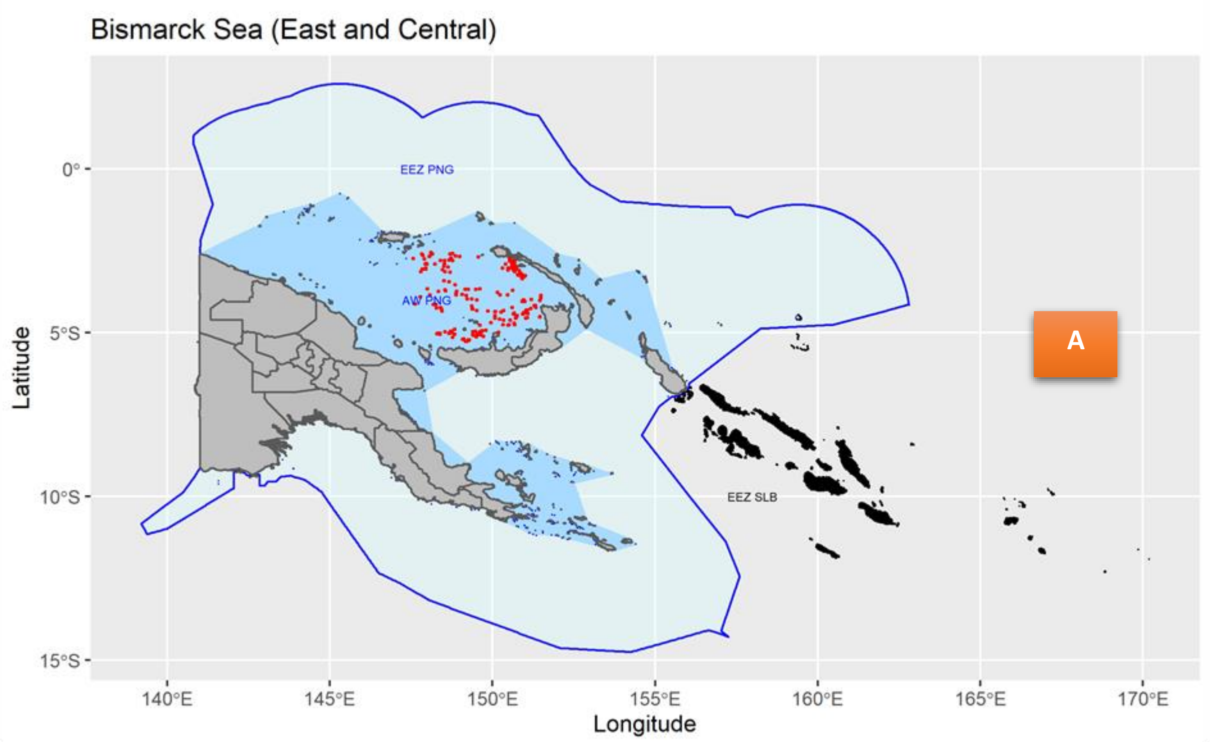
Fish tagged and released from the north-west area travel in all directions (Figure 9A). Some are seen to travel to the high seas and into Indonesian EEZ to the West. Some travel north to Micronesia. However, the proportion of recapture is the highest in the AW (Figure 9B) as indicated by the size of the pie graph and close to where they are released. A much smaller proportion is caught in the EEZ and beyond.

Fish tagged and released from the north-east area travel in all directions (Figure 11A). Some are observed to travel southeast to Solomon Islands EEZ, west to Indonesia and north to Micronesia and the high seas. A few are seen to travel east beyond the EEZ. The proportion of recapture is higher in the EEZ as indicated by the size of the pie graph (Figure 11B).

Fish tagged and released in the west area travel in all directions (Figure 13A). Some are seen to travel southeast to the Solomon Islands EEZ, west towards Indonesian waters, north towards Micronesia and the high seas. However, the proportion of recapture is highest in the AW (Figure 13B) as indicated by the size of the pie graph and caught close to where they were released from.

Fish tagged and released in the south area are dispersed mostly towards the north and west (Figure 15A). Some are observed to be dispersed towards east to the Solomon Islands EEZ and northeast beyond the EEZ to the high seas. The proportion of recapture is highest in the AW (Figure 15B) as indicated by the size of the pie graph.

Fish tagged and released in the East area dispersed in all directions (Figure 17A). Some are seen to travel north to Micronesia and the high seas, west towards Indonesian waters and southeast towards the Solomon Islands EEZ. The proportion of the recapture is highest in the EEZ (Figure 17B) as indicated by the size of the pie graph.



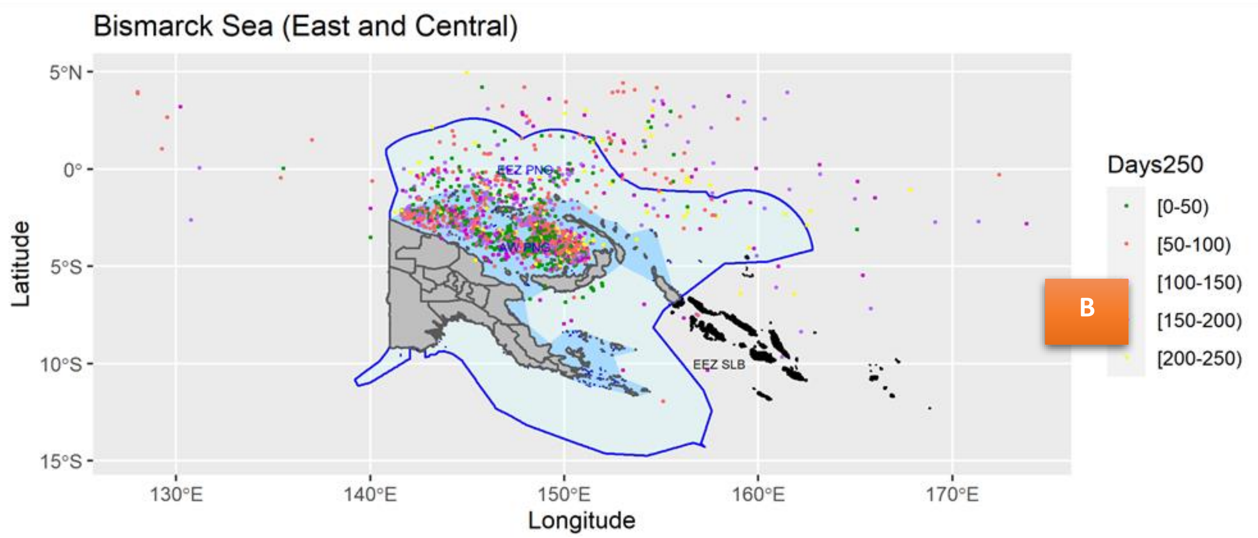


Figure 6: *Release (A) and recapture (B) of skipjack tuna in the Bismarck Sea (East and Central). The days at liberty as shown in the legend of recapture map is colour coded which shows most skipjacks spending around 250 days before recapture.*

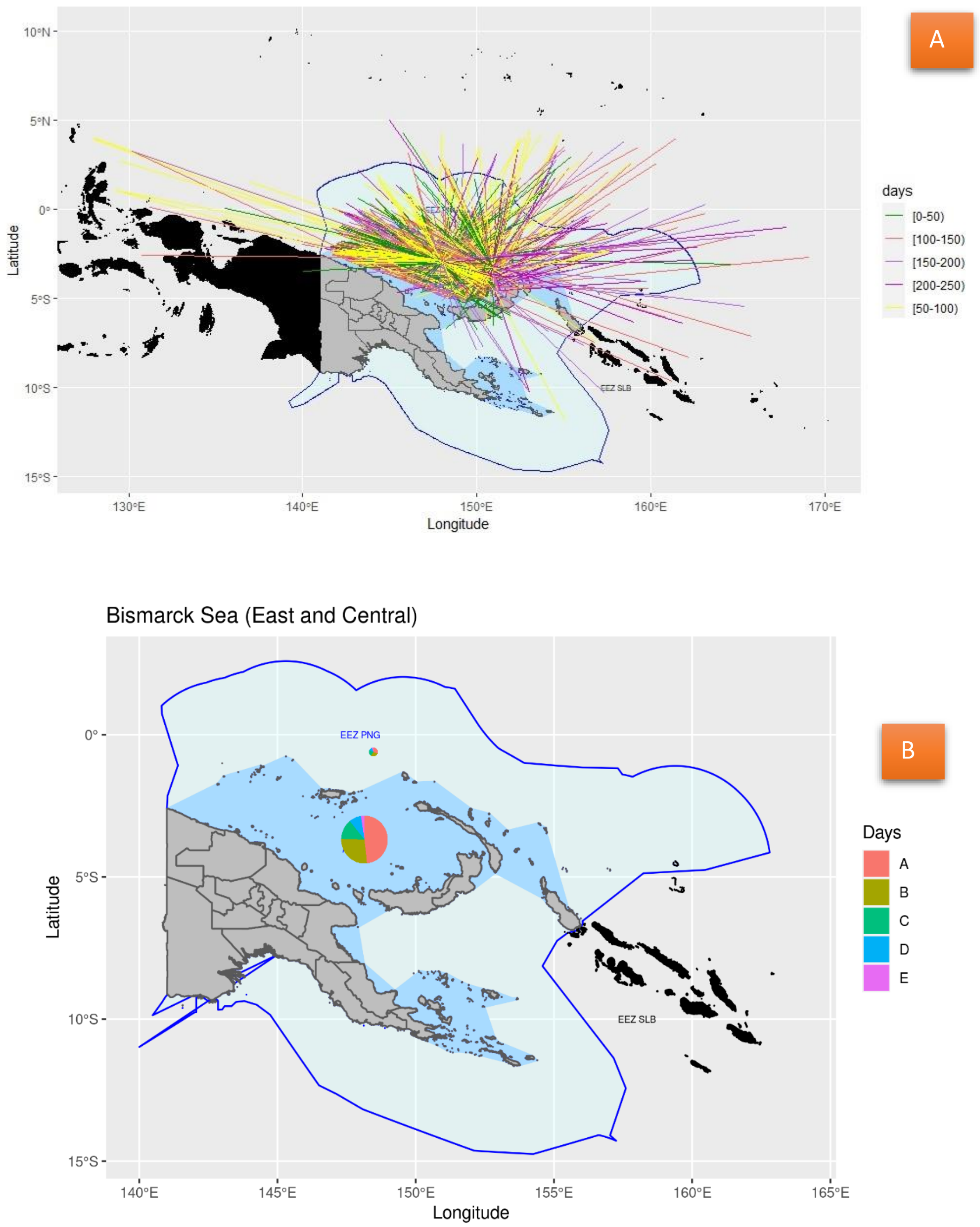
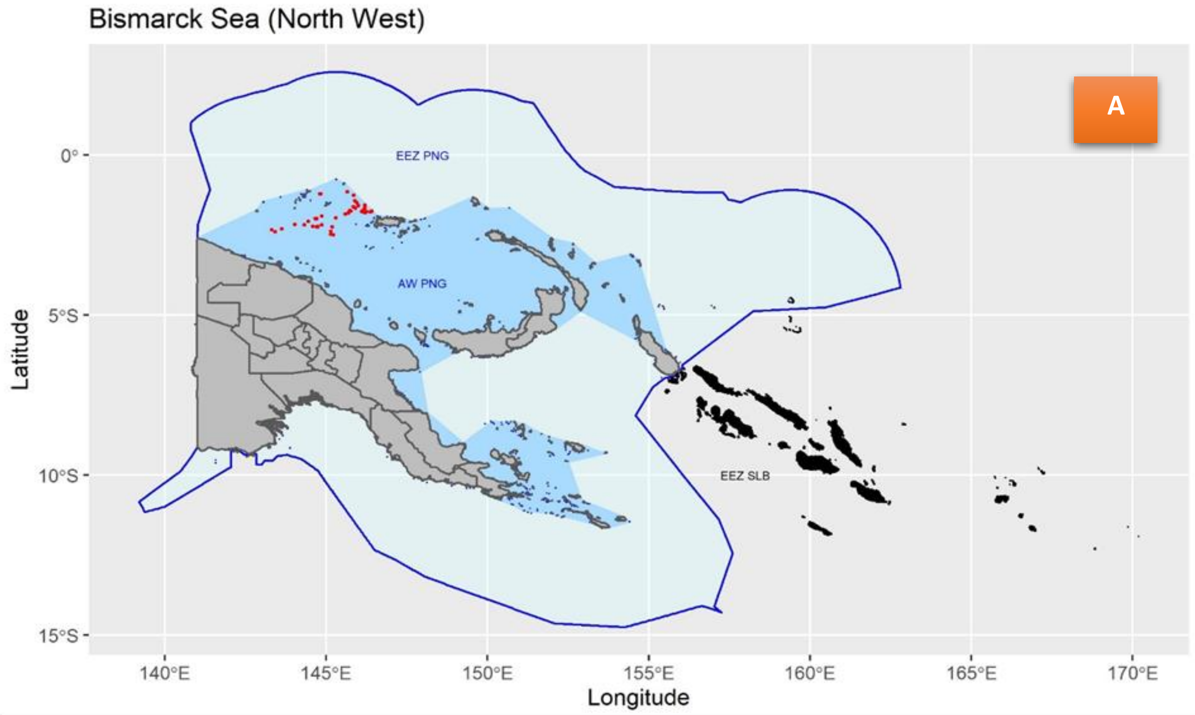


Figure 7: *Displacement map (A) showing the movement pattern of fish after release from Bismarck Sea (East and Central) colour-coded by days at liberty. The pie chart represents the proportion of recaptures by AW and EEZ (B). Within each pie proportion caught by days at liberty are represented where (A) represents days at liberty of 0 -50 (B) represents days at liberty of 50 – 100, (C) represents days at liberty of 100 -150, (D) represents days at liberty of 150 – 200, and (E) represents days at liberty of 200 – 250 days. The fish disperse in all directions, but most are recaptured in AW.*



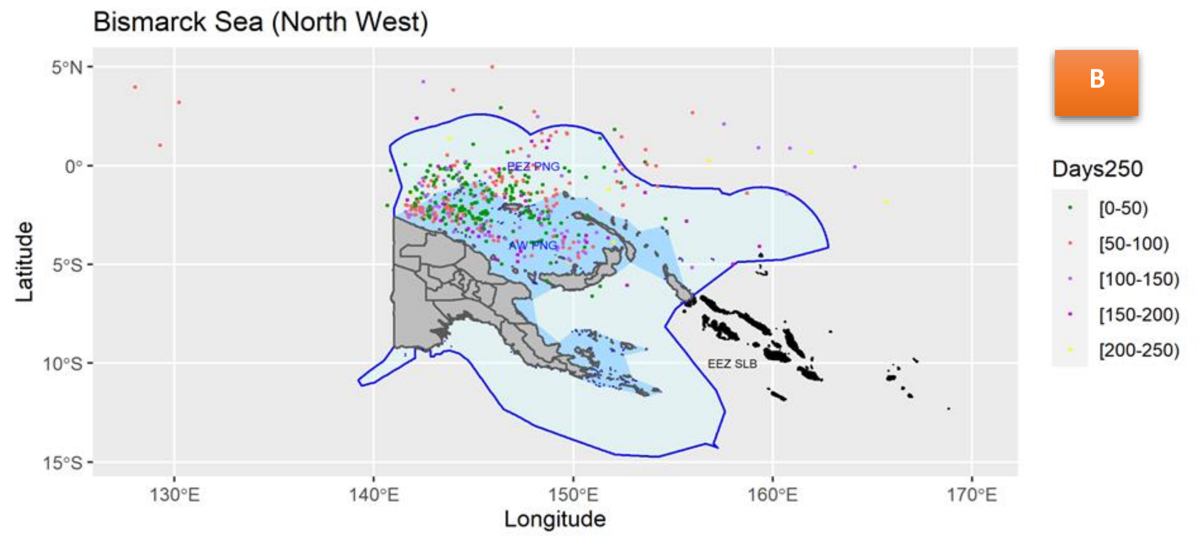


Figure 8: *Release (A) and recapture (B) of skipjack tuna in the Bismarck Sea (Northwest) of the AW waters. Skipjacks release in Northwest are recaptured almost all around the AW waters including the neighbouring EEZ's. The days at liberty as shown in the legend of recapture map shows most skipjacks spending around 250 days before recapture.*

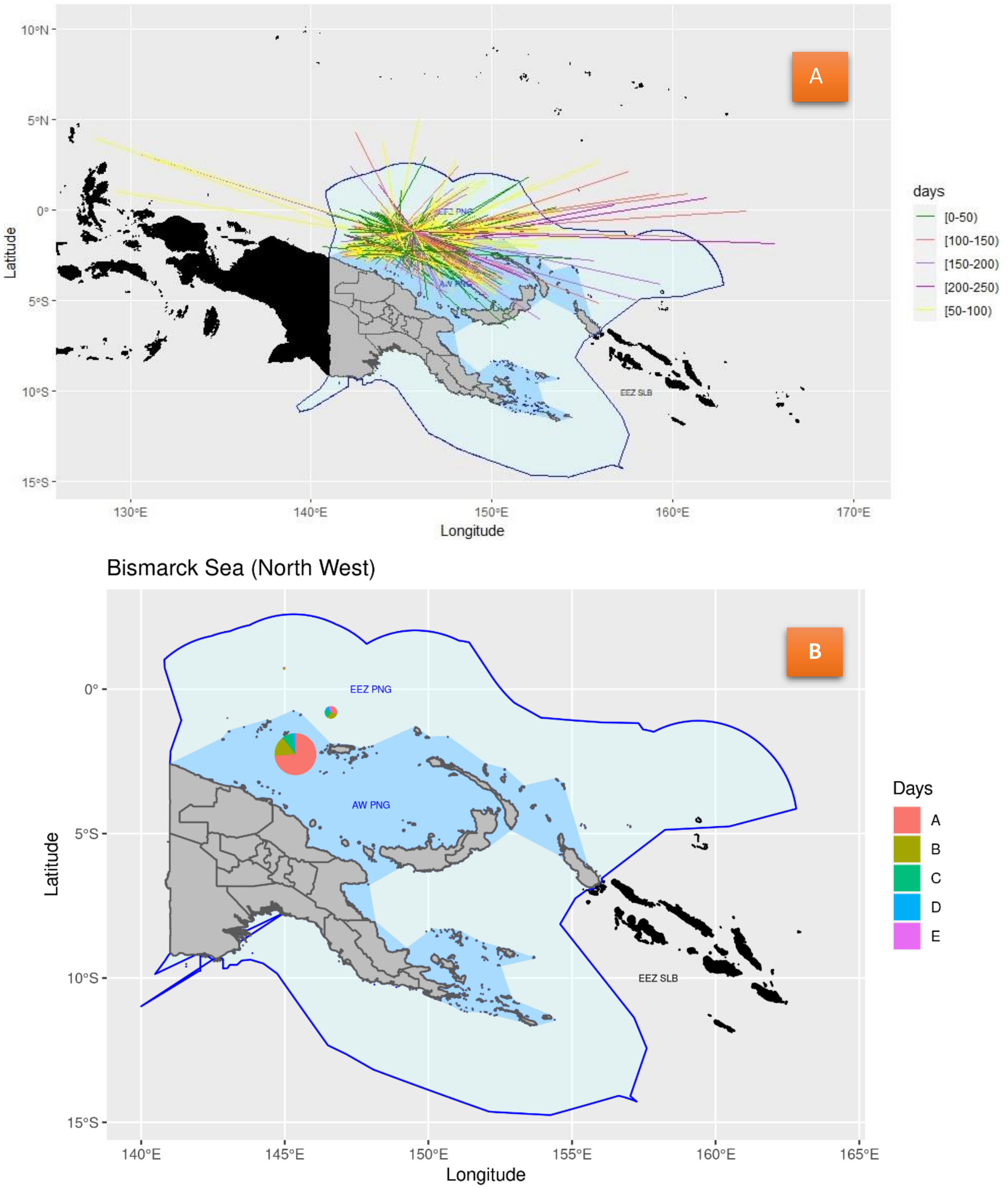
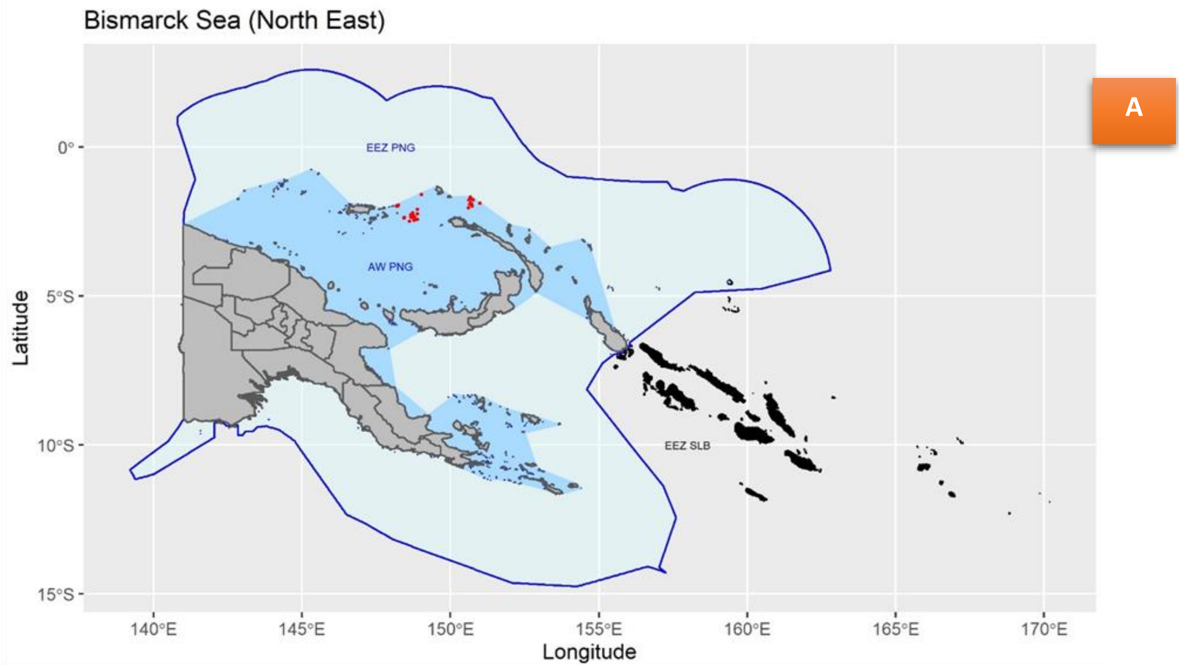


Figure 9: *Displacement map (A) showing the movement pattern of fish after release from Bismarck Sea (North West) colour-coded by days at liberty. The pie chart represents the proportion of recaptures by AW and EEZ (B). Within each pie proportion caught by days at liberty are represented where (A) represents days at liberty of 0 -50 (B) represents days at liberty of 50 – 100, (C) represents days at liberty of 100 -150, (D) represents days at liberty of 150 – 200, and (E) represents days at liberty of 200 – 250 days. The fish disperse in all directions, but most are recaptured in AW.*



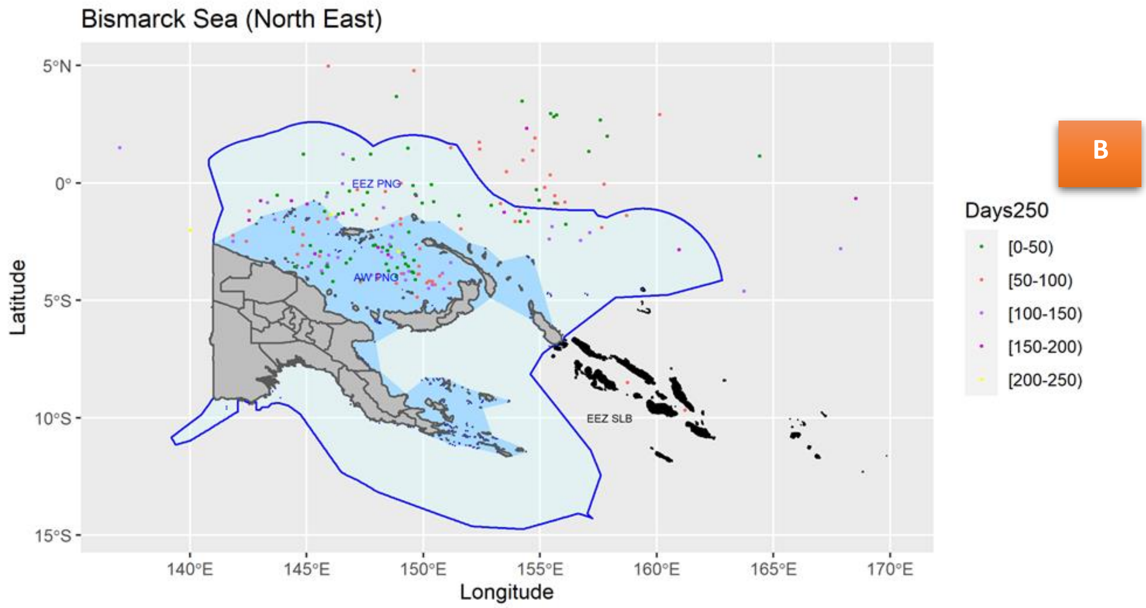


Figure 10: *Release (A) and recapture (B) of skipjack tuna in the Bismarck Sea (Northeast) of the AW waters. Skipjacks released in the Northeast are recaptured almost all around the AW waters including the rest of the EEZ and neighbouring EEZ's. The days at liberty as shown in the legend of recapture map shows most skipjacks spending around 250 days before recapture.*

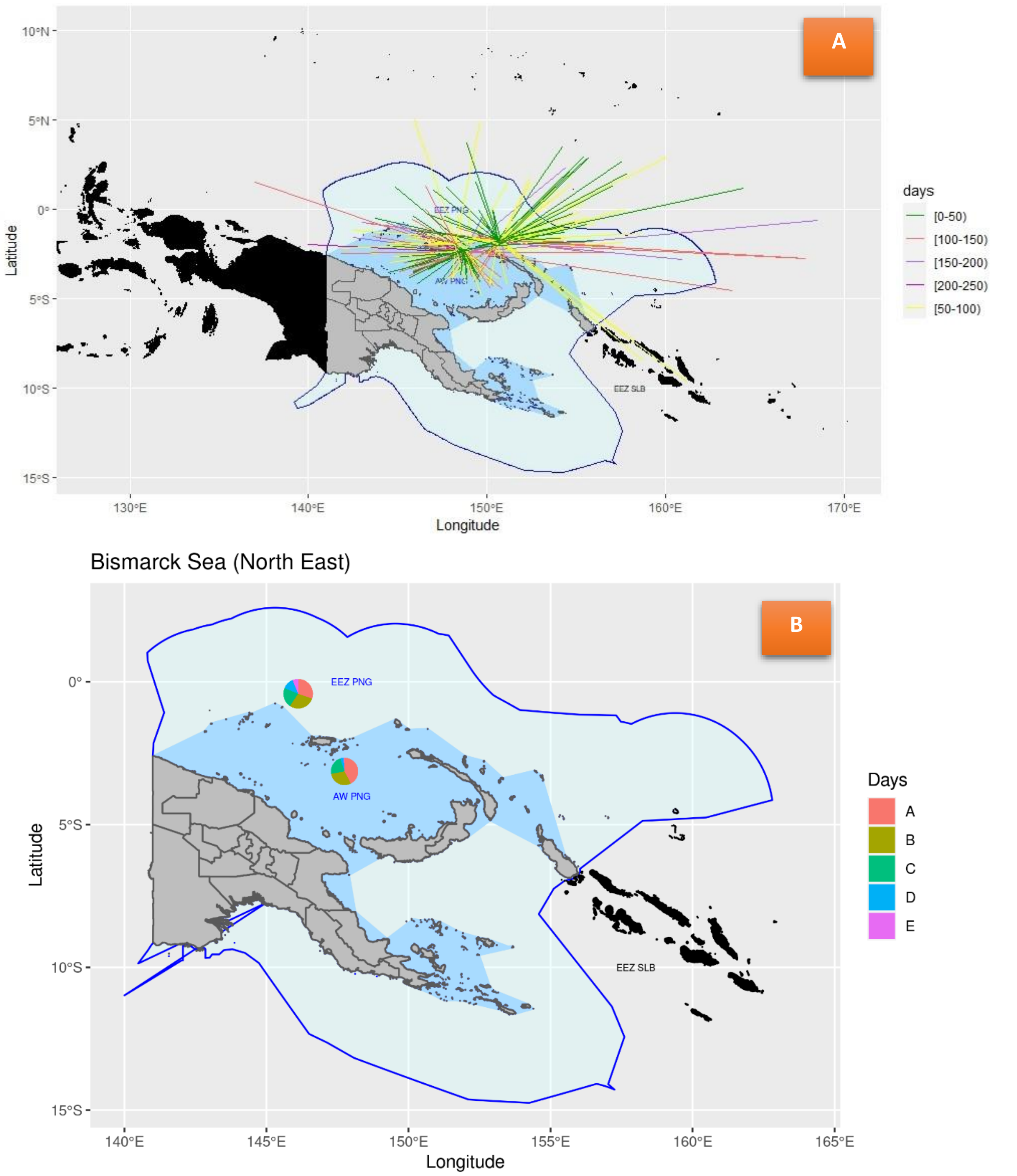


***Figure 11**: Displacement map (A) showing the movement pattern of fish after release from Bismarck Sea (North East) colour-coded by days at liberty. The pie chart represents the proportion of recaptures by AW and EEZ (B). Within each pie proportion caught by days at liberty are represented where (A) represents days at liberty of 0 -50 (B) represents days at liberty of 50 – 100, (C) represents days at liberty of 100 -150, (D) represents days at liberty of 150 – 200, and (E) represents days at liberty of 200 – 250 days. The fish disperse in all directions, but most are recaptured in EEZ.*

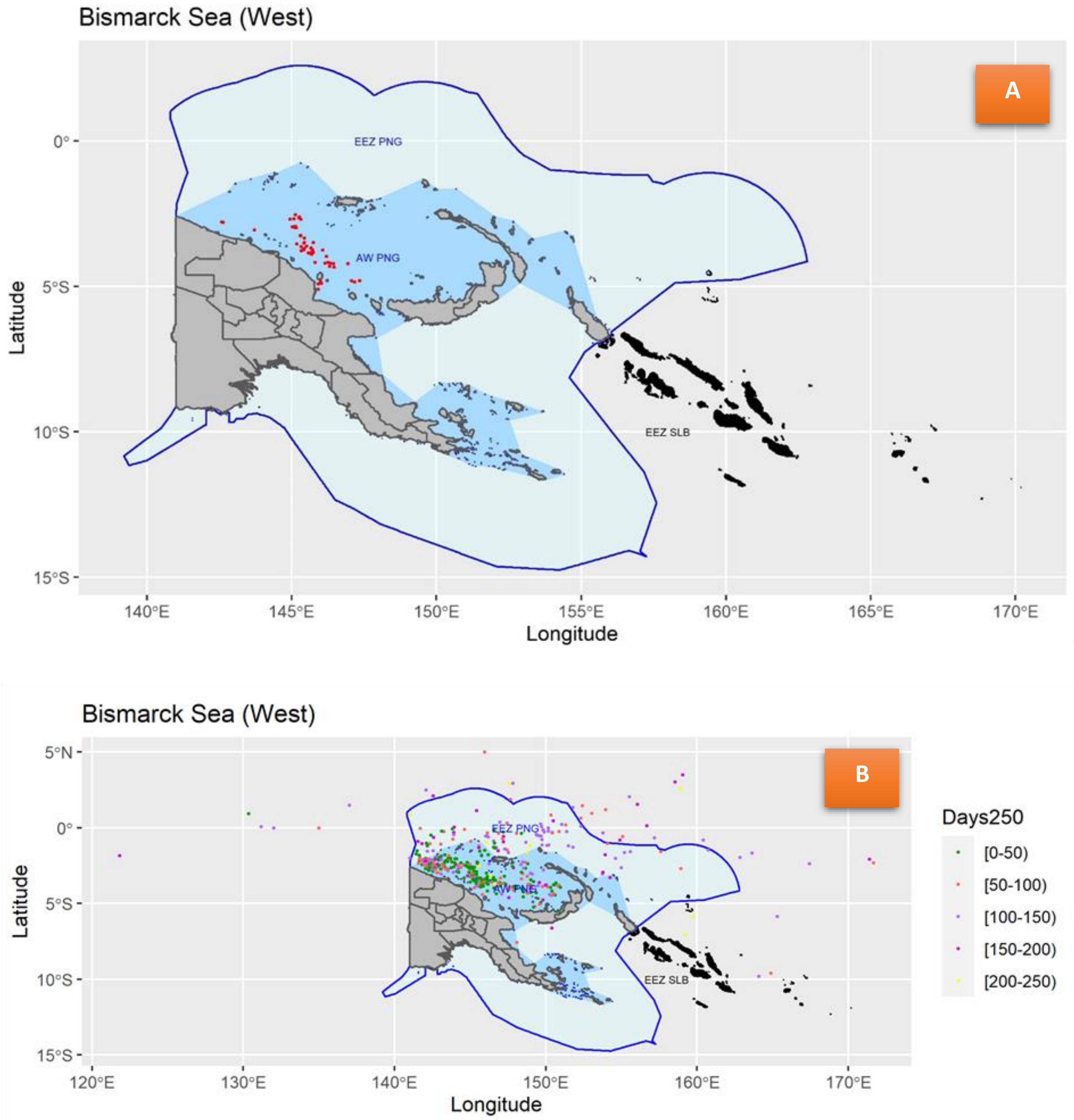


Figure 12: *Release (A) and recapture (B) of skipjack tuna in the Bismarck Sea (West) of the AW waters. Recapture map shows fish caught in AW waters including the neighbouring EEZ's. The days at liberty as shown in the legend of recapture map shows most skipjacks spending around 250 days before recapture.*

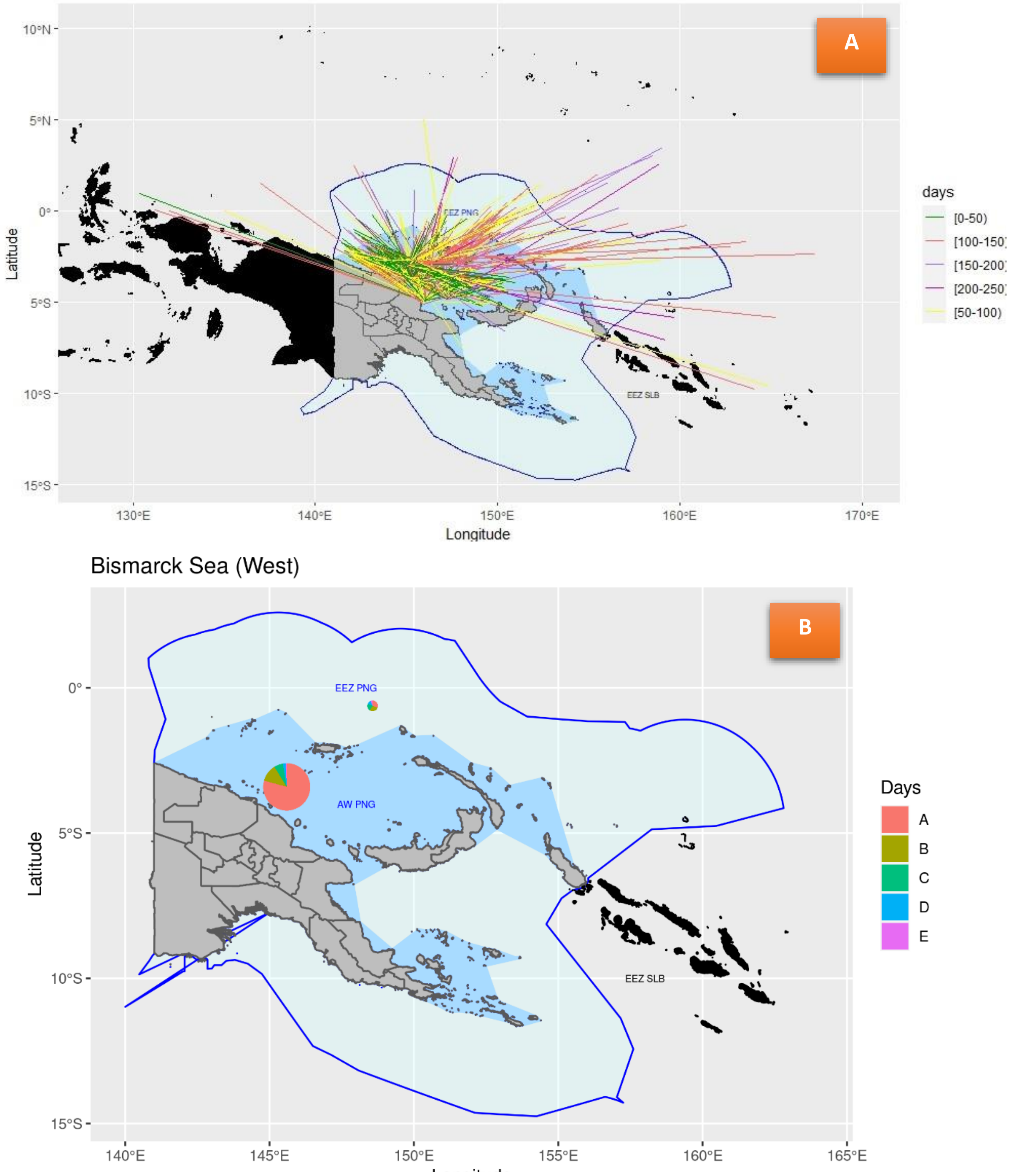
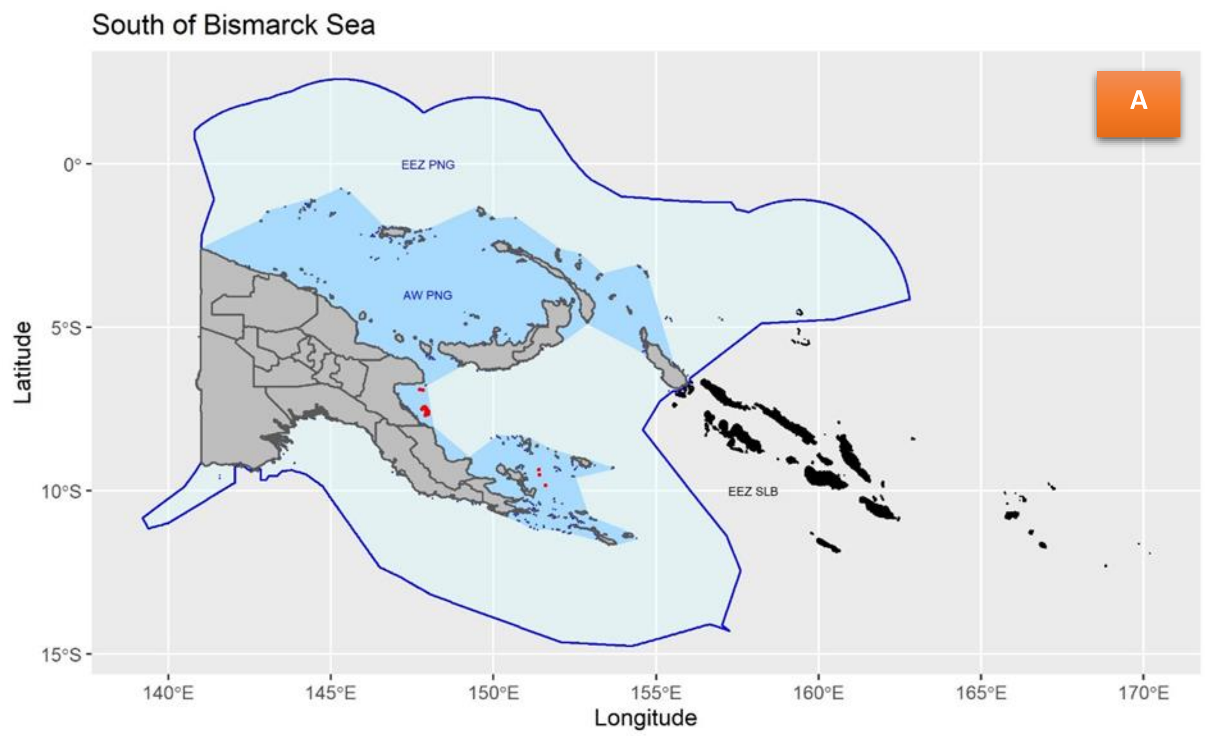


Figure 13: *Displacement map (A) showing the movement pattern of fish after release from Bismarck Sea (West) colour-coded by days at liberty. The pie chart represents the proportion of recaptures by AW and EEZ (B). Within each pie proportion caught by days at liberty are represented where (A) represents days at liberty of 0 -50 (B) represents days at liberty of 50 – 100, (C) represents days at liberty of 100 -150, (D) represents days at liberty of 150 – 200, and (E) represents days at liberty of 200 – 250 days. The fish disperse in all directions, but most are recaptured in AW.*



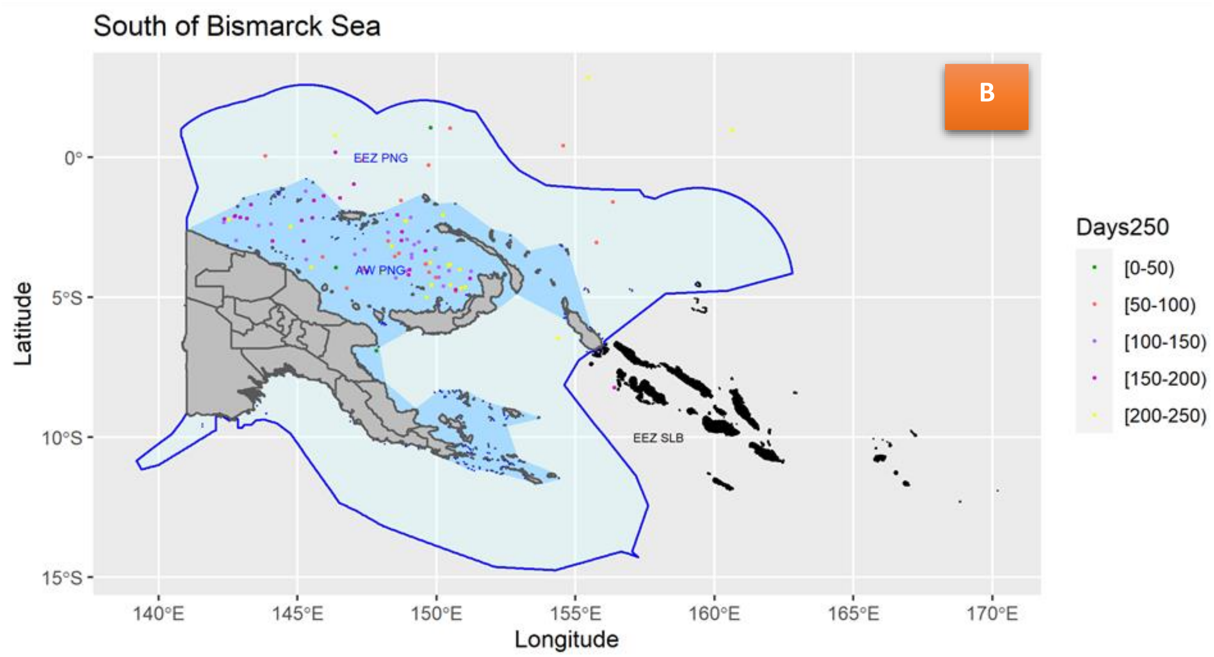
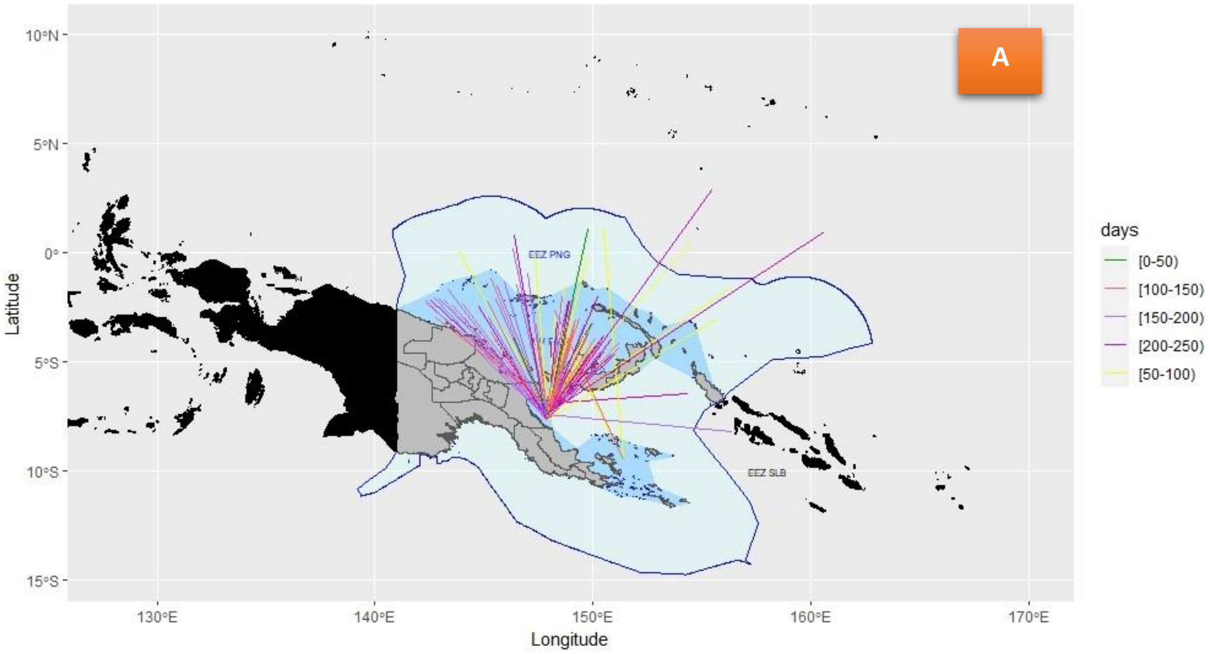


Figure 14: *Release (A) and recapture (B) of skipjack tuna in the Bismarck Sea (South) of the AW waters. Skipjacks released in South are recaptured in the Central and West areas of the AW. The days at liberty as shown in the legend of recapture map shows most skipjacks spending around 250 days before recapture.*



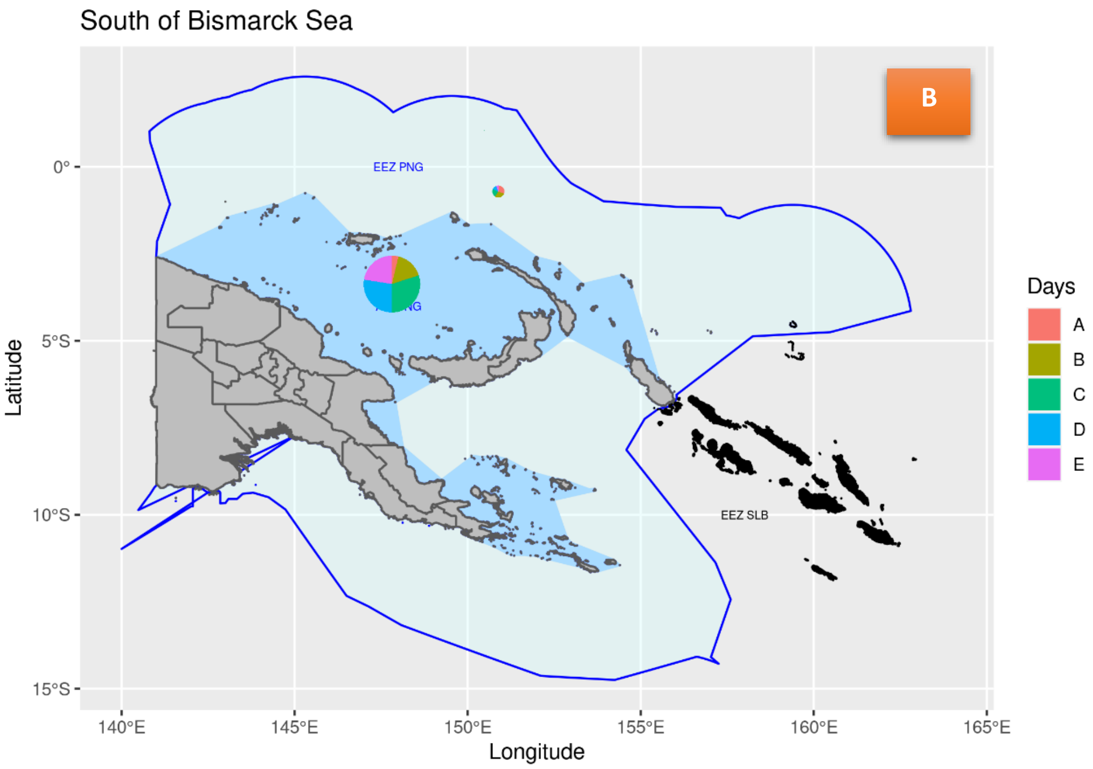


Figure 15: *Displacement map (A) showing the movement pattern of fish after release from South of Bismarck Sea colour-coded by days at liberty. The pie chart represents the proportion of recaptures by AW and EEZ (B). Within each pie proportion caught by days at liberty are represented where (A) represents days at liberty of 0 -50 (B) represents days at liberty of 50 – 100, (C) represents days at liberty of 100 -150, (D) represents days at liberty of 150 – 200, and (E) represents days at liberty of 200 – 250 days. The fish disperse in all directions, but most are recaptured in AW.*

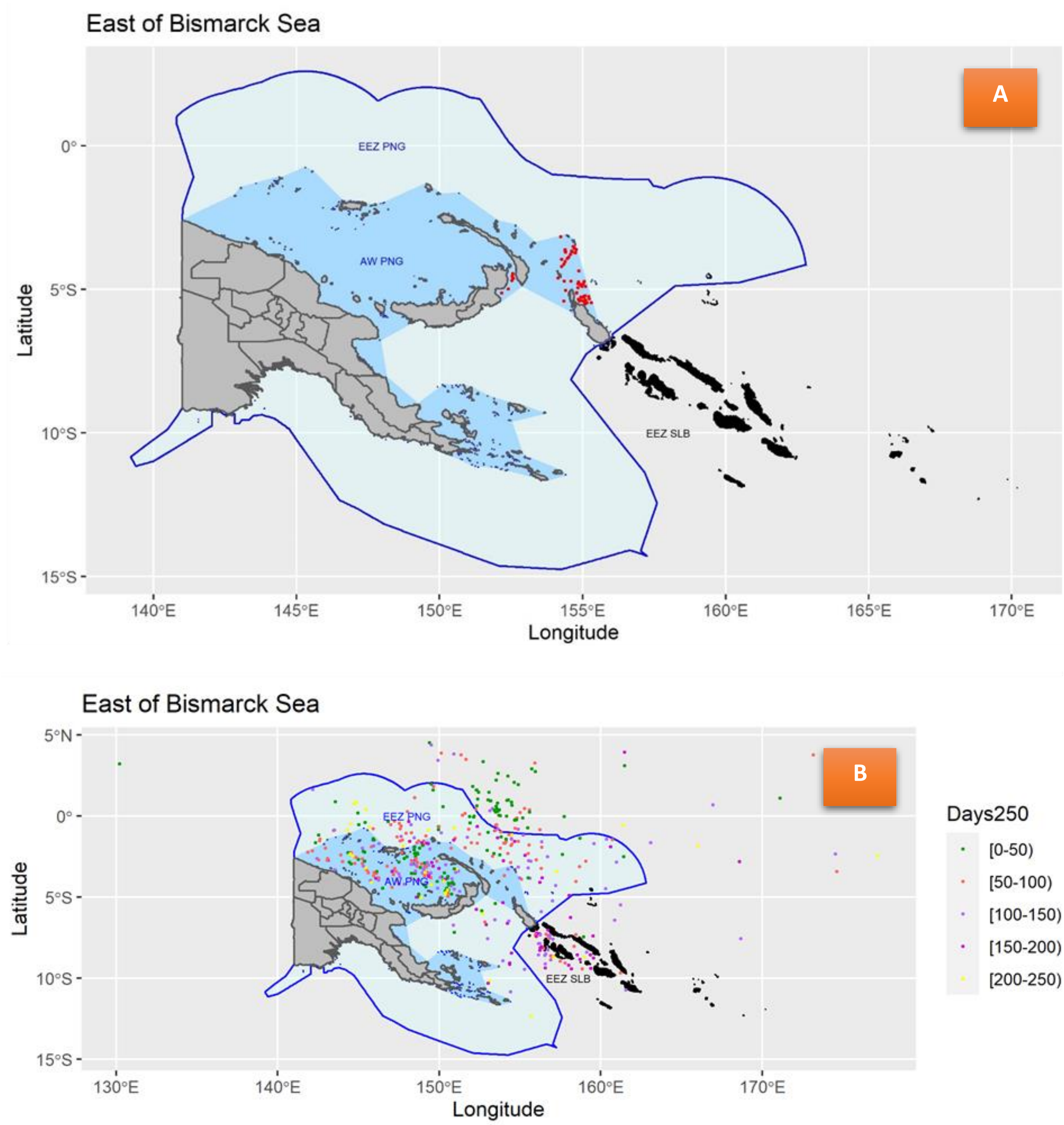
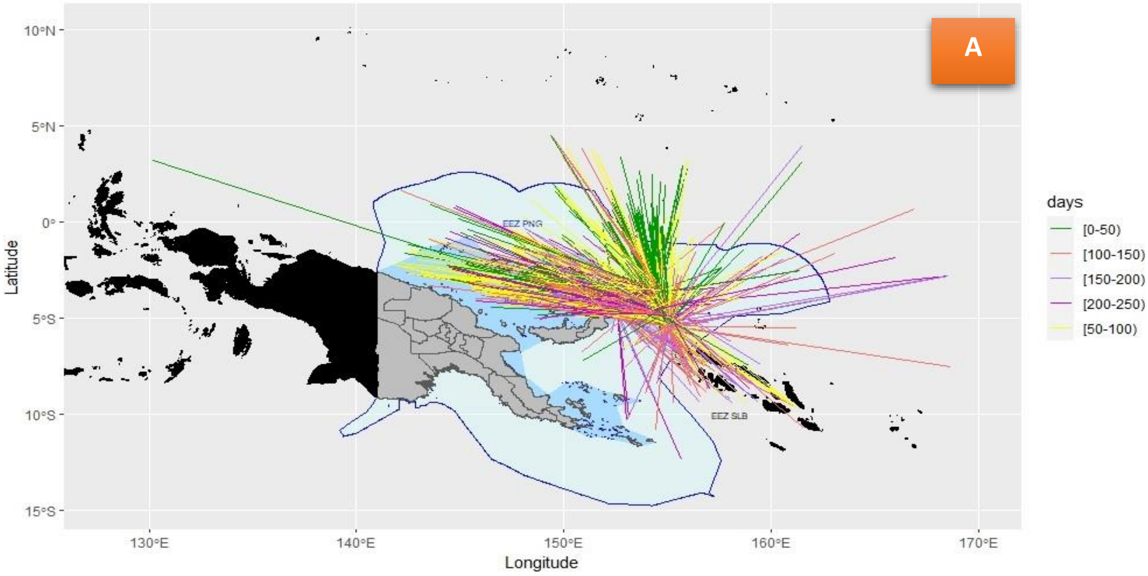


Figure 16: *Release (A) and recapture (B) of skipjack tuna in the Bismarck Sea (East) of the AW waters. Skipjacks released in South are recaptured in the Central and West areas of the AW. The days at liberty as shown in the legend of recapture map shows most skipjacks spending around 250 days before recapture.*



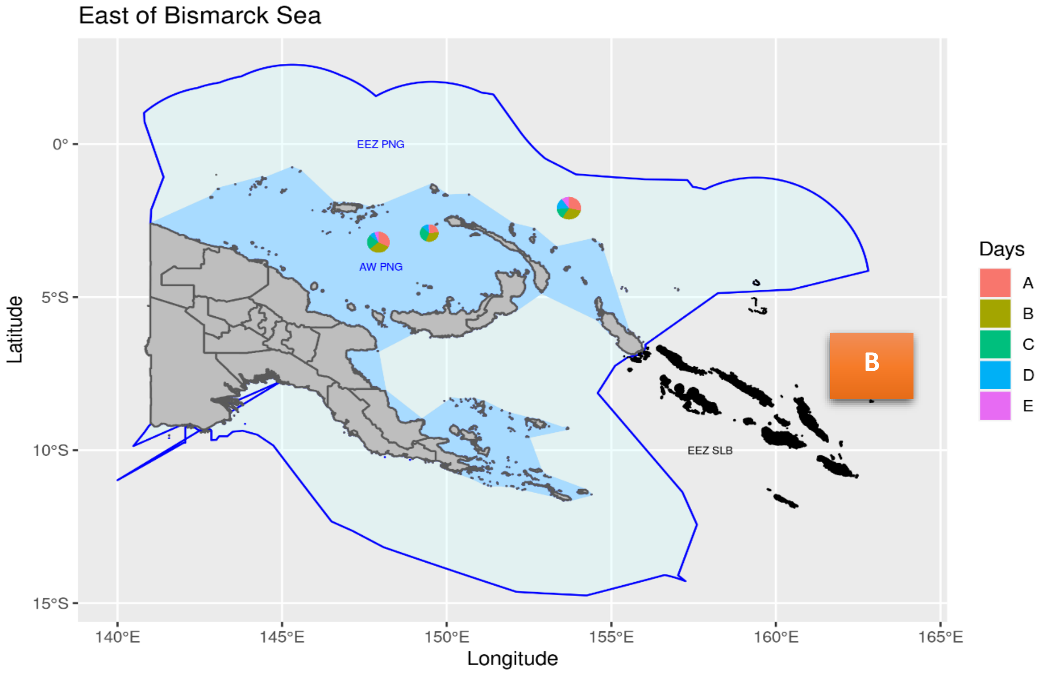


Figure 17. Displacement map (A) showing the movement pattern of fish after release from East of Bismarck Sea colour-coded by days at liberty. The pie chart represents the proportion of recaptures by AW and EEZ (B). Within each pie proportion caught by days at liberty are represented where (A) represents days at liberty of 0 -50 (B) represents days at liberty of 50 – 100, (C) represents days at liberty of 100 -150, (D) represents days at liberty of 150 – 200, and (E) represents days at liberty of 200 – 250 days. The fish disperse in all directions, but most are recaptured in EEZ.

The mean length of fish released was 43 cm (grey histogram) and recaptured fish was 49 cm (blue histogram) (Figure 18). The spread of fish released ranged from 25 cm – 66 cm. For the recaptured fish, spread ranged from 30 cm – 100+ cm. This indicates growth during days at liberty between release and recapture.

5.1.2 Release and recapture length proportion

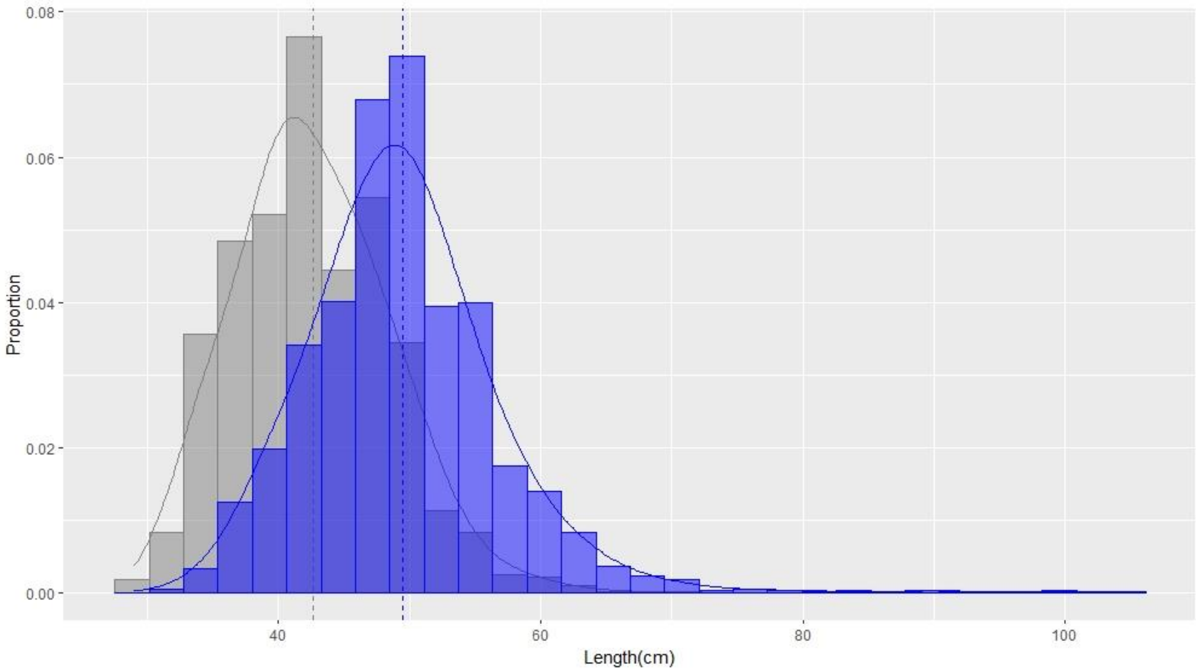


Figure 18: *Proportion of mean length of release and recaptured fish.*

The length distribution and mean lengths of recaptured fish were compared between AW and EEZ for the six study areas. Note that the study area is defined by the area of release i.e. the recaptured fish were released from these areas. Bismarck Sea (East and Central) area had AW mean length of approximately 49 cm and 53 cm for EEZ. The spread of the distribution for the AW in the Bismarck Sea (East and Central) was within 32 cm – 72 cm and EEZ was 35 cm – 75 cm. The two distributions do not overlap, and it is evident that more of the larger fish are recaptured in the EEZ. Mean lengths for Bismarck Sea (West) were 49 cm for AW and 54 cm for EEZ. The spread of length distribution of AW ranged from 32 cm – 72 cm and EEZ ranged from 37 cm – 101 cm. A similar pattern is observed here, where the two distributions do not overlap and more of the larger fish are recaptured in the EEZ. Fish recaptured by Bismarck Sea (North East) release area, had a mean length of 54 cm if recaptured in EEZ and 48 cm when recaptured in AW. The range for AW recaptures ranged from 35 cm -72 cm and 40 cm -91 cm for EEZ recaptures. East of Bismarck had mean lengths of 53 cm for AW and 54 cm for EEZ. The spread of length distribution for AW in this area was from 37 cm – 101 cm and 42 cm and 95 cm for the EEZ. South of Bismarck Sea had mean lengths of 56 cm for AW and 57 cm for EEZ. Spread of length distribution for AW ranged from 35 cm – 74 cm and 46 cm – 70 cm for EEZ (Figure 19). North -West of Bismarck had mean lengths of 47 cm for AW and 49 cm for EEZ. The spread of length distribution for AW in this area was from 33 cm – 90 cm and 34 cm and 78 cm for the EEZ.

The difference in mean length and length distributions are bigger in fish from East and Central, North-East and West. The bigger fish released from these regions tend to travel to the EEZ. From these 3 areas, where considerable size differences exist, only North East region show a high proportion of EEZ recaptures.

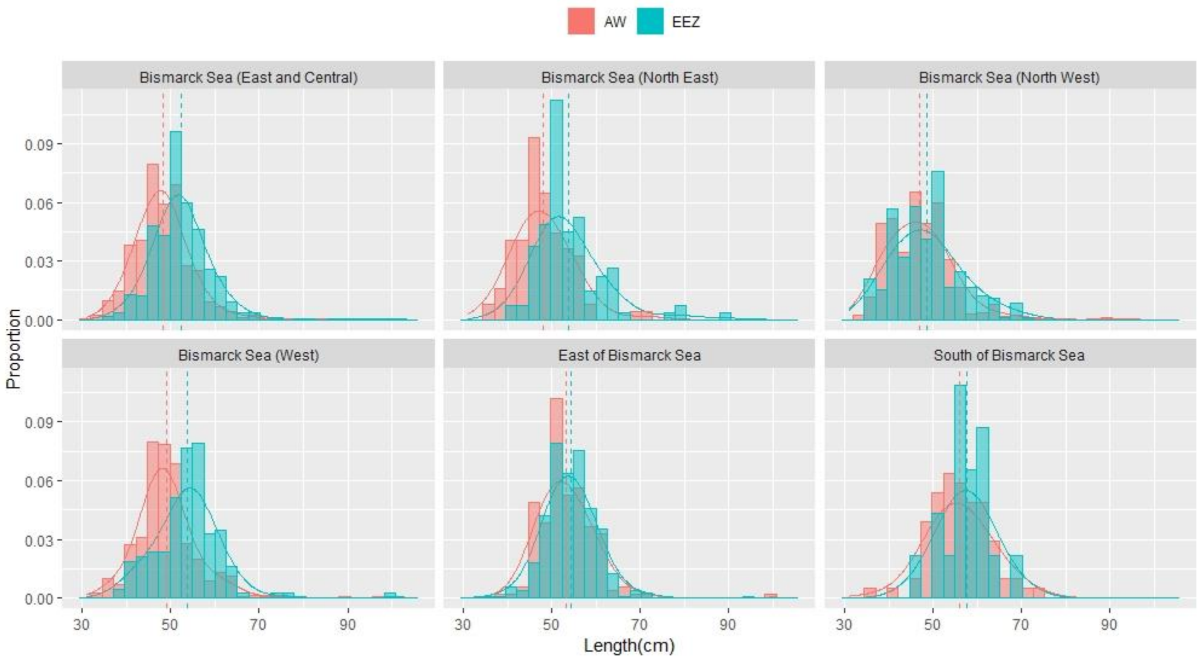


Figure 19*: Proportional distribution of histogram plot with mean lengths compared between AW and EEZ by the six study areas.*

5.2 Length Frequency from observer sampling

The size and mean length comparison between samples collected in AW and EEZ of observer sampling data (Figure 20) shows fish from both these regions do not have considerable differences in size. In some years the mean length differs slightly such as 2010, 2011, 2012, 2018, 2019 and 2020 but other years are very similar. Larger proportions of bigger fish are observed in the EEZ in some years such as 2010, 2011, 2015 and 2020.

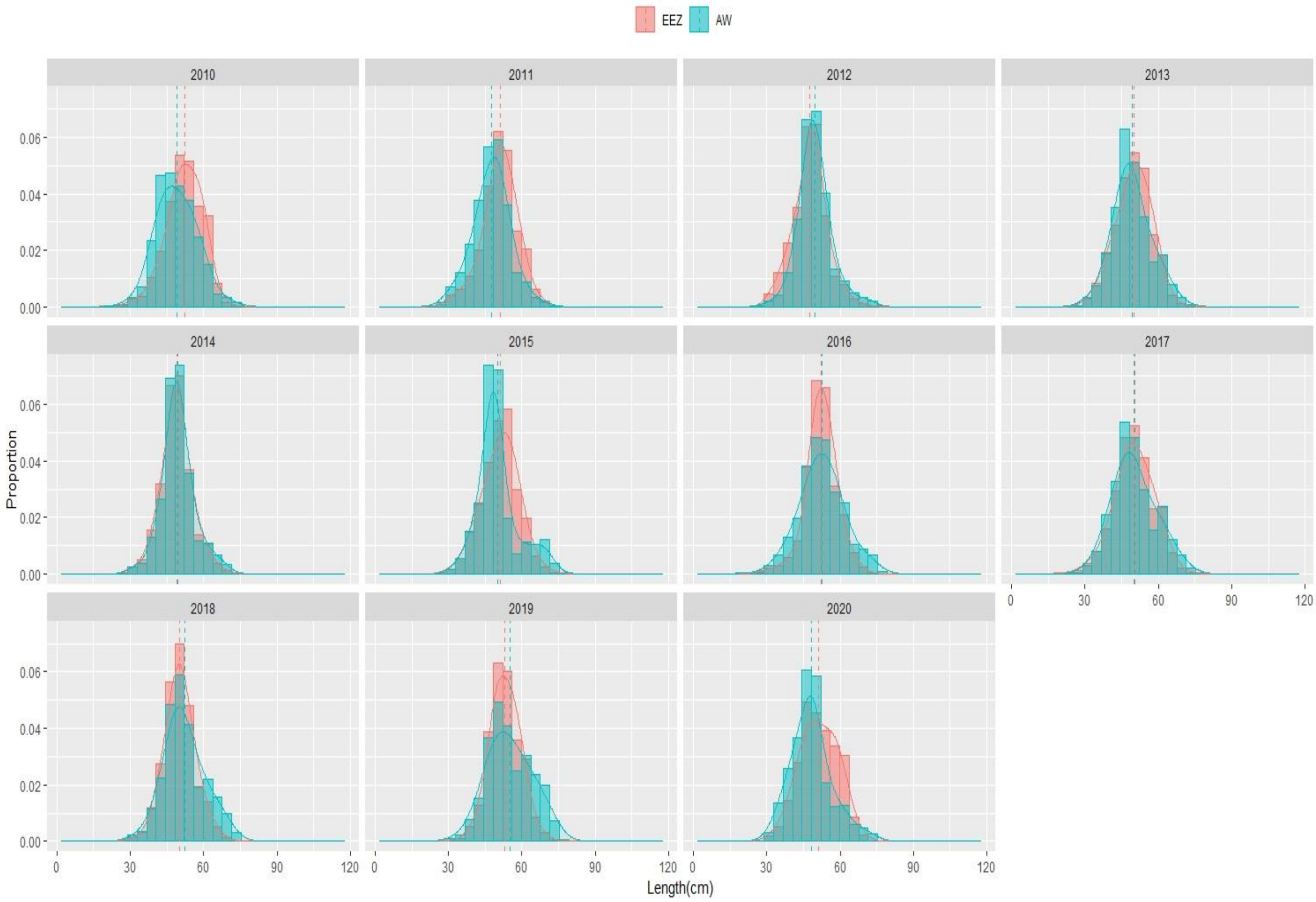


Figure 20: *Length Frequency distribution of skipjack tuna from years 2010 – 2020 of Port Sampling. Size, mean length comparisons made between the AW and EEZ per year.*

It is seen that fish travel furthest in the first 0-75 days approximately (Figure 21). From there the distance travelled by days levels off. The distance histogram (Figure 22) by area, shows that most fish in the East and Central, West, North West where there are high proportions of AW recaptures, also coincide that the fish don't travel far and are mostly caught within 0 – 50 m distance, whereas those from south and east travel far.

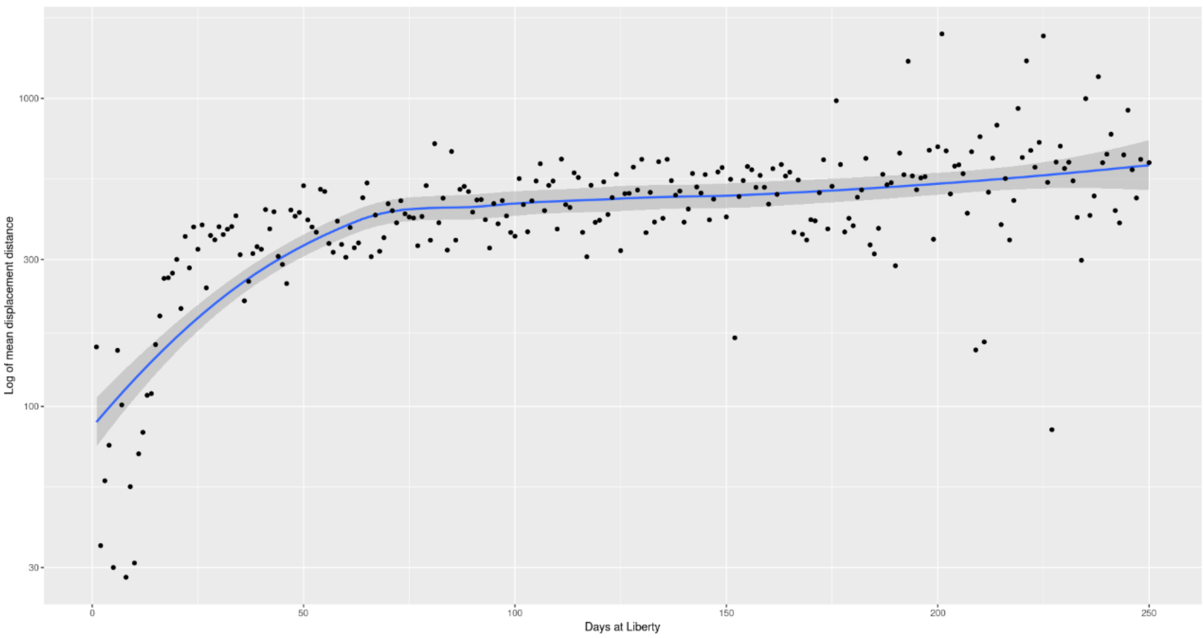


Figure 21: Log of mean displacement distance versus days at liberty

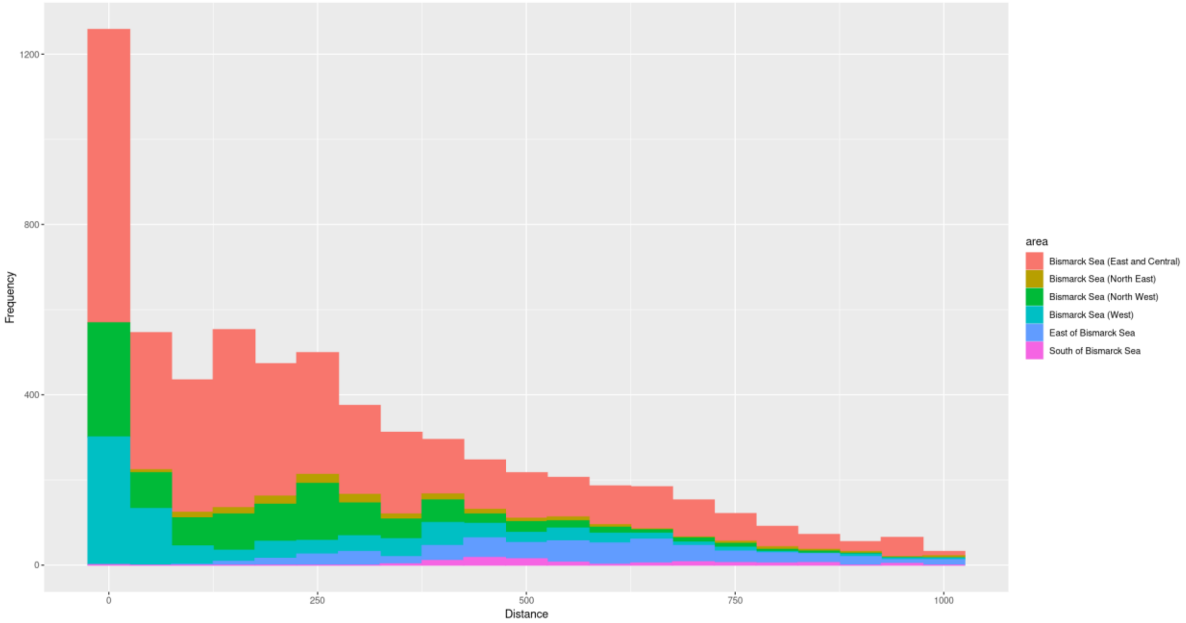


Figure 22: *Distance histogram by area*

6 DISCUSSION

6.1 Release and recapture in the study areas

Levin (1992), in his study *The Problem of Pattern and Scale in Ecology*, emphasized that understanding patterns through the processes that create them is fundamental to science and essential for developing resource management principles. He further noted that behavioural ecology examines the interactions between animals and their environment, highlighting that a key objective in fisheries science is to use knowledge of small-scale behaviour to explain large-scale movements and distribution. In this study visual illustrations were used to study the extent of skipjack tuna movement between Archipelagic Waters and Exclusive Economic Zone using conventional tagging data and to analyze any size difference of skipjack tuna from AW and EEZ waters.

Tagging studies are commonly used in fisheries research (Pine et al, 2011) to improve estimation of animal population size, mortality, movement and growth. In a study conducted by (Sibert & Hampton, 1999) on the "Mobility of tropical tunas and the implications for fisheries management"; data from three tuna tagging experiments in the western and central

Pacific Ocean (WCPO) were studied. Displacement in that study was defined as the net distance moved by each fish. They estimated only 50% of fish move beyond the median displacement distance. The remainder apparently persisted in an area closer to the place where they were tagged. This study shows a similar result where most fish released from central part of the PNG AW are recaptured close by. The Bismarck Sea is also known for its high concentration of FADs. According to SPC, 2007, anchored FADs were widely distributed in the Bismarck area – approximately 700 FADs. This could explain the high amounts of catch in the AW. These FAD act as hotspots for tuna aggregation as they create a suitable feeding environment potentially altering the habitat preference of the fish.

If the location of the recaptures can be seen as a proxy of habitat, then it can be inferred that most of these fish reside in the AW. Except the fish that are tagged and released at the outer edges of the AW tend to travel to the EEZ. There are also FADs present on the eastern side of the EEZ which could be attracting the fish.

There were fish observed to have travelled far into other neighboring EEZ's and high seas. This may be attributed to the skipjack's ability to swim long distances on high speed (Dizon et al, 1978). Another interesting observation was that fish released in the South travelled all the way up to the west and central area of the AW. Their movement coincide with greater days at liberty because they cover longer distances when travelling from the south.

Nonetheless, it cannot be ruled out that this fish that are recaptured in the AW could be travelling into the EEZ in the interim period and migrating back to the AW given the high speed at which tuna travel. On the other hand, fish recapture could be more indicative of where the fishing effort is applied and not so much of the actual distribution of the fish itself. (Morgan, 2011) reported that fishing captains rely on echo sounders, sonar, prior knowledge of tuna species' depth distributions and behaviour, as well as visual observations of mixed-species aggregations to estimate the number and size of fish around Fish Aggregating Devices (FADs) before deploying nets.

6.2 Archival tagging

The actual path a fish takes during liberty can be studied using archival tags. To date, there are only 3 archival tag data available for skipjack tuna for this region. Archival tags are inserted in the fish body cavity through a small incision made in the ventral body wall. During the Pacific Tuna Tagging Program excursions inside PNG waters the majority of the fish tagged were captured using jigging lures and rods at night around FADs. Which mostly enabled larger yellowfin and bigeye tuna being mostly captured (SPC, 2006). Using archival and conventional tags, the movements, dispersion, and mixing of bigeye tuna (*Thunnus obesus)* was studied (Schaefer, et al., 2014). In that study, data indicated that there were significant differences in the linear displacements by release locations, days at liberty, and fish length at release. An unscented Kalman filter model with sea surface temperature measurements integrated was used to process 48 archival data tags from big eye tuna at liberty for 30 days or longer to obtain most probable tracks, improved estimates of geographic positions, and movement parameters. Constrained latitudinal dispersion, some regional fidelity, broad eastward longitudinal dispersion, and substantial mixing of bigeye tuna between release longitudes were all observed. The degree of mixing of bigeye tuna between these release locations in the equatorial central Pacific Ocean and those in nearby areas of the equatorial eastern and western Pacific Ocean is dependent on distances between areas, with the closest areas mixing the most (Schaefer, et al., 2014). A similar approach can be taken for the skipjack tuna in the two regions – Archipelagic waters and Exclusive Economic Zone.

6.3 Feeding and spawning grounds

Skipjack tuna reproduce in places where the sea surface temperature (SST) is generally greater than 24°C. Skipjack tuna larvae can be found all year round in tropical Pacific Ocean regions, and their density is higher in the WCPO than in the eastern Pacific Ocean, indicating that tropical regions are the primary spawning grounds for skipjack tuna in the WCPO (Ashida et al, 2017). In a study by (Nakamura, 1965), on food and feeding habits of skipjacks from Marquesas and Tuamotu Islands, it was observed that larger skipjack ate comparatively more fish and less crustaceans when examining the stomach contents. (Nakamura, 1965), explained, skipjacks from inshore areas ate more reef originating organisms than those from areas farther offshore. It was also seen that there were no differences found in food of the two different sexes. Heavy feeding periods were observed to be in midmornings and in late afternoon hours with slack periods during middays. Such a feeding pattern may be related to, 1) the distribution and availability of forage organisms and zoolankton as well as their daily migrations 2) a midday satiation of the eating desire.

6.4 Influence and Management of FADs

There are two general types of fish aggregating devices (FADs): anchored or free-drifting and floating objects. Understanding fish behavior and the spatial structure of fish communities around FADs is critical to proper management of tuna fisheries. It is generally believed that fish use floating objects primarily for protection from predators, as source of food availability, as a meeting location and to increase survival of eggs, larvae and juveniles (Morgan, 2011). (Leroy, et al., 2012) noted a significant increase in purse seine catches on floating objects in the Western and Central Pacific Ocean, driven by the rapid expansion of both fixed and free-floating FADs. Examining the ecological impacts of drifting and anchored FADs, the study found that FAD fishing has influenced the stock status of the three primary target tuna species in the equatorial WCPO, with skipjack being the most frequently caught by purse seine. Additionally, the findings indicated that FADs affect the behaviour and movement patterns of these target species. Because of such factors, it is imperative to have in place regulatory measures. (Morgan, 2011) explained that within the coastal waters of individual countries, tuna fisheries are managed by national governments. However, in the high seas—areas beyond national jurisdiction—regional fisheries management organizations oversee the management of many tuna species. As a member of the Western and Central Pacific Fisheries Commission (WCPFC), Papua New Guinea falls under this framework, where the use of FADs in the high seas and beyond national jurisdiction is regulated by the Commission.

7 CONCLUSION AND RECOMMENDATIONS

Data showed that most fish were recaptured within 0 – 250 days and a high proportion were caught in the Archipelagic waters overall. It is evident that based on where the fish are tagged and released the proportion recaptured in the AW versus the EEZ can differ. This study only analyzes locations of release and recapture and does not track the path of individual fish. Therefore, it is difficult to conclude that these fish reside in the AW during their entire days at liberty. Given the high migration speed of tuna, fish could be travelling out to the EEZ in the interim period and migrating back to AW.

It is recommended that a home range analysis can be done to delineate the home range or habitat of the species as (Solmundsson, et al., 2015) explained. A fish that stays year-round within a spawning area is said to display site fidelity, whereas fish that leave the spawning area but return in subsequent spawning seasons display homing.

The use of archival tags for further studies is also recommended for better understanding of movement patterns. To better the residence times of fish, advection-diffusion reaction models can be applied.

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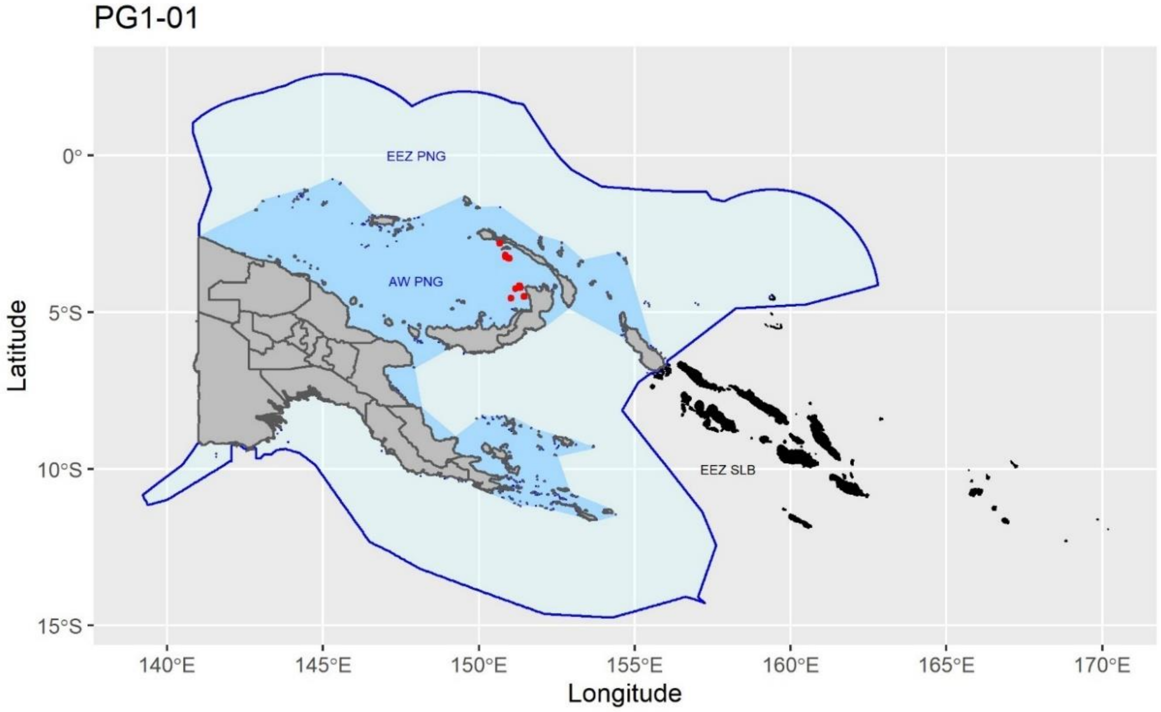
ACKNOWLEDGEMENTS

My sincere gratitude goes to Dr. Warsha Singh for her continual supervision throughout this study. I am immensely grateful for her encouragement, assurance, support, and the direction I got right from the beginning. I am deeply and truly inspired by her very warm and positive charisma and especially her patience, but most of all, her professionalism in what she does. Being a former fellow, she is a true role model for women in the Pacific Island Communities especially the Melanesian women folks. I also wish to also thank Dr Jonas Jonasson for his contributions and 'sharpness' in assessing and pointing out areas of this study that required scrutiny and for being part of his ARAM team. I am earnestly thankful to my current Executive Manager, Mr Thomas Usu for the guidance and support given throughout this work. Also, to my colleague, Mr Benthly Sabub, for his assistance in sending data used in this study. I would also like to thank Mr Bruno Leroy from the South Pacific Community for his assistance in granting me access to the SPC tagging database. I also wish to thank and acknowledge my former Executive Manager, Mr Brian Kumasi for his contributions and guidance towards this work and the staff of National Fisheries Authority in PNG that helped me realise this dream. I would also like to acknowledge the co-ordinating team of the GRO Fisheries Training Programme, Mary Frances Davidson, Julie Ingham, Mr Stefan Ulfarsson, and Agnes Eydal for the guidance and feedback provided during all the fellow-meetings conducted. Also, to former staff, Dr. Tumi Tómasson and a special thank you to Mr Thór Ásgeirsson for travelling all the way to Papua New Guinea to interview and select fellows from that region, but most of all, for having to listen and realise the capacity gaps and challenges the Pacific Islanders face in terms of fisheries management. Despite, the strict timing of six months, this is the best training programme, I have attended so far and I'm grateful for the opportunity given. I wish to also thank my friend and colleague, Aiysah Umar (Aiysah Aiysah) from Indonesia for the true friendship and support shown to me throughout my stay in Iceland. Finally, to my family, especially my husband who stood by myside throughout the six months encouraging and pushing me. I truly appreciate you all. Thank you for the wonderful experience.

APPENDIX

Maps in this appendix are of the tuna tagging (catch and release) exercise that were undertaken by the research teams. The top map indicates (red spots) where the tunas were caught, tagged, and released. The bottom map indicates (as per legend) where they were captured and after how many days as per the tags that were retrieved.



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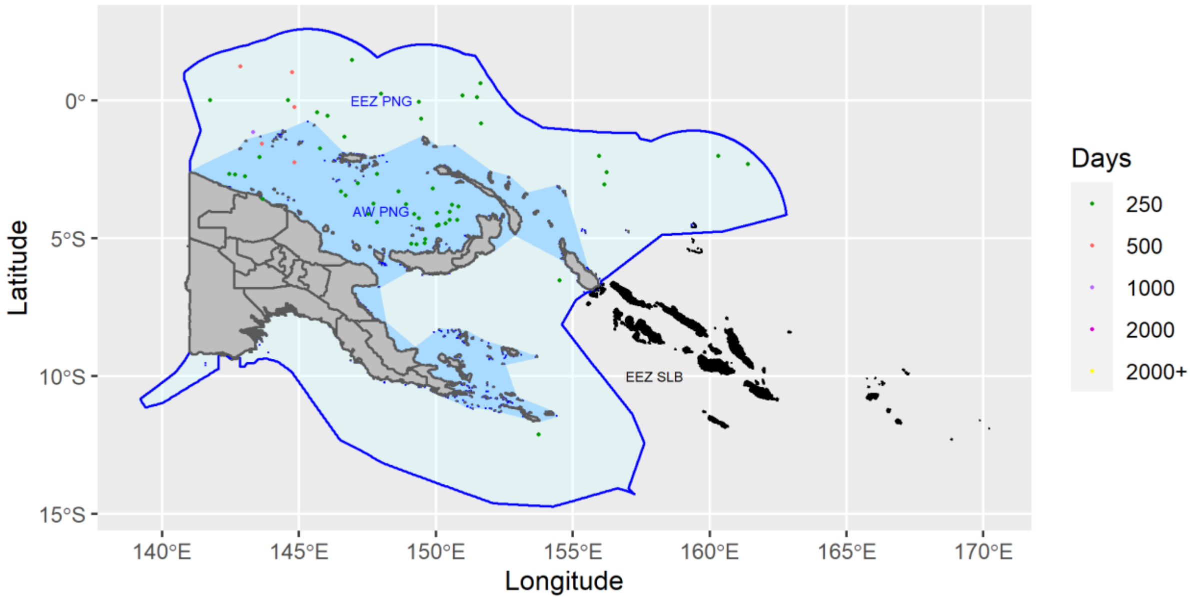
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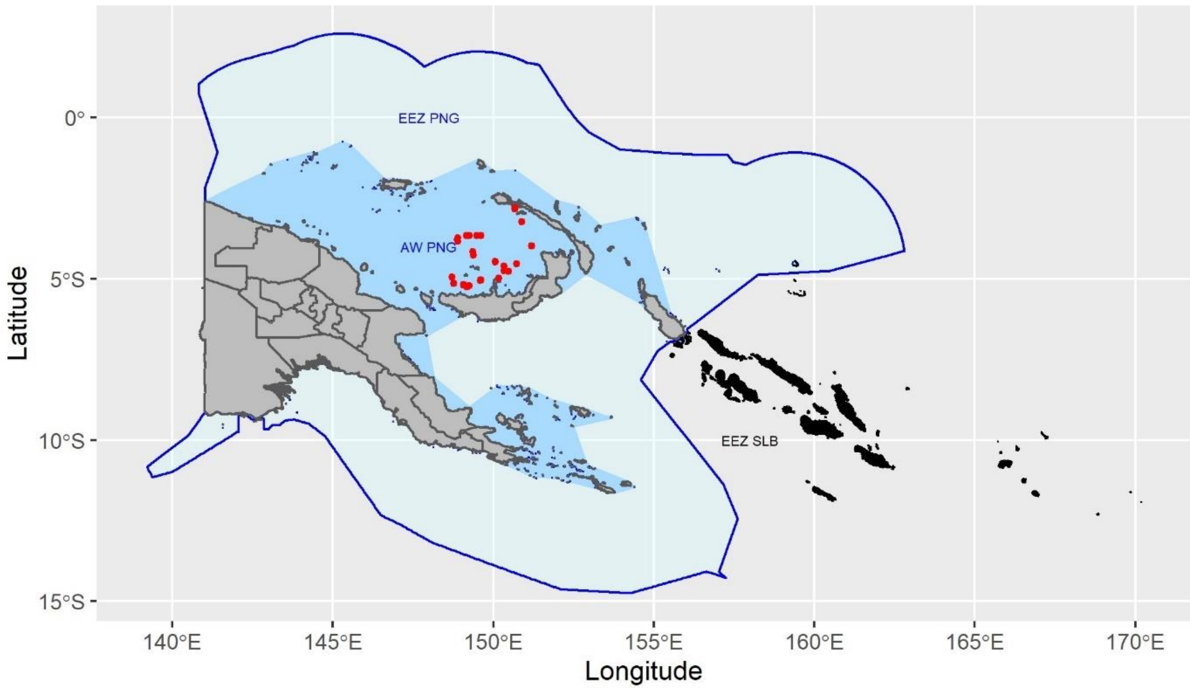
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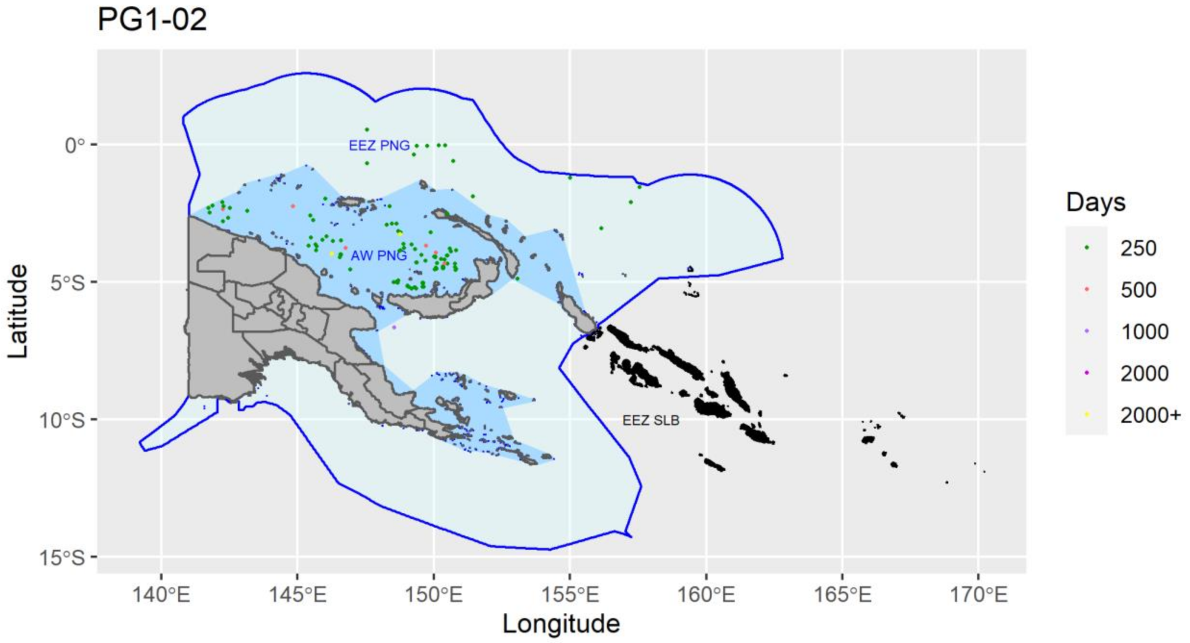
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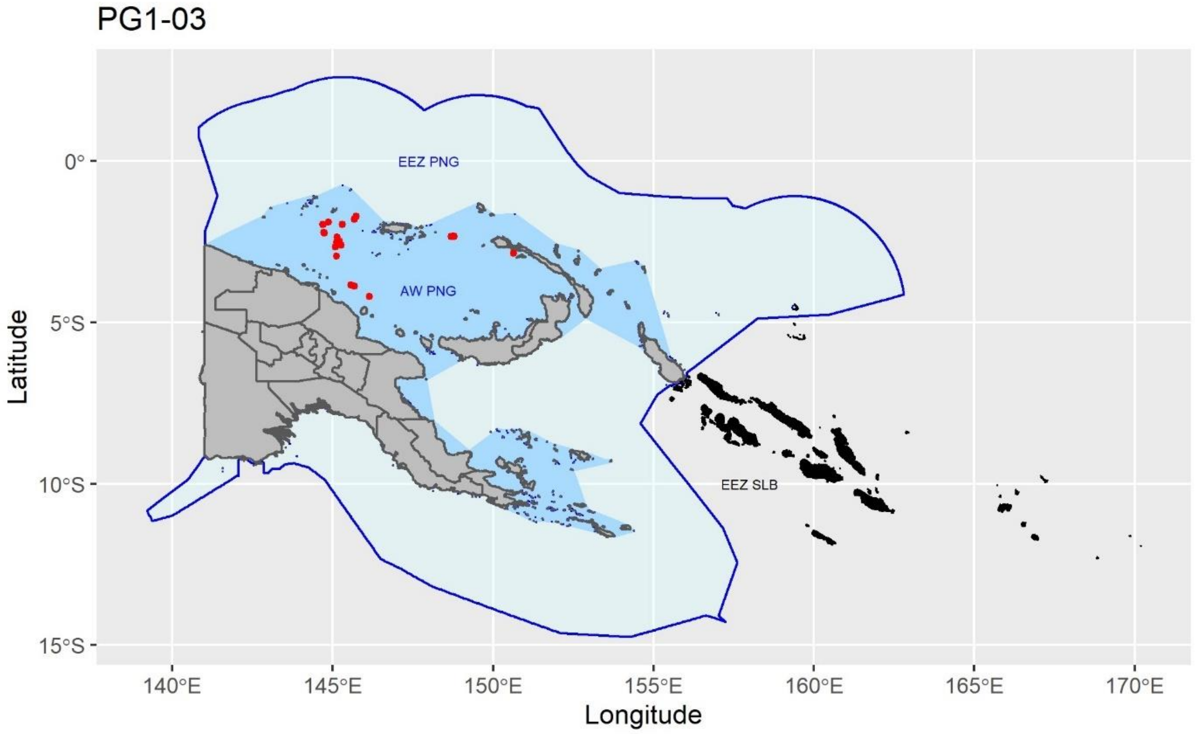
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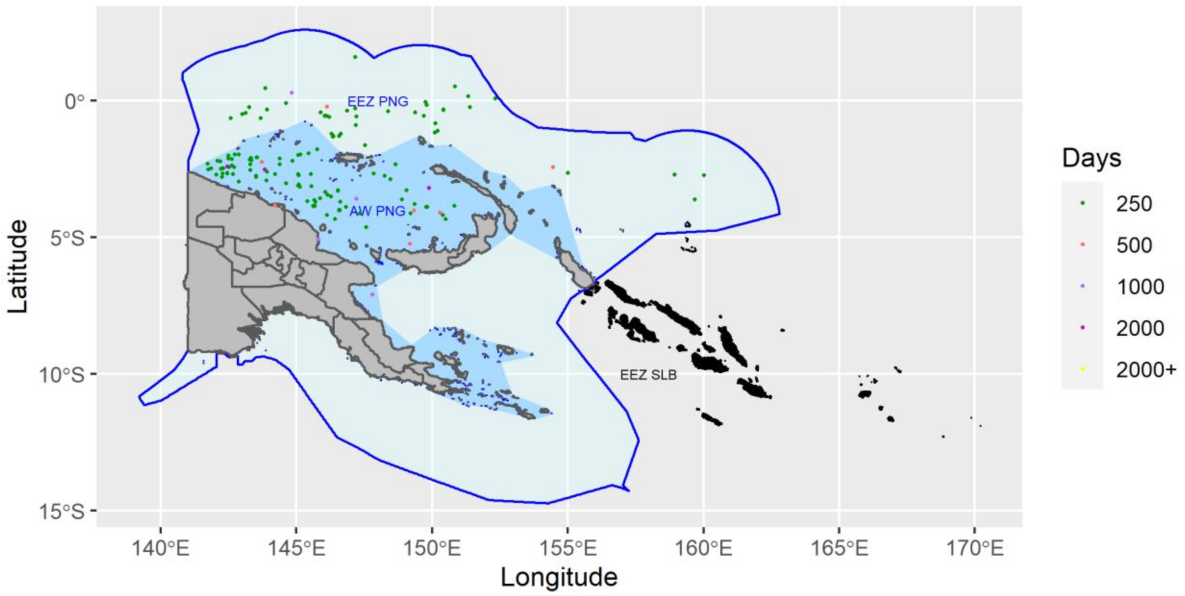
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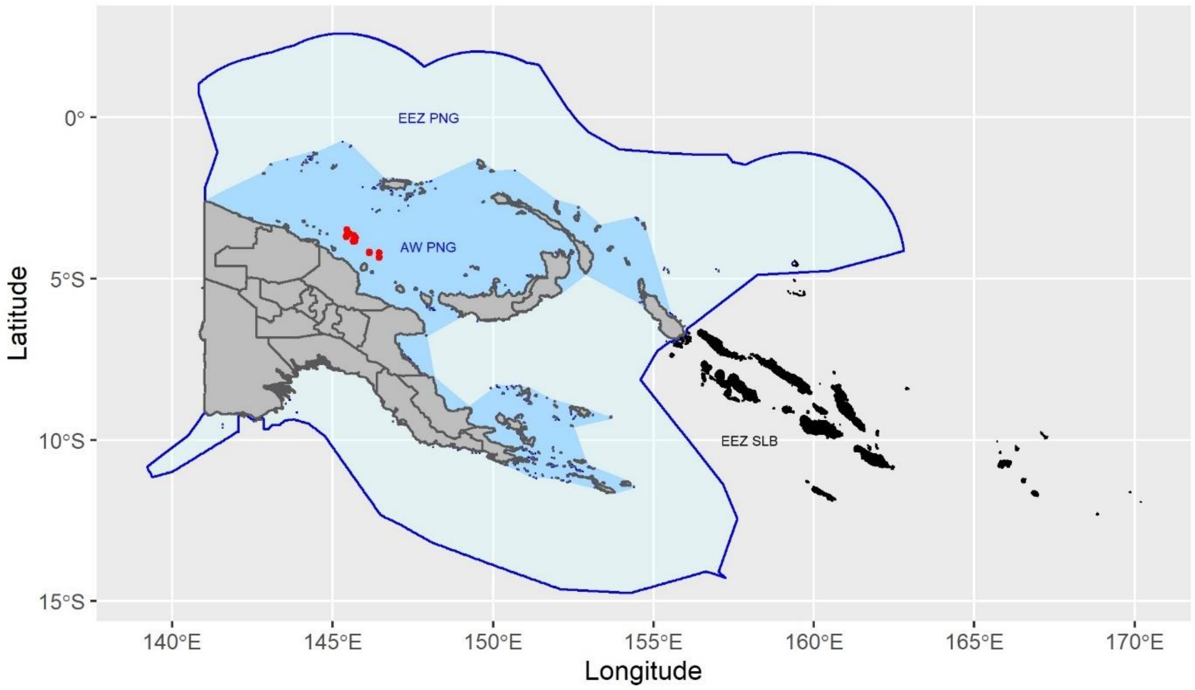
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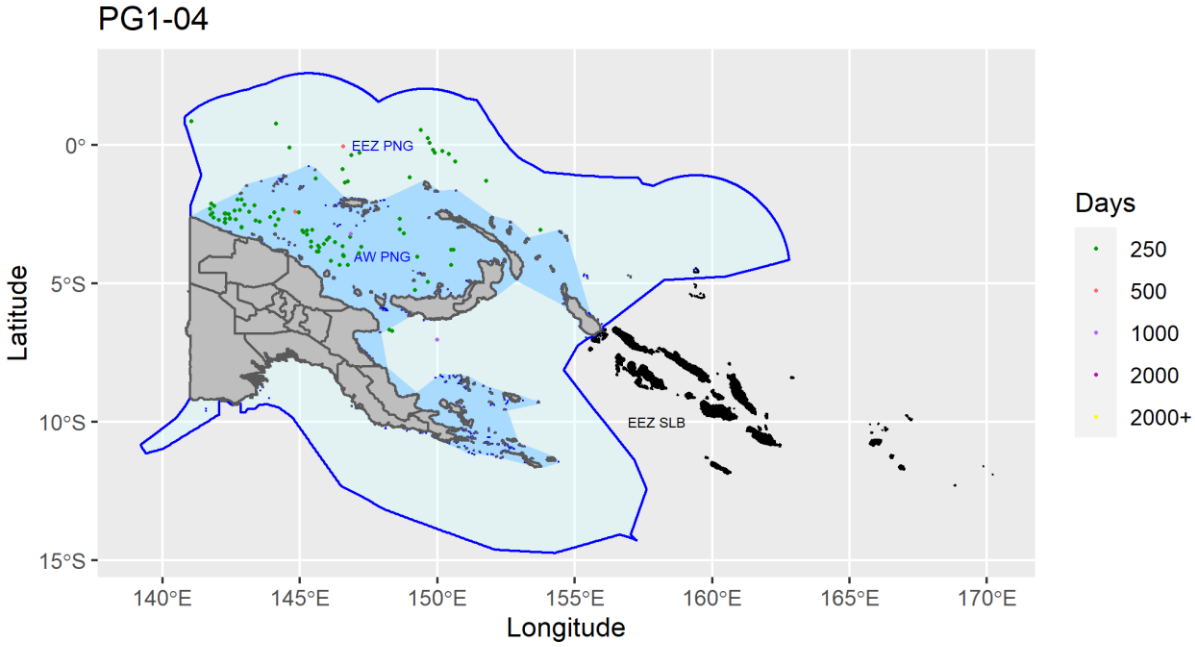
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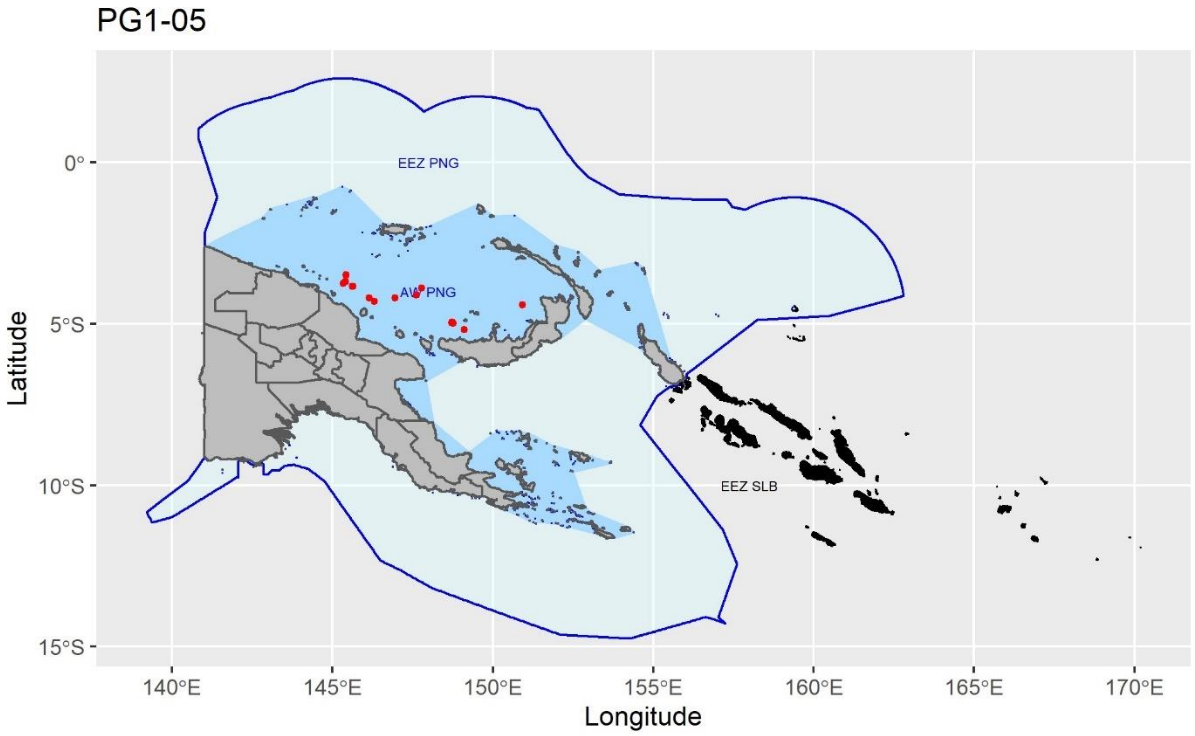
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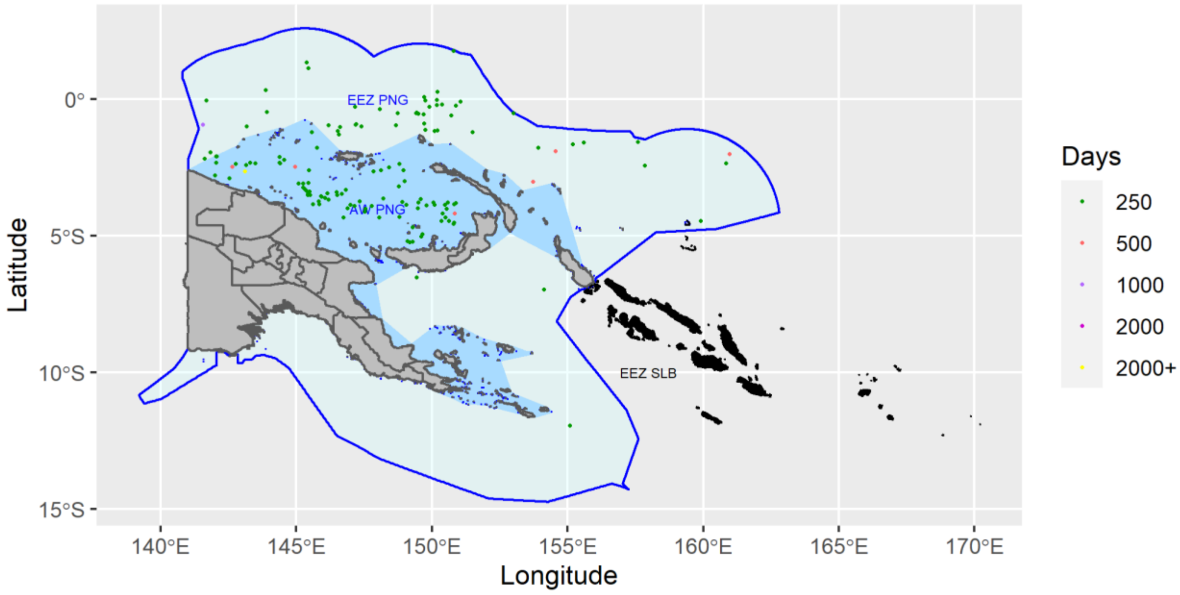
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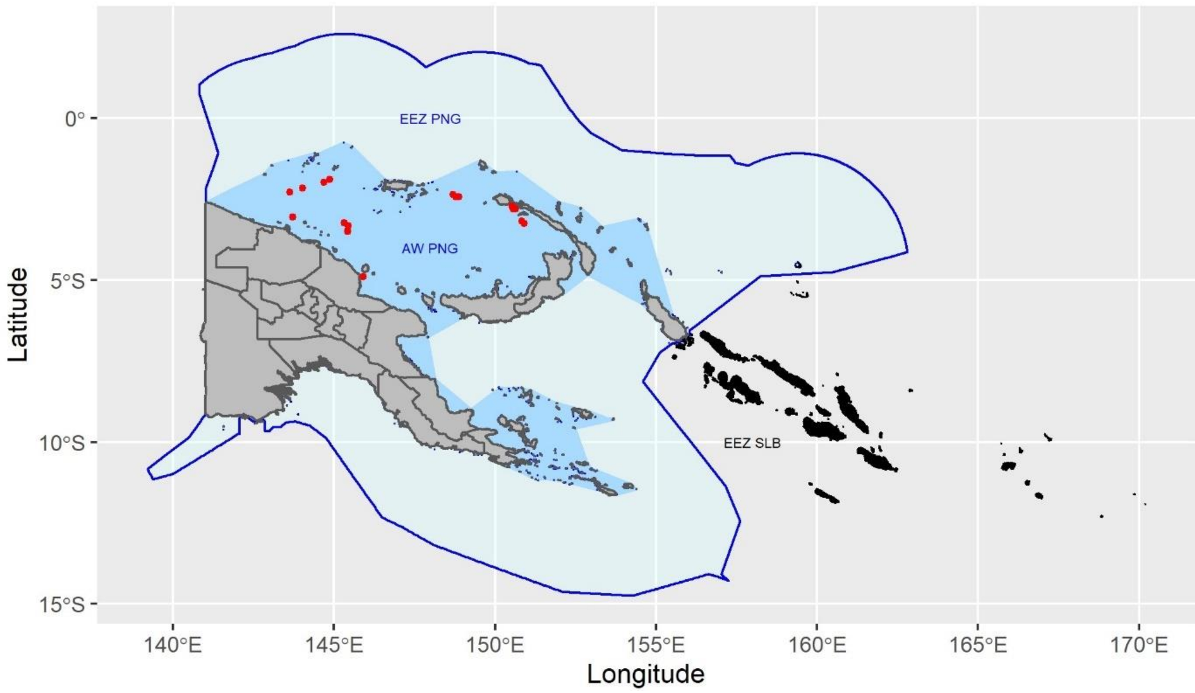
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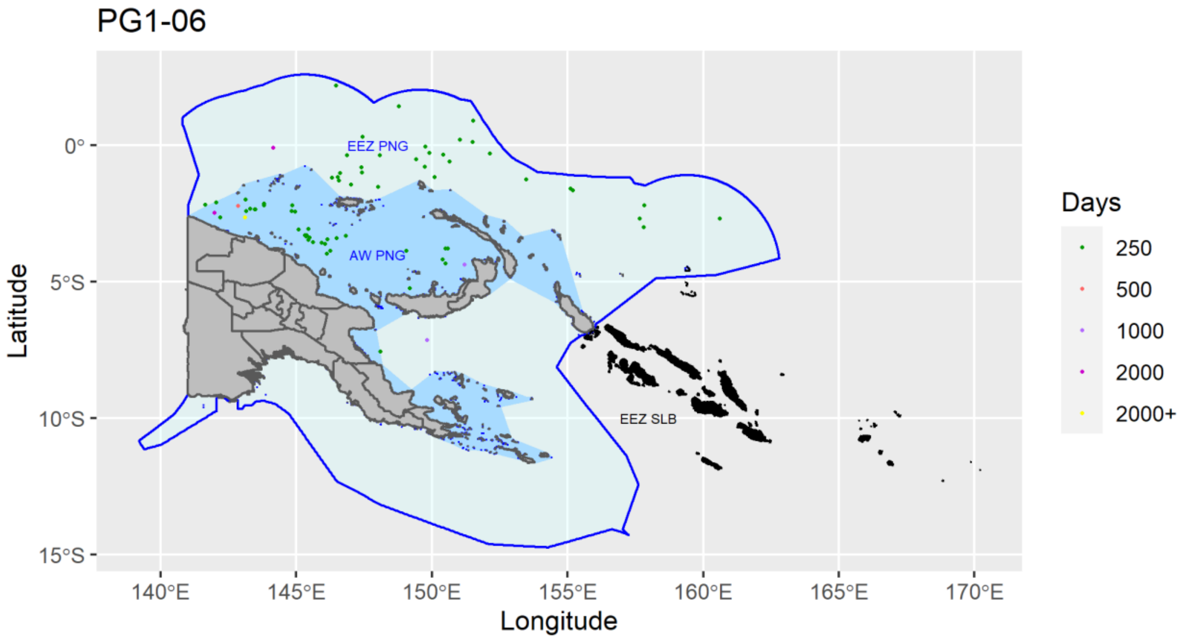
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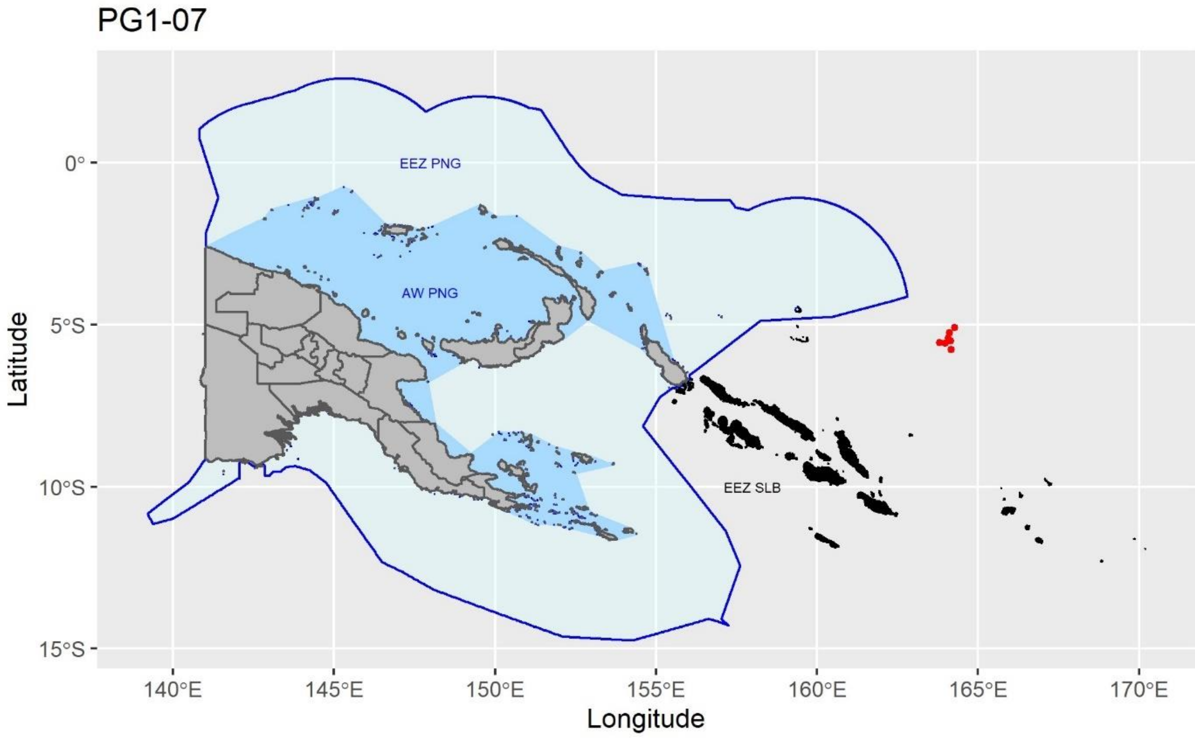
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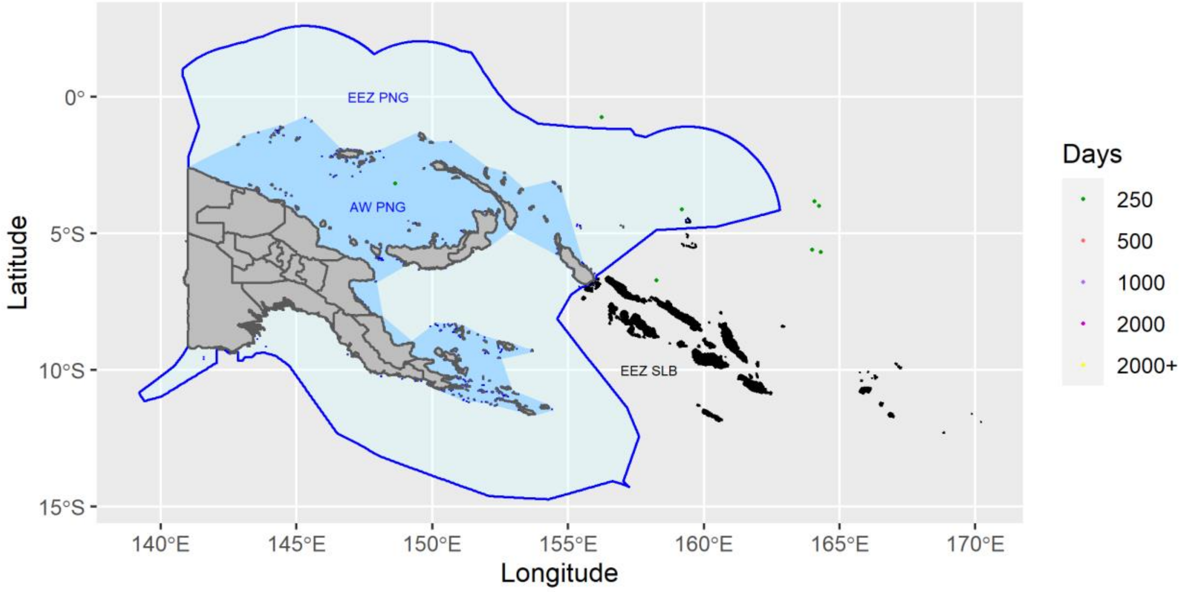
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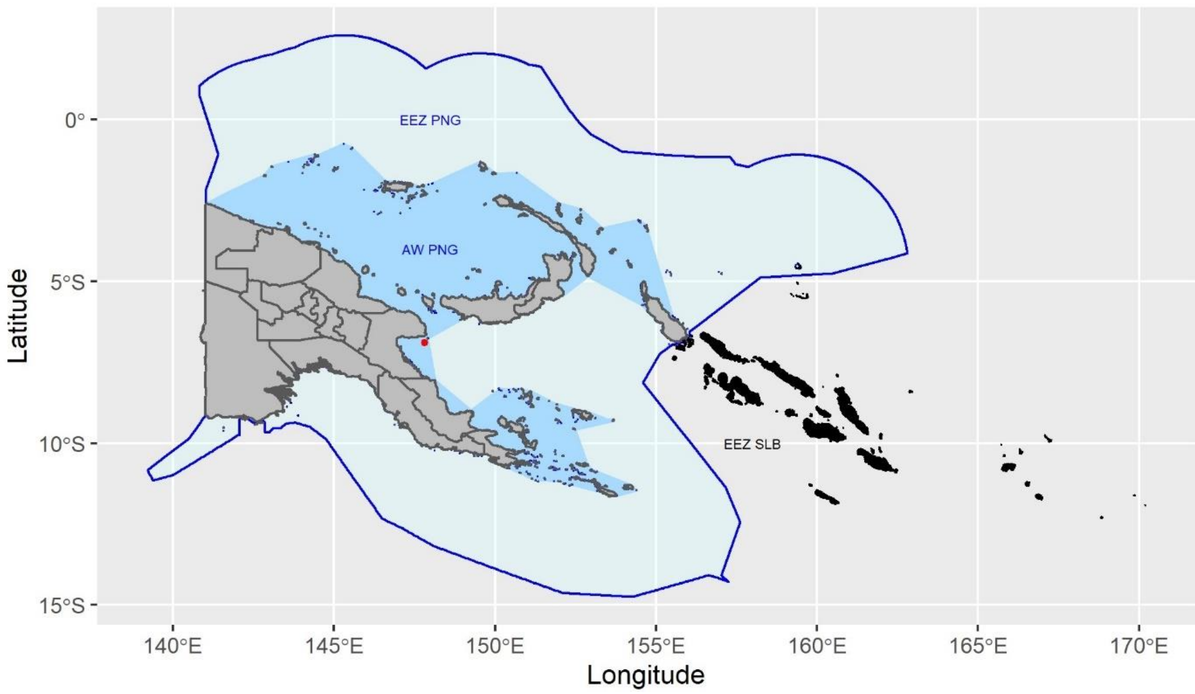
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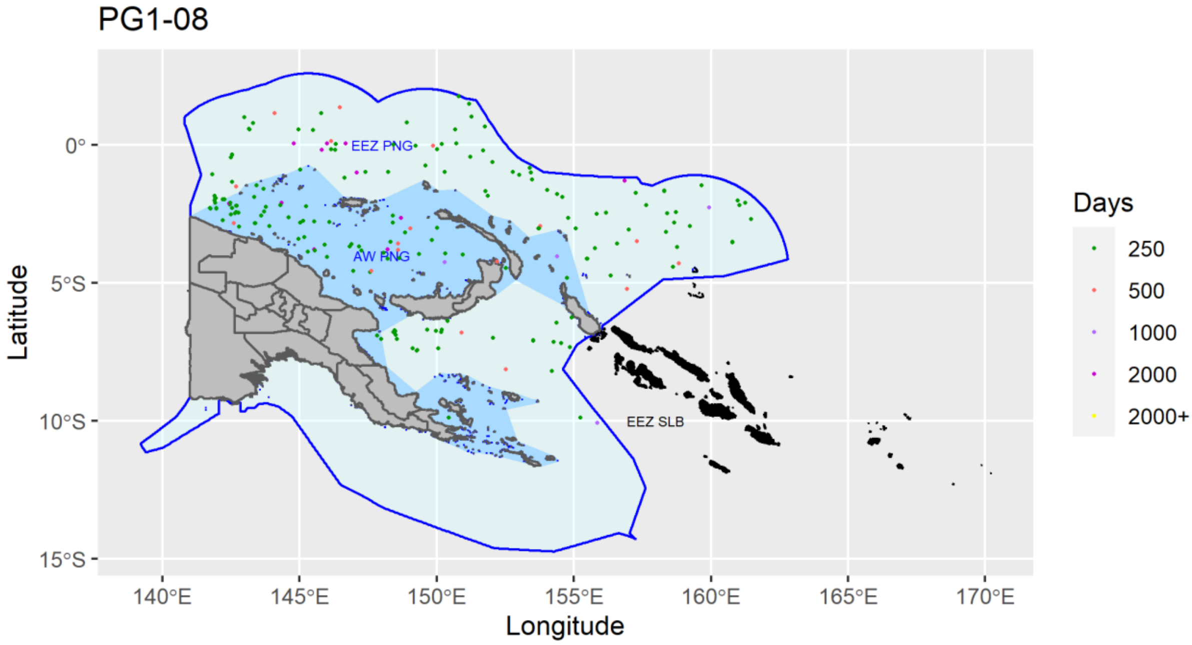
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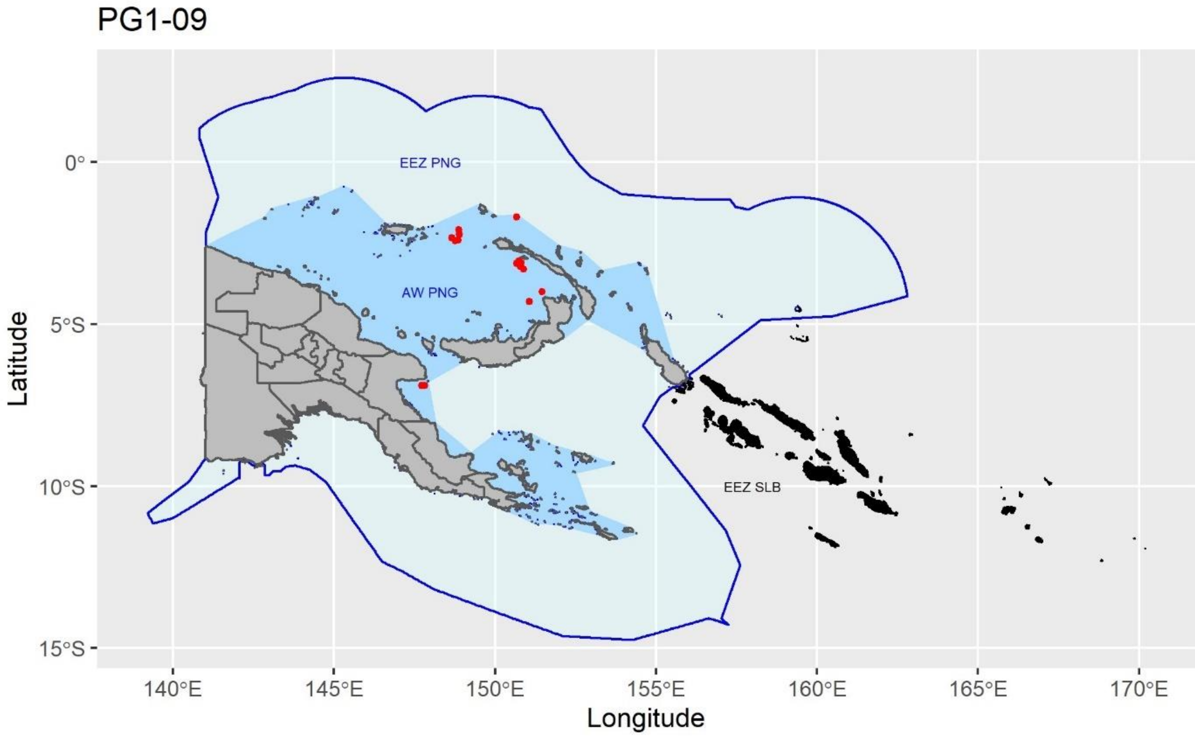
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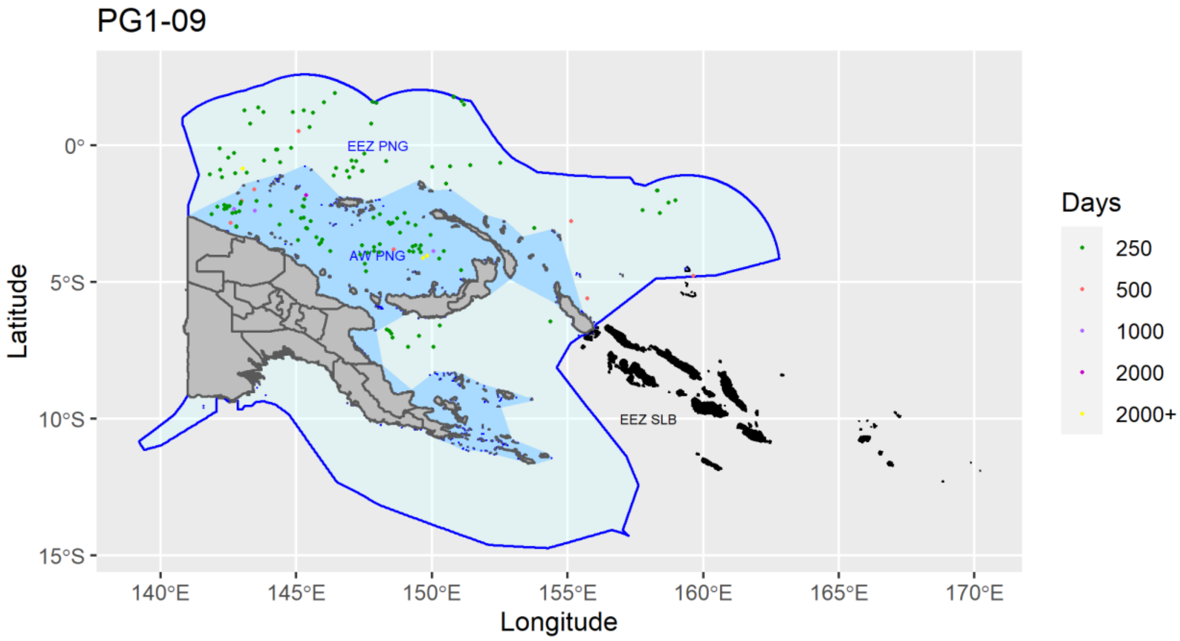
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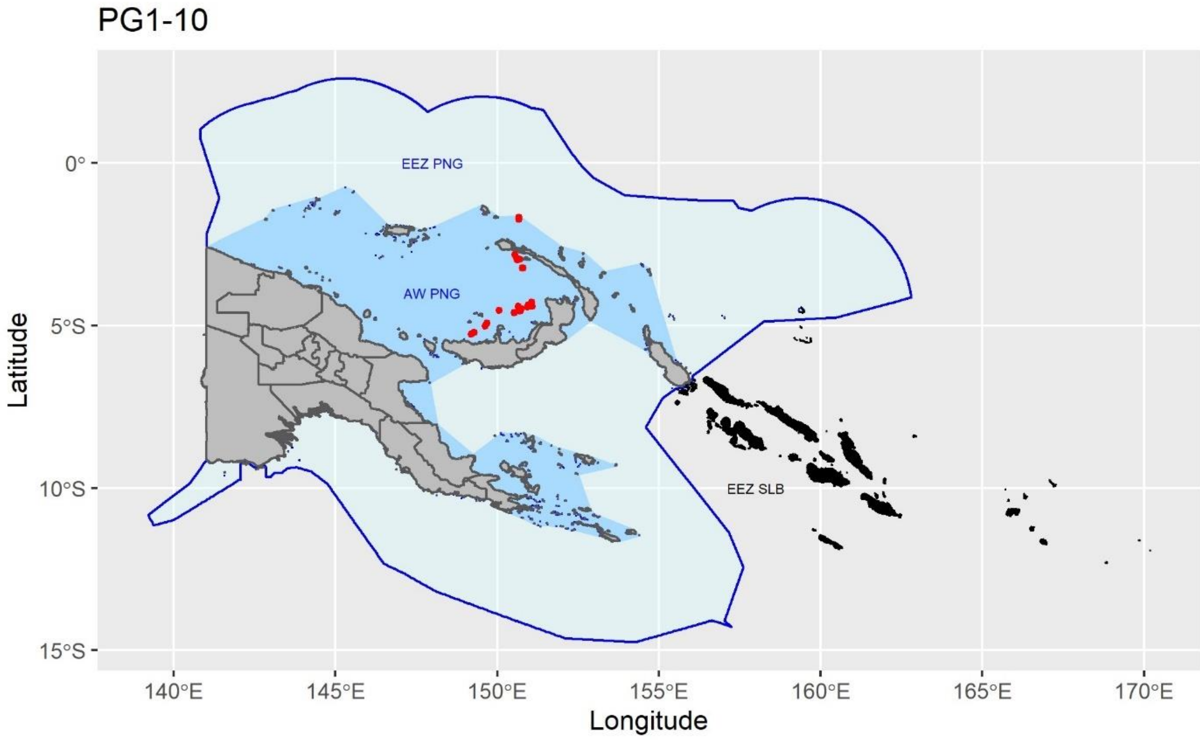
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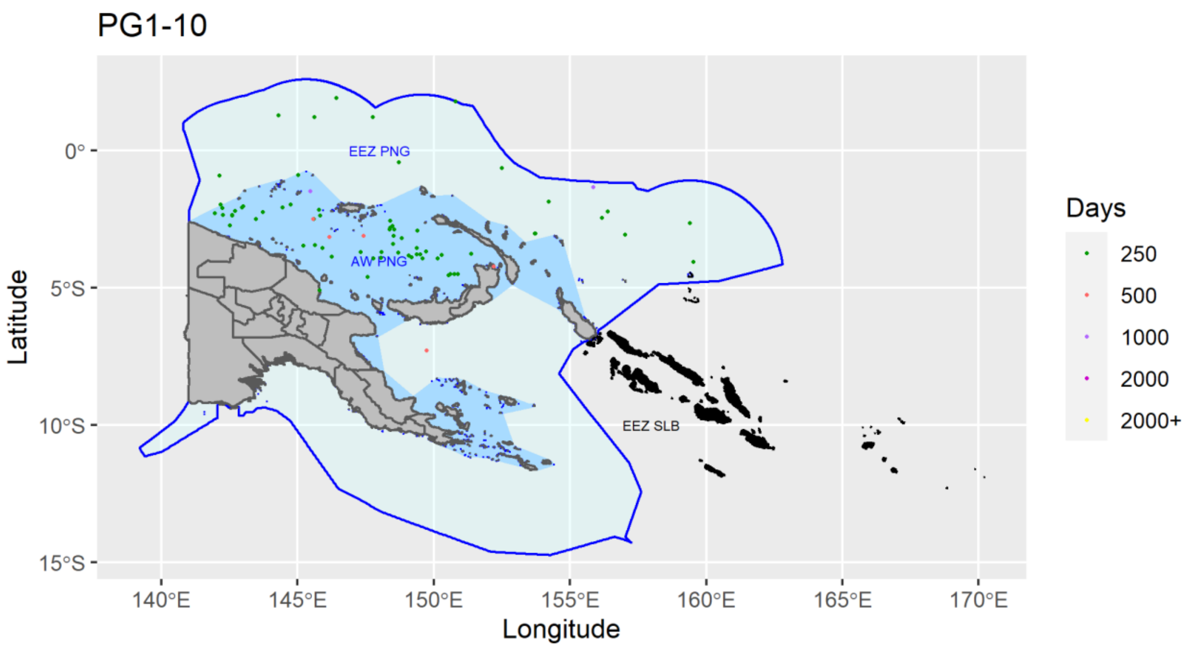
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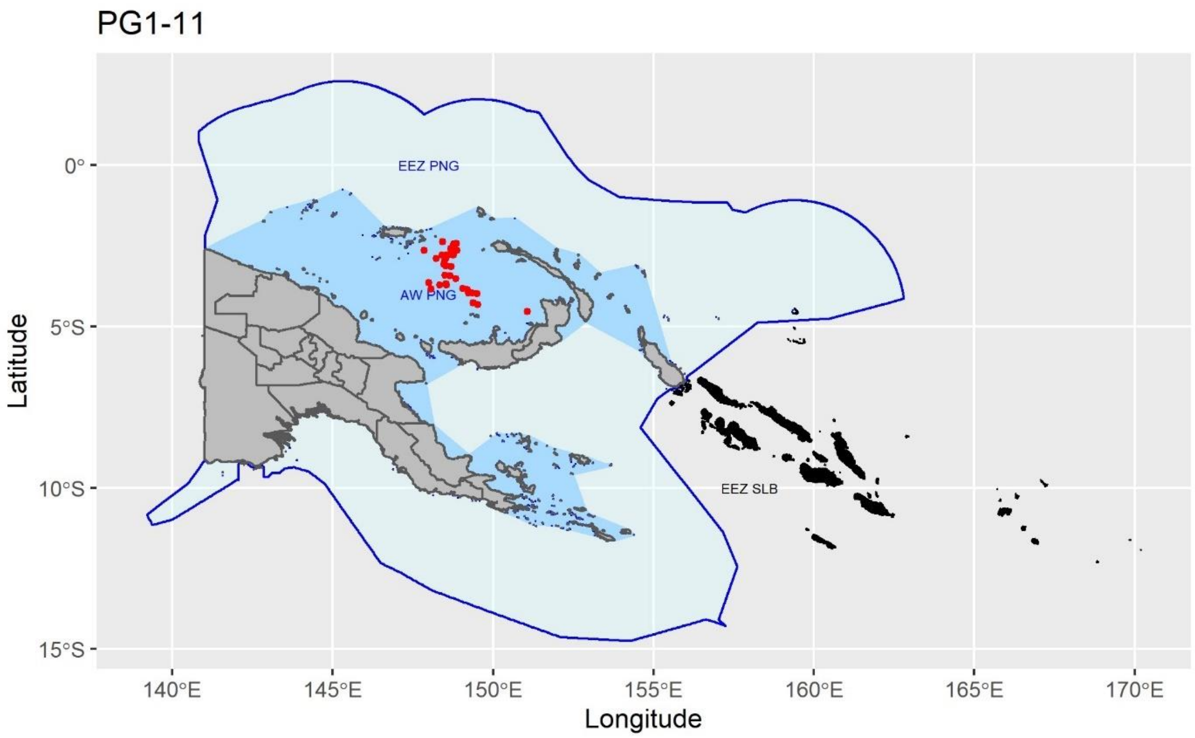
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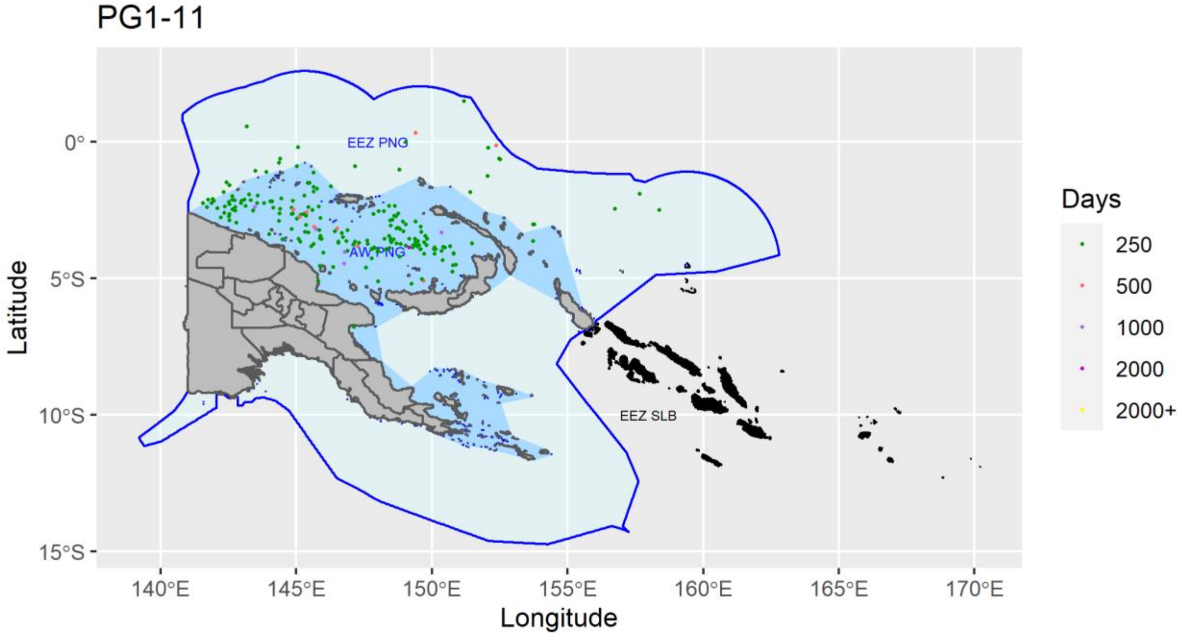
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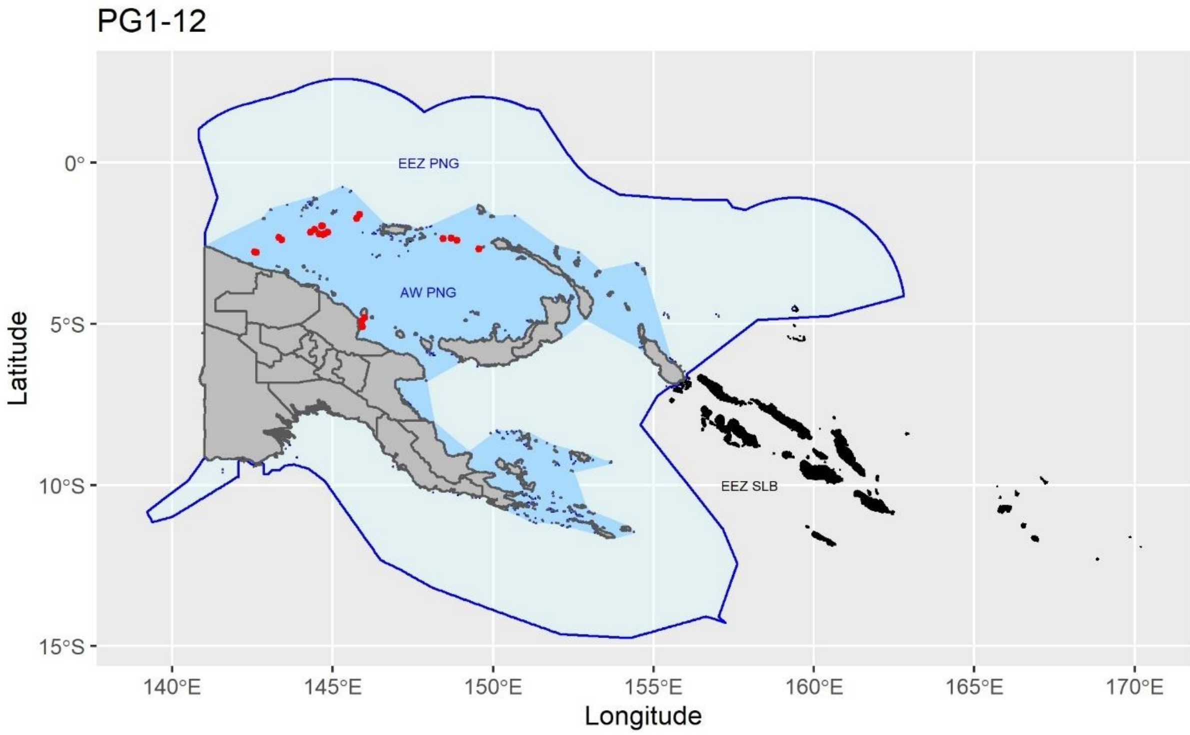
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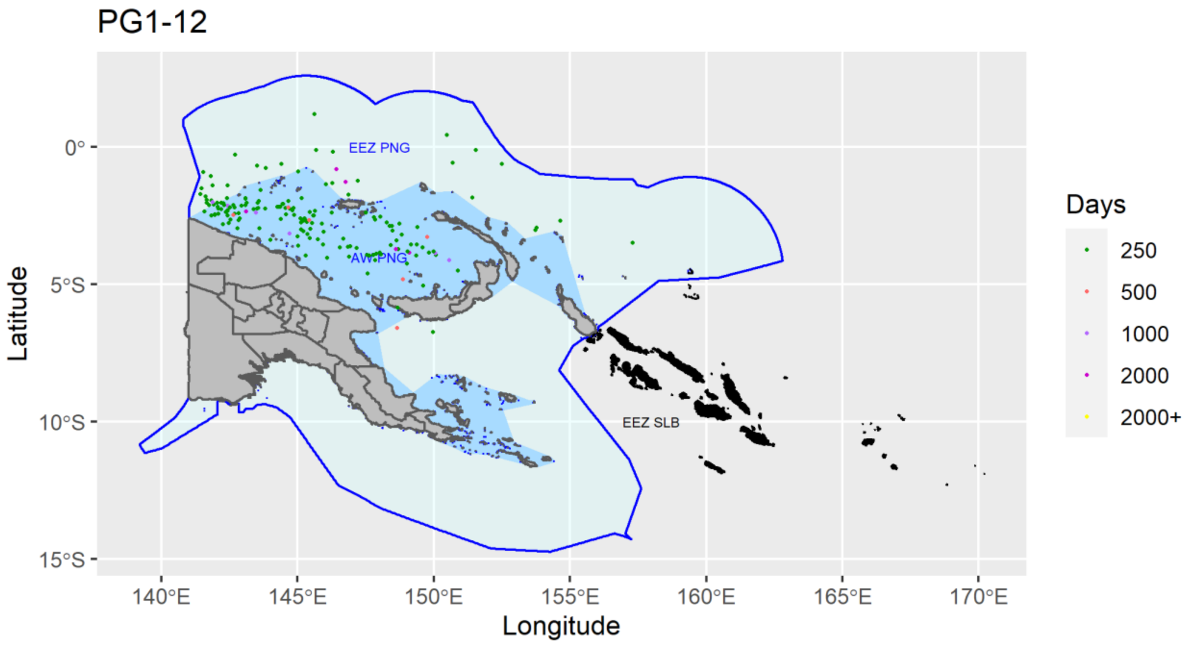
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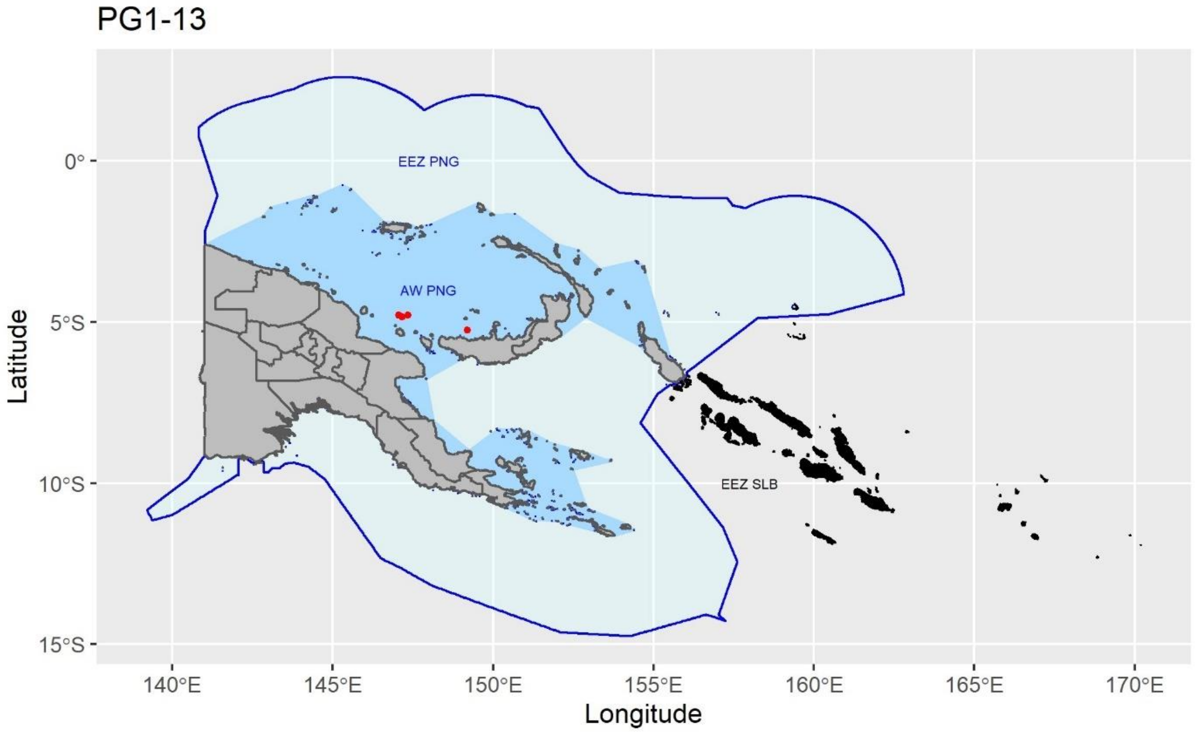
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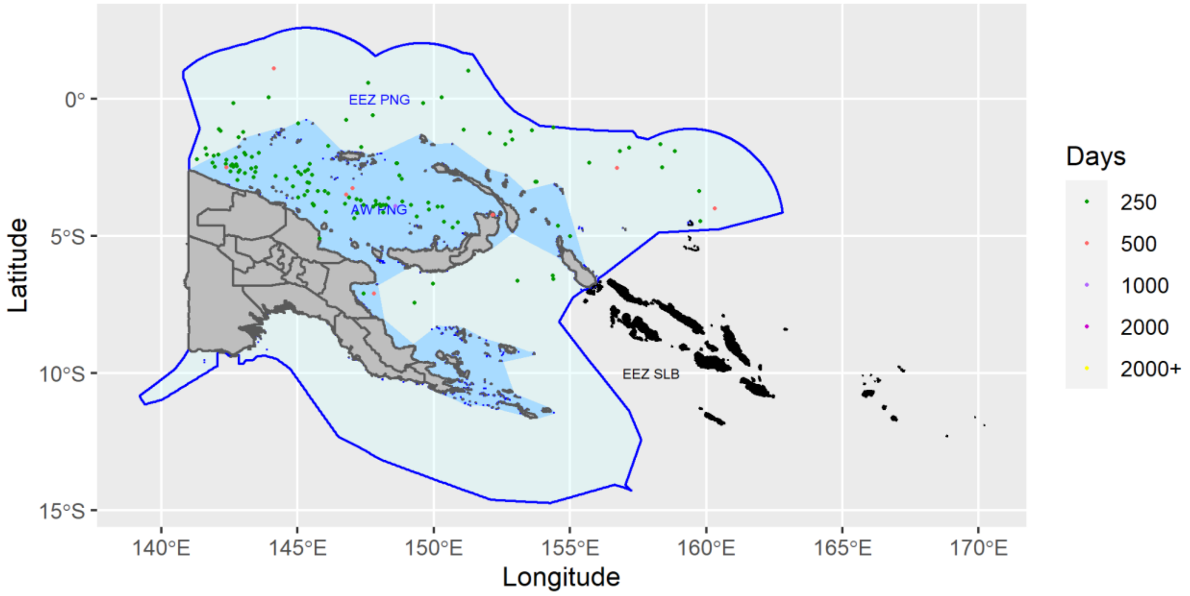
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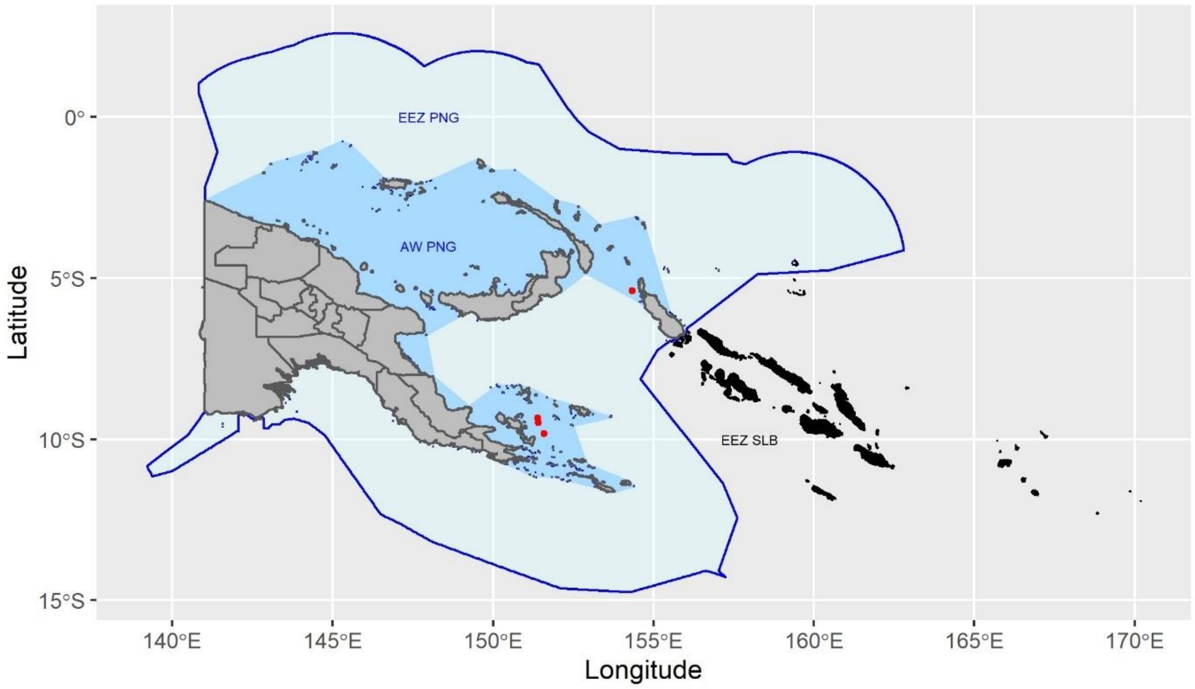
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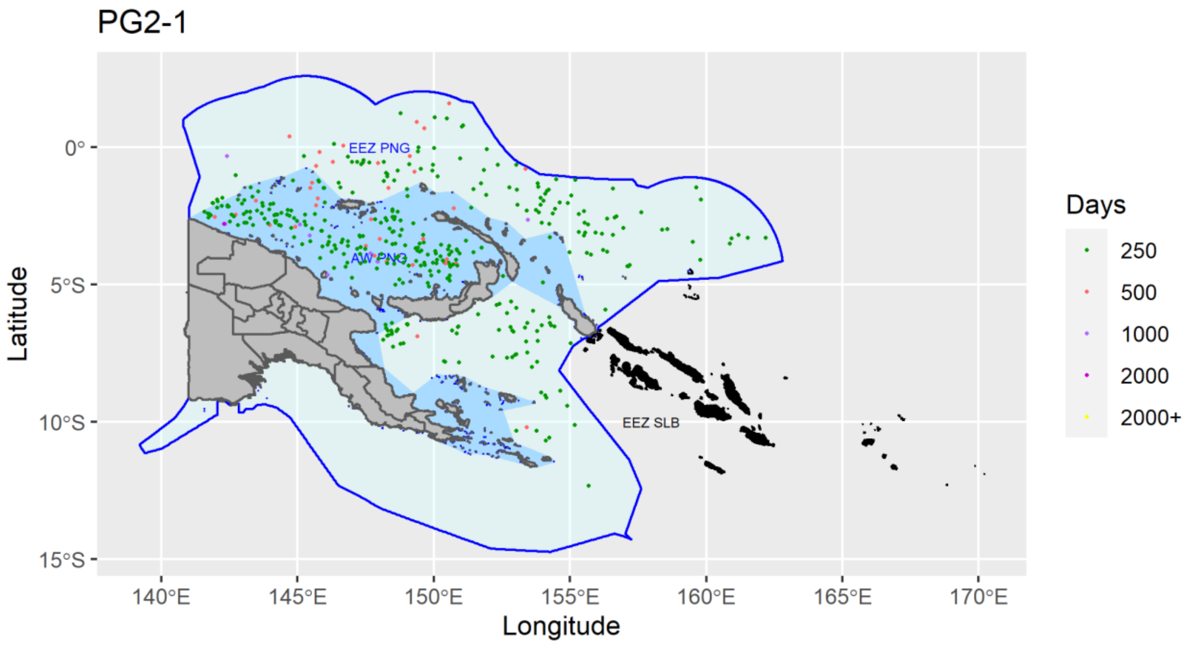
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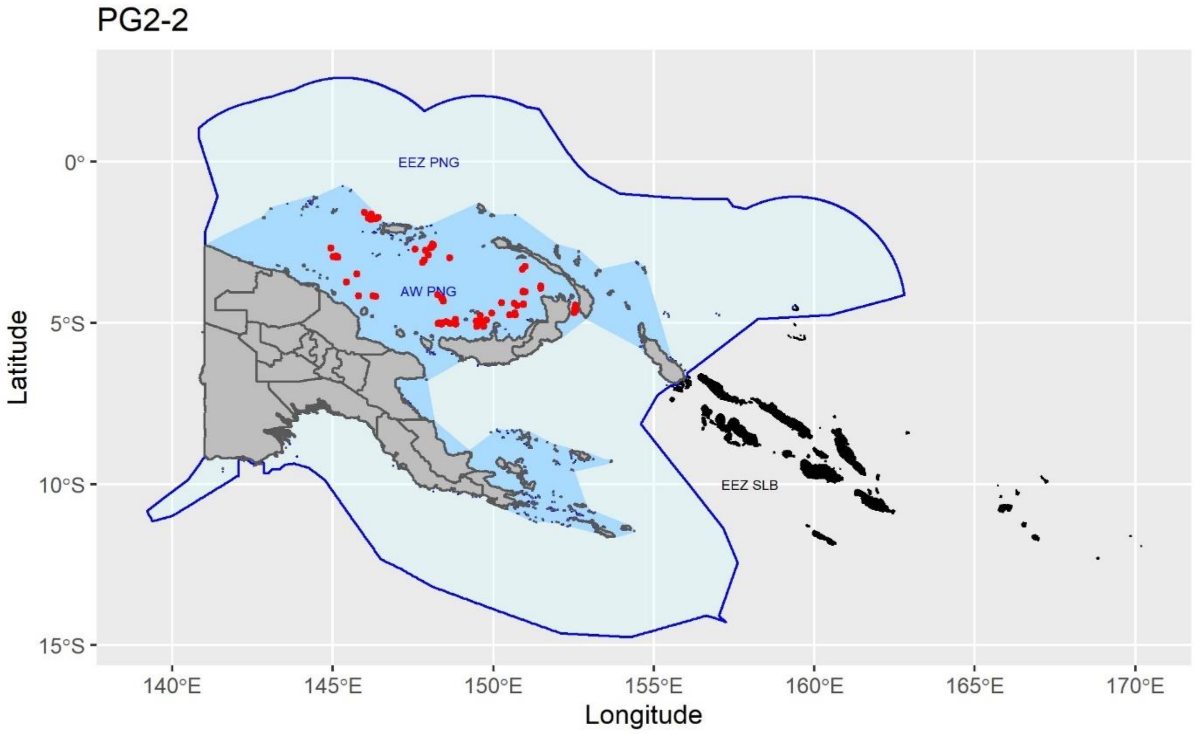
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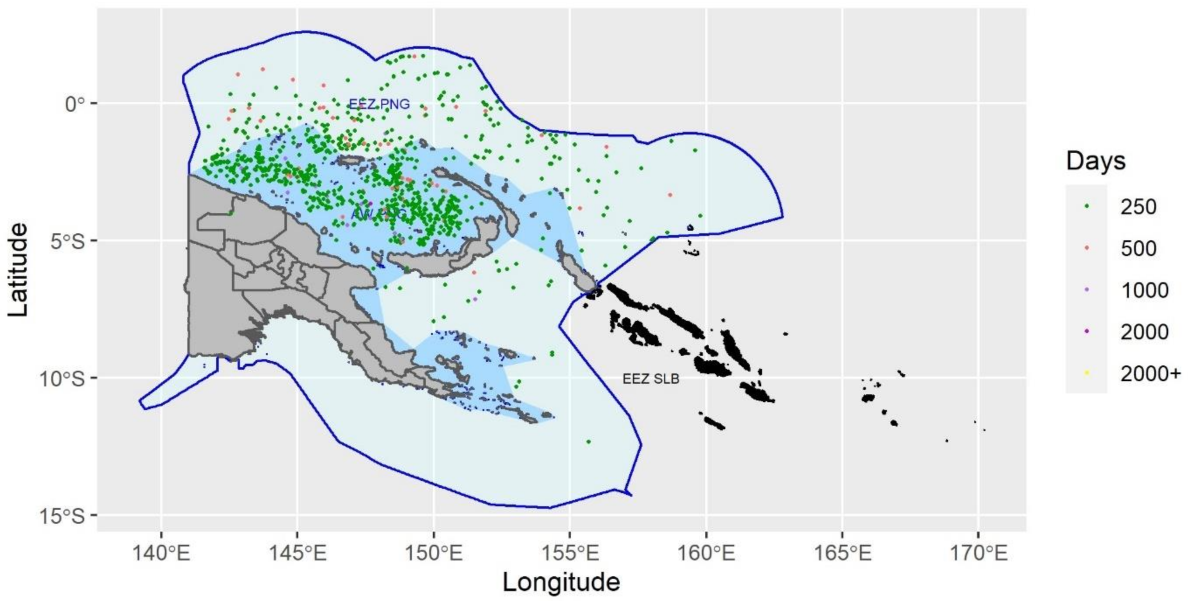
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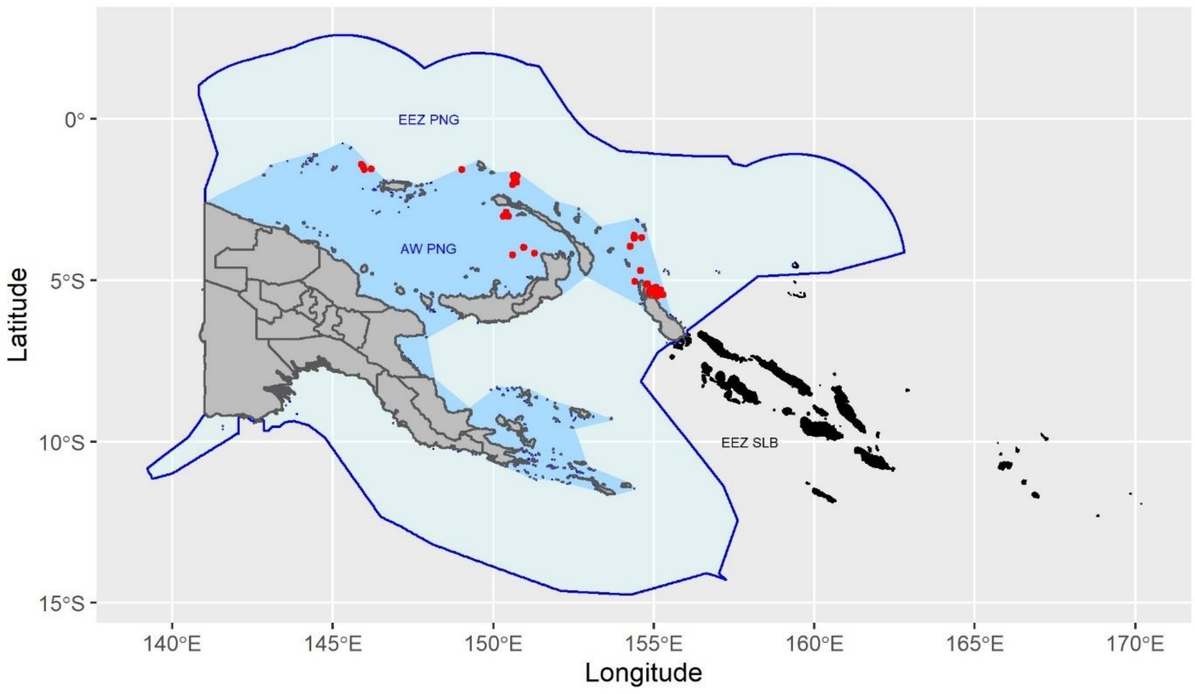
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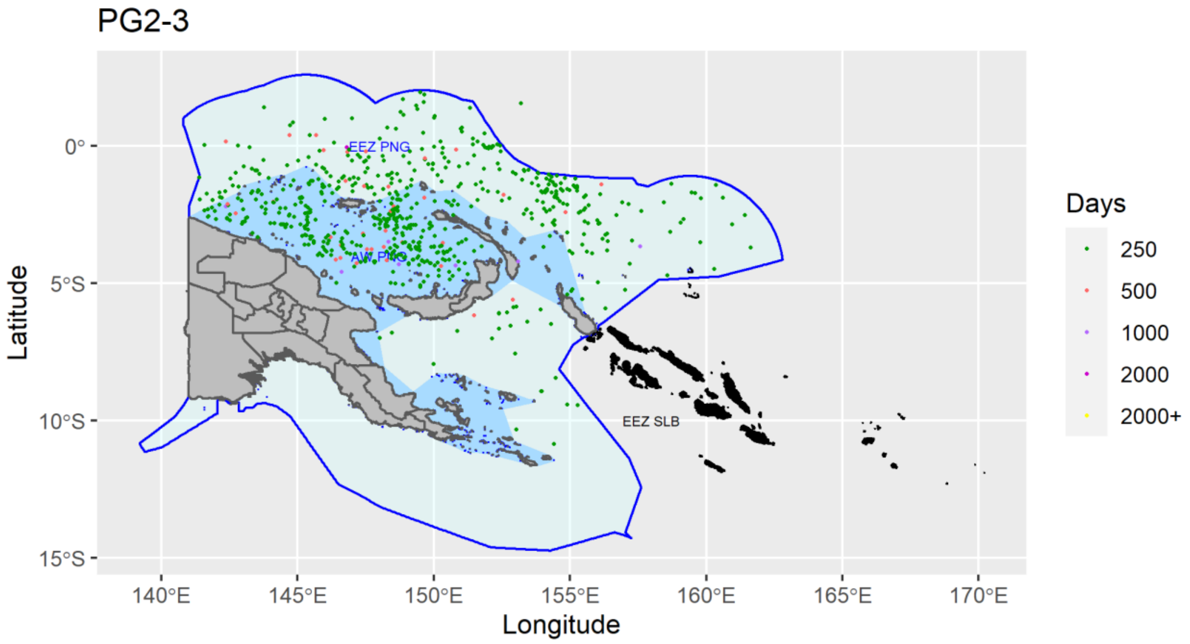

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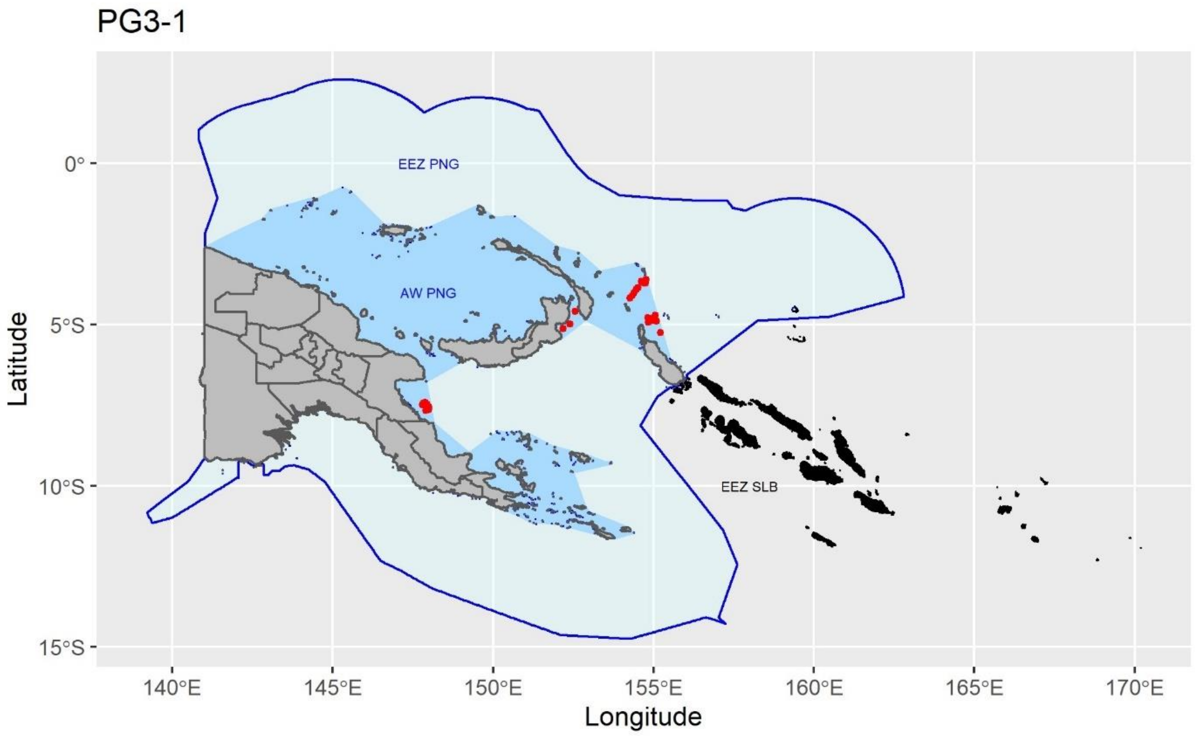

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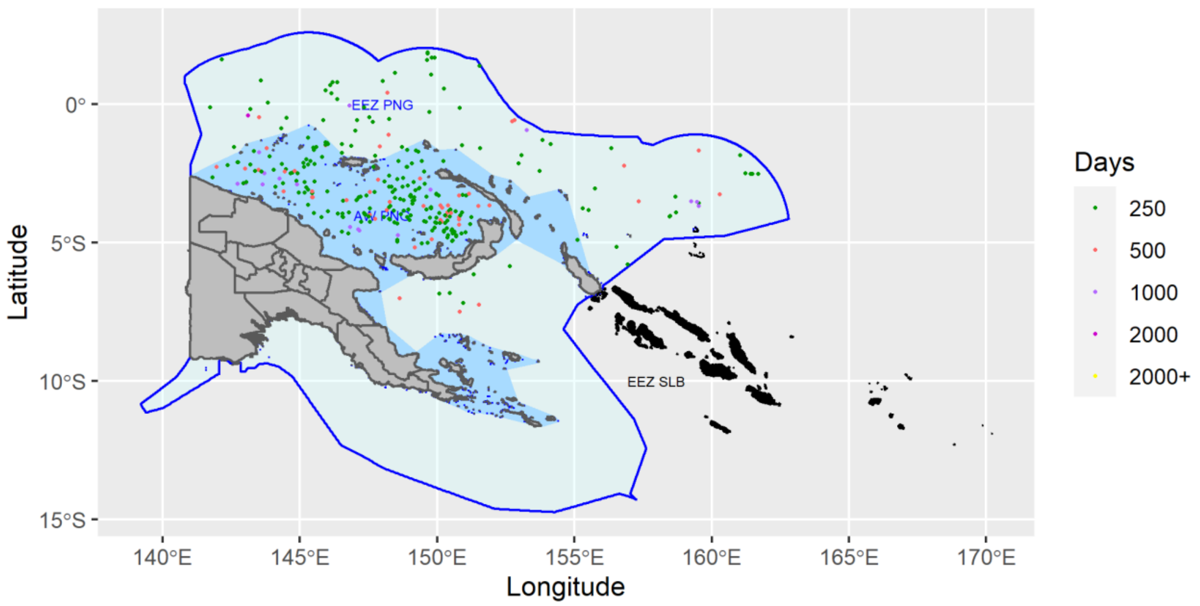
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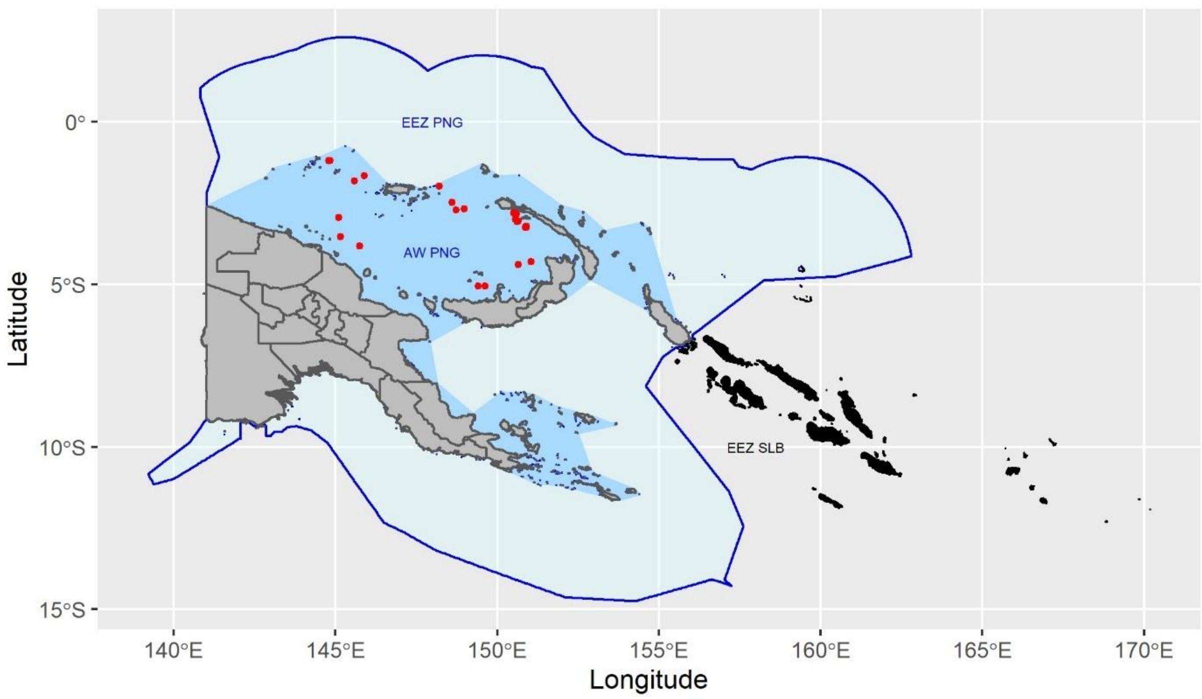
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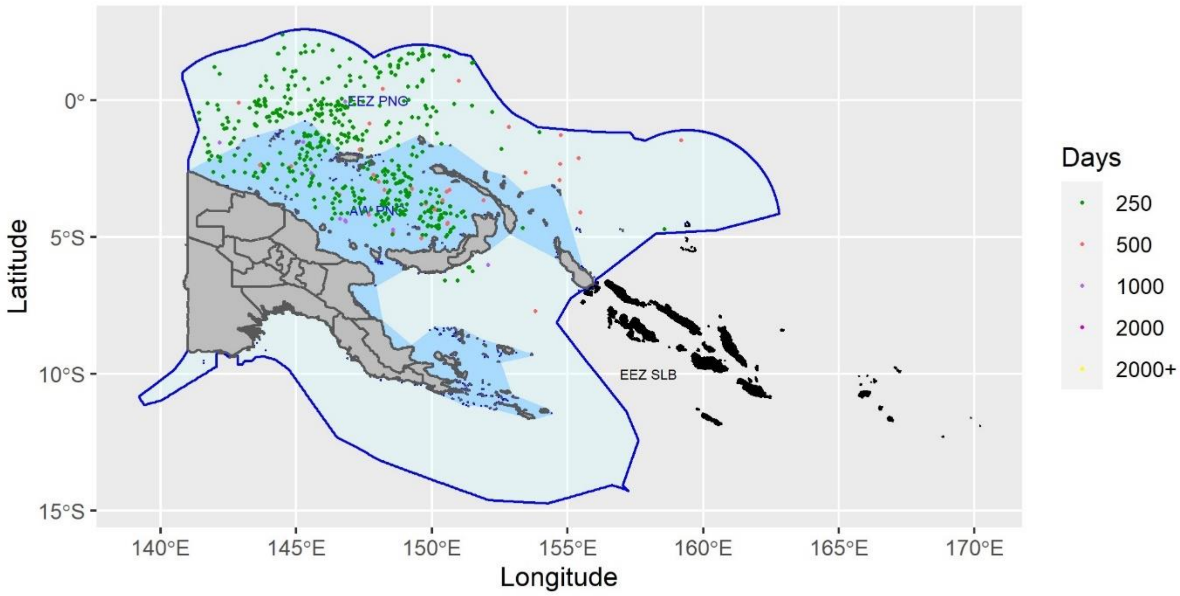
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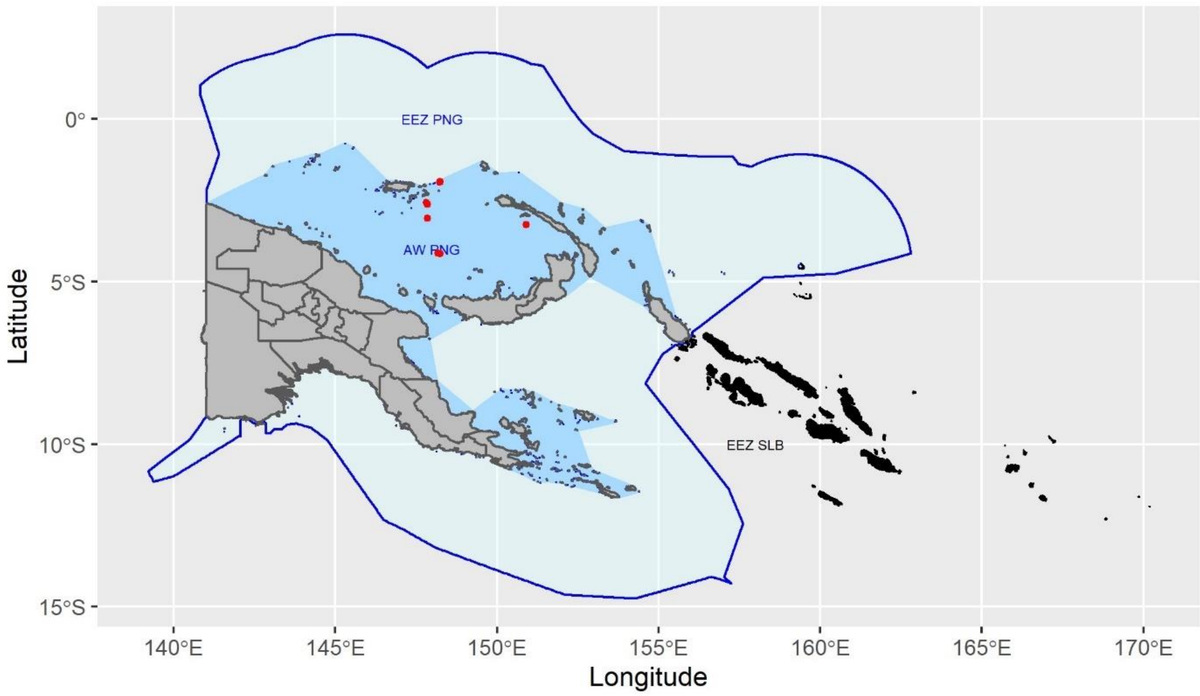
2000+

PG3-3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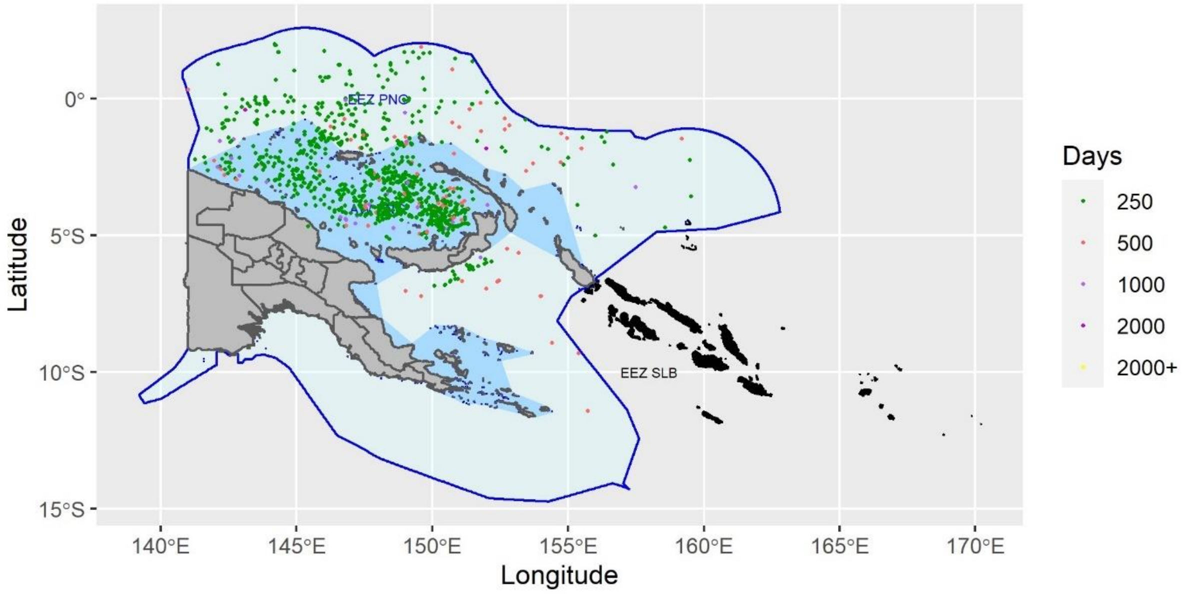
AW PNG
EEZ SLB
Latitude
0°
5°S
10°S
15°S
140°E
145°E
150°E
155°E
160°E
165°E
170°E
Longitude

PG3-3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0°
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15°S
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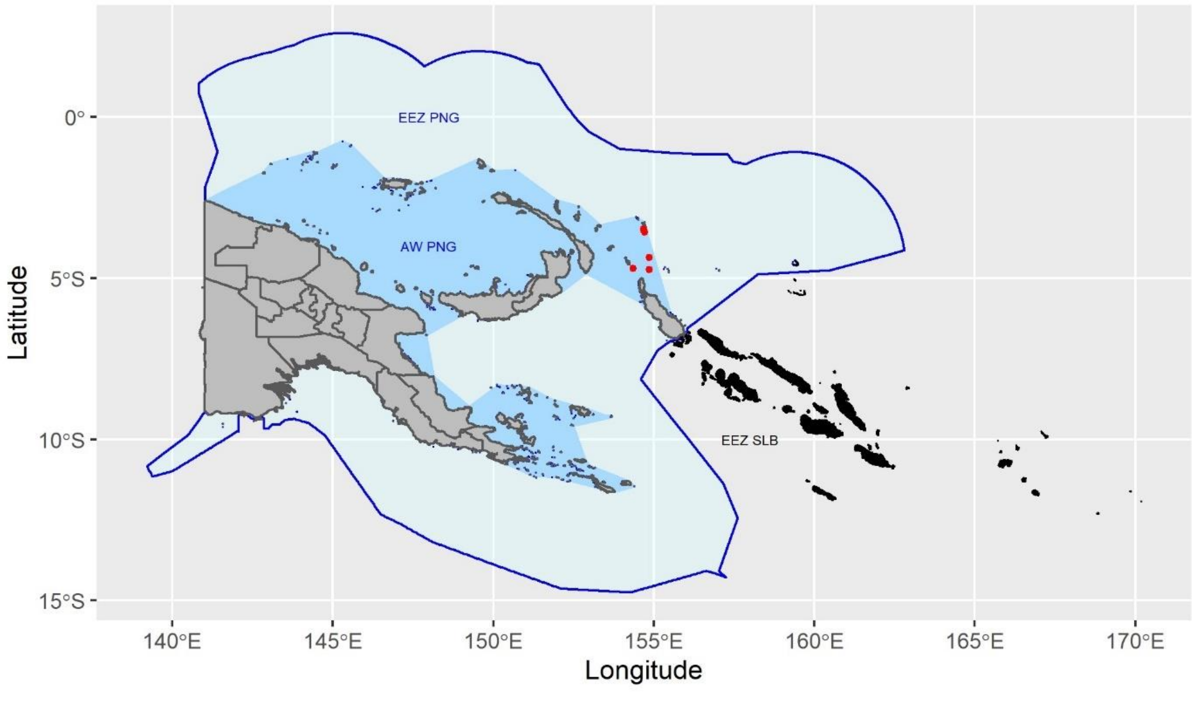
160°E
165°E
170°E
Longitude
Days
250
500
1000
2000
2000+

PG5-1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AW PNG
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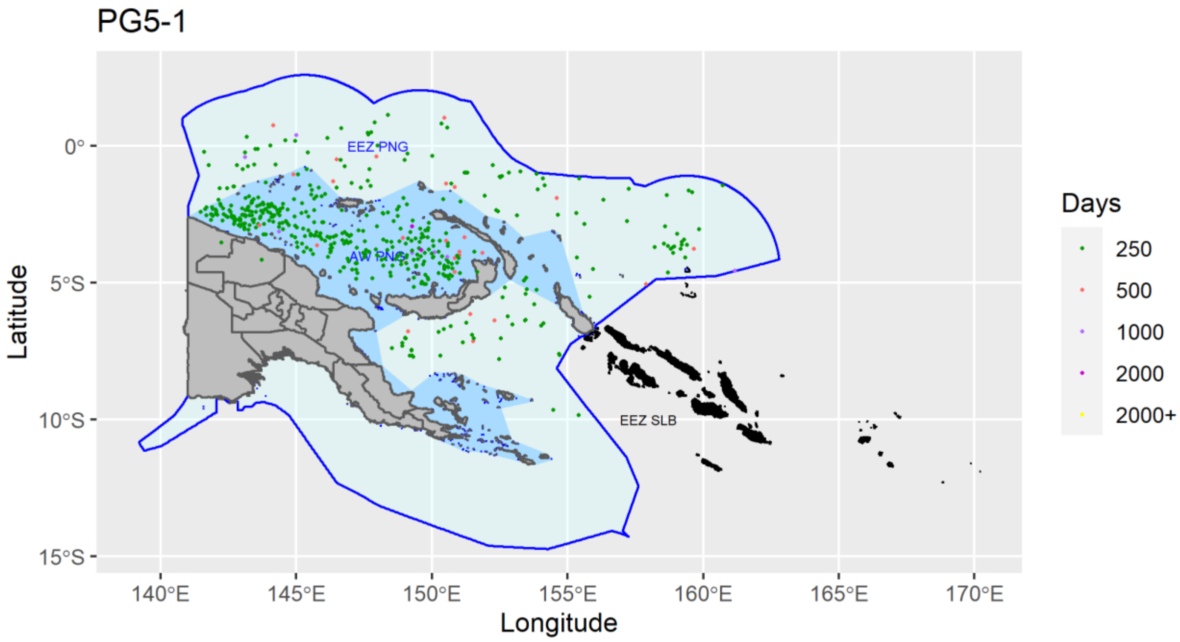
Longitude


PG5-1
Days
250
500
1000
2000
2000+
EEZ PNG
AW PNG
EEZ SLB
Latitude
0°
5°S
10°S
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Longitude
140°E
145°E
150°E
155°E
160°E
165°E
170°E