Winter 2022

CHARACTERIZING THE TRADITIONAL FISHERIES OF SALARY, MADAGASCAR WITHIN A MARINE PROTECTED AREA

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BY

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BACHELOR OF SCIENCE IN MARINE BIOLOGY

ROGER WILLIAMS UNIVERSITY, 2017

THESIS

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements for the Degree of

Master of Science

in

Biological Science: Marine Biology

December 2022

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Defense on September 7, 2022

Approval signatures are on file with the University of New Hampshire Graduate School

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor Dr. Elizabeth Fairchild. Thank you for taking a chance on me and allowing me to be a part of your lab these past two years. The core foci of this project have been a lifelong love of mine and I am so grateful that you chose me to take on the responsibilities of this project, even while I lacked previous research experience. Thank you for being an incredible mentor throughout this process. To Dr. Easton White and Dr. Merrill Baker-Médard, thank you for the technical support on this project. From helping me learn to code to continually explaining the complex social aspects of the project, I am so grateful for all of the time you have put towards bettering not only myself but also this project. Dr. Nathan Furey, thank you for always chiming in with helpful ideas and experience. I would not have been able to complete this project and degree without the input of all four of my advisors.

There were countless people that helped me along in my progression for this project. Members of both the Fairchild and White labs helped me many times with coding issues and presentation preparation. Dr. Jessica Bolker for continuously being not only a source of writing help, but also navigating some of the complications of graduate school and growing as a scientist. Special thanks to Gabe Lefkowitz at Middlebury College for his help on translating Malagasy terms to English.

Getting to this point would never have been possible without the love and support of my family. I thank my parents for their constant love and support, especially when I started to falter in my perseverance. My mom for her blind support and my dad for his tough love when it was needed. They have pushed me to be the human and scientist I am today. Thank you to my partner, Mark Wallerstein, for the countless number of hours of listening to me talk science, for all the meals you had ready and waiting when I peeled myself away from work, and always my first call when I finally got my graphs to work, even though you had no idea what I would be talking about.

I would like to thank Roger Williams University and Dr. David Taylor for expanding my love of marine biology to fully encompass the field of fisheries and marine ecology. I would also like to thank Broward County Sea Turtle Conservation Program, Dr. Derek Burkholder, Curtis Slagle, Abby Nease, and Glenn Goodwin for allowing me to professionally grow under your guidance, helping to qualify me for the UNH program, and letting me hang with the turtles.

Finally, I would like to thank the University of New Hampshire as a whole. UNH provides the support and the village that it takes to accomplish a master's degree. University of New Hampshire's teaching assistantship funding is one of the key reasons I was able to accept the opportunity with Dr. Fairchild. I would also like to thank the National Science Foundation for the grant that allowed for this work to take place as well as summer funding for working on this project. This research was supported by grant #1923707, "CNH2: Socio-Ecological Feedbacks of Marine Protected Areas: Dynamics of Small-Scale Fishing Communities and Inshore Marine Ecosystems" from the National Science Foundation.

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Abstract

Protected Areas are a tool used by the International Union Conservation of Nature (IUCN) to limit changes to and preserve important and fragile ecosystems, allowing varying permissible activities within their boundaries. Locally Managed Marine Areas (LMMAs) are a similar tool, but with a higher emphasis of community engagement in the planning process with community-based ownership and regulation. In Madagascar, there are both IUCN Marine Protected Areas (MPAs) and LMMAs established to help conserve their high marine biodiversity and healthy reef systems. While the LMMAs and some of the MPAs permit sustainable fishing, it is unknown if the traditional, small-scale fisheries are sustainable or if they impart permanent negative impacts to current exploited marine populations. These analyses examine 11 years of fisheries data collected from the town of Salary, Madagascar. The goals of this study were to: 1) devise methods from local fish collectors that attend to cross-cultural and cross-linguistic challenges to collect robust catch data to characterize previously undocumented fisheries, then 2) analyze these landings data using generalized linear models and examine the health of the exploited populations for signs of impact. Monitoring the status of ecosystems in an MPA is essential to preserving the ecological balance of reefs, but also the livelihoods of Salary's residents. We found 51 unique identifiable fishing sites, with six highly frequented sites, where fishers capture Eel, Fish, Gastropods, Octopus, Sea Cucumber, Squid, Seaweed, Lobster/Crabs, and Seahorses by Hand, Hook and Line, Spears, Spear guns, and Nets. Fish and Octopus were the highest landed marine organism categories from the highest frequented sites (Belamera, Nanohofa, Ananamose, Andamabe, Anjokozoko, Nandoa),

however, only at Belamera were there indications of overfishing Octopus that might not be conducive to the MPA status. While we were able to determine that as of 2021, Salary's fisheries seem to be sustainable, we acknowledge the limited scope of these data and recommend the continuation of data collection and evaluation to ensure the health and legitimacy of the MPA. Ensuring the health of MPAs is essential to the health of coastal communities and our oceans.

Introduction

Conservation and Marine Protected Areas

Conservation is a multidisciplinary approach that focuses on putting forth effort and action into ensuring that resources can be utilized now as well as in the future. Conservation can be carried out through a multitude of methods such as examining populations and listing them on watchlists or even geographically based. One geographical method to conserve an area is by designating it a protected area to limit changes to and preserve important and fragile ecosystems. There are six different categories of protected areas, both terrestrial and marine, as defined by the International Union for Conservation of Nature (IUCN) (Dudley, 2008; Table 1). These categories vary in the allowed activities that can occur within their boundaries, from strict nature reserves to sustainable use of resources (Table 1). For reference, a national park is delineated as a Category 2 IUCN recognized protected area (Table 1). When these protected areas are within water, they are referred to as Marine Protected Areas (MPAs). MPAs currently encompass 6.35% of the world's oceans, 1.89% of which are no-take MPAs (IUCN 2017). Seven countries account for establishing around 80% of the surface MPAs (IUCN 2017), but over 65 countries and territories that have a network of over 400 MPAs protecting their coral reefs (Burke et al. 2011).

The purposes of MPAs are to save ecosystem services, protect high biodiversity, and provide both social and economic benefits to the communities surrounding them (Picone et al. 2020). MPAs can be designed to focus on encompassing places of ecological importance like breeding or feeding grounds, migration pathways, or even home ranges of different marine animals (Picone et al. 2020). As the networks of MPAs grow, the intent is that sanctuaries from anthropogenic damage and exploitation of natural resources are created for the inhabitants, enough to restore the areas to a goal of equilibrium or "pristine biomass" as defined by McClanahan et al. (2007). Another goal of more restricted MPAs is to create "spill-over," whereby prohibiting fishing in an area results in a thriving population to the point that it spills over into the surrounding areas that have less restrictions, and thus "enhances" the surrounding waters (Guidetti et al. 2008).

Table 1. International Union for Conserving Nature's (IUCN) categories for both marine and terrestrial protected areas (Dudley 2008).

Protected Area Category	**General Terms**
Category Ia	Strict Nature Reserve
Category Ib	Wilderness Area
Category II	National Park
Category III	Natural Monument or Feature
Category IV	Habitat/Species Management Area
Category V	Protected Landscape/Seascape
Category VI	Protected areas with sustainable use of natural resources

MPAs are meant to combat anthropogenic impacts to habitats in the ocean. Successful MPAs show positive biological change over time, returning an area to pre-anthropogenic impact conditions. As described by Edgar et al (2014), there are five key factors that can help an MPA to be successful: no take, well enforced, old (>10 years), large (>100 km^2), and isolated by deep water or sand. This success can be represented in multiple ways depending on the original goal for establishing the MPA. An increase in total biomass or a favorable change to the area or species inhabiting the protected zone may indicate MPA effectiveness. For example, long established (since 1988) no-take zones in

Australia's Great Barrier Reef show positive increases in biodiversity as a result of the fishing restrictions (Fraser et al. 2019). Similar results can be seen in the Mediterranean with an MPA that was established in 1983 (García-Rubies et al. 2013). In the Medes Islands MPA, dusky grouper (*Epinephelus marginatus),* zebra seabream (*Diplodus cervinus*), and European bass (*Dicentrachus labrax*) have reached carrying capacity, the brown meagre (*Sciaena umbra*) is approaching stabilization, and biomass of the common dentex (*Dentex dentex)* continues to increase (García-Rubies et al. 2013). MPAs may not only increase biodiversity but can help protect species phenotypes considered favorable in markets that otherwise may have been fished out as is the case with European lobsters (*Homarus gammarus*) in Norway (Sørdalen et al., 2020). Lobsters with bigger claws are harvested more heavily than those with smaller claws, resulting in smaller claws becoming a more dominant trait in male lobsters (Sørdalen et al. 2020). However, within the MPA, where large-clawed lobsters are protected from fishing, this paradigm does not hold true (Sørdalen et al. 2020).

Ecotourism can be a motivator to establish successful MPAs. For example, in the Sea of Cortés is an established MPA named Cabo Pulmo National Park (CPNP), a 71.11 km^2 park with 25 km^2 reserved as a no-take zone (Guidetti et al. 2008). The community around CPNP took initiatives to strictly enforce the no-take zone and, as a result, there has been a 463% increase in fish biomass within the MPA, which in turn has led to the CPNP becoming a popular ecotourism spot (Aburto-Oropeza et al. 2011). Since the establishment of the MPA in 1995, top predators have increased by 11 times their starting numbers and carnivores have increased four-fold (Aburto-Oropeza et al. 2011). These types of fishes can be important attractors for ecotourists. Ecotourism can provide alternative incomes to fishing and can be a large motivator for a community to set social acceptance levels leading to higher adherence of rules as set by the MPA. Protecting the MPA can be seen as an extension of protecting the livelihoods of the community (Guidetti et al. 2008).

Decadal time scales are a realistic expectation for noticeable change to occur within MPAs, especially if the goal is to increase biodiversity or attempt to return an ecosystem to equilibrium (García-Rubies et al. 2013). Assessing too soon after a MPA is established may result in perceived failure since it may be too early to show any significant changes (Guidetti et al. 2008). This scale can vary even more when comparing MPAs where fishing is allowed verse not. For example, in the Great Barrier Reef, Fraser et al. (2019) determined that the "newer" no-take zones, added in 2004 to the established 1988 no take zones, were far more likely to have "neutral" impacts than the older no-take zones. These impacts were not negative, as they might have been if fishing was still occurring, but neither were they positive, indicating that insufficient time had passed to measure if the MPA was promoting recovery and avoiding loss (Fraser et al. 2019). Similarly, in the CPNP reserve, an assessment was conducted only four years after the MPA was established and showed there were no significant differences within the reserve and any surrounding waters, other reserves, or areas open to fishing (Aburto-Oropeza et al. 2011). Fourteen years later, however, total fish biomass had increased 463% within the MPA (Aburto-Oropeza et al. 2011). This biomass explosion included the top predators and carnivores that make CPNP the ecotourism attraction that it is today.

Not all MPAs are successful even though adequate time has passed. Lack of success often result from improper regulation or lack of enforcement within the MPA. "Paper parks" are one such example. A paper park is an officially declared MPA, with regulations and restrictions in place, but then, in practice, not treated differently from any other surrounding area (Guidetti et al. 2008). Paper parks occur for a variety of reasons, typically stemming from community disapproval of the MPA, lack of enforcement, lack of sufficient funds, and continued overexploitation (Tam 2015). For instance, in the Philippines, 13 MPAs established before 1998 were evaluated for effectiveness (White and Courtney 2004). Over half the MPAs (7 out of 13) had little to no management, including the oldest MPA, established in 1988 (White and Courtney 2004). Lack of enforcement resulted in the failure of a MPA in the Gulf of California in Mexico (Rife et al. 2013). An initial increase in the abundance of target invertebrate species occurred after the MPA was established, however, lack of compliance and poaching resulted in an overall loss of biomass (Guidetti et al. 2008).

If community engagement and buy-in does not exist, one way to combat a paper park is by increasing enforcement (Guidetti et al. 2008). For example, of 15 Italian marine reserves studied, three had adequate enforcement which was directly correlated to higher biomass of the target species (e. g., *Dipoludus spp.*, *Dentex spp., Dicentrarchus spp., Sarpa spp.)* (Guidetti et al. 2008). Abundance of large predators like the critically endangered *Epinephelus marginatus* and urchin predators like *Dipoludus spp.* also increased as a result of stricter enforcement which reduced poaching (Guidetti et al. 2008). When the community rejected the idea of a MPA as being a worthwhile endeavor, there also was a correlating lack of enforcement effort (Guidetti et al. 2008) indicating the importance of having community buy-in to MPAs.

Madagascar Background

Madagascar is an island in the Indian Ocean, separated from the continent of Africa by the Mozambique Channel. Originally colonized by the French, Madagascar only gained its independence in 1960. The country has a population of approximately 26 million people that is growing 2.8% annually (Gough et al. 2020). Madagascar is listed as the eleventh poorest country in the world, with more than 80% of the population living off less than $1.90 per day (Gough et al. 2020). The combination of population growth and poverty results in a population that relies heavily on the country's natural resources for both income and sustenance.

Within Madagascar, half of the population lives within 100 km of the 5,600 km^2 coastline making the ocean the biggest natural resources available to them (Burke et al. 2011). Further, 10% of the Malagasy population live within 30 km of a reef, close enough to be able to harvest marine organisms (Burke et al. 2011). As such, Madagascar is one of 110 countries that are heavily reliant on reefs, for both economic and social reasons (Burke et al. 2011). The dependency on marine products varies slightly by region in Madagascar. As the southwest is drier than the north and farming is not as tenable, fishing is the primary source of income (McClanahan et al. 2014).

One Malagasy group who resides in the southwest and depends on the ocean is the Vezo, an ethnicity of people that draw their identity from their connection with the ocean (Astuti 1995). Vezo define themselves as "people who struggle with the sea and live on the coast" (Astuti 1995). Interviews with Vezo fishers, indicated that maritime activities are more characteristic of their ethnicity than either the place of their people's origin or genetic makeup (McClahahan et al. 2014). The Vezo people believe it is their birthright to use the sea as they see fit, including opportunistically hunting endangered species (Rife et al. 2013). The Vezo people use a vessel or pirogues or, in Malagasy, “laka” to visit fishing sites (Gough et al. 2009). Lakas are made from one singular tree species, *Givotia madagascariensis*, hollowed out and waterproofed with tar on the underside and oil-based paint on the top half (Gough et al. 2009). Lakas, then, are fitted with an outrigger and mast for sailing (Astuti 1995). Each fisher will personalize their lakas after purchasing them, fitting in seats and rails (Gough et al. 2009). The relationship between the Vezo and their fishing vessels are just one example of how deep their connection is with utilizing the ocean to supplement their life needs. A cultural connection to the ocean as deep as the Vezo’s may be resistant to a non-Vezo voice asking them to change their way of life.

Decolonizing Conservation and Dina

One of the ways of countering the problems of failed MPAs and neocolonial conservation is to emphasize stakeholder involvement in the creation and regulation of protected areas. The failures with paper parks and lack of community buy-in typically stem from the community not being involved in the planning of the MPAs. Instead of top-down planning, an approach that incorporates gradual education and creates awareness in the community tends to create better community buy-in and, thus, more successful MPAs (Tam 2015). This difference in approach needs to be practiced and perceived, not only by inviting stakeholders to be involved in planning, but also listening and considering their suggestions (Berkes 2007). Often community members with generational knowledge provide a better picture of what is happening with different reefs and fishing grounds that could be more meaningful than any quick survey.

Decolonizing conservation is a movement enabling countries to decide for themselves what types of conservation will work for their goals and their communities rather than being told by foreign entities (e.g., non-governmental organizations (NGOs), other institutions, parachute scientists) what to protect and how to do it (Rakotoson and Tanner 2006). In countries like Madagascar that do not have a strong central government and have high amounts of NGO involvement, MPA establishment can be forced. This might occur in areas that have high potential for preserving biodiversity but are unable to be no-take zones due to the ocean-dependent communities nearby. When heavy community involvement occurs in the planning and developmental stages for a MPA, the protected area often is referred to as a Locally Managed Marine Area (LMMA). Whether or not a MPA is classified as an LMMA is dependent on how the area is managed. LMMAs also incorporate stakeholder input and rely on the communities for enforcement and education and, as a result, generally have high success or positive outcomes (Rocliffe et al. 2014). As a result, LMMAs combat the disconnect that have caused previous top-down managed MPAs to fail. Enforcement by marine patrols and maritime units become unnecessary if communities deem that it is socially unacceptable to violate the rules of LMMAs.

In Madagascar, the local governing laws of LMMAs are called dina (Rakotoson & Tanner, 2006). These dina differ from statutory laws in that they are created at the level of a village, then approved at the regional level before they are legitimized at the national level (i.e., bottom-up approach). They are seen by some scholars as a way of balancing a Western legal framework with the traditional rights of coastal resource users (Rakotoson and Tanner 2006). Dina vary from region to region and are not recorded in a way that can be easily found by non-community members, despite the fact that they are registered by regional and national governmental institutions. Rather, they tend to be disseminated orally within communities.

Madagascar and its Conservation Efforts

Madagascar has been the site of multiple types of conservation efforts for over 30 years, receiving conservation-focused attention from not only its own government, but worldwide from donors and NGOs, like Blue Ventures (BV), Conservation International, Wildlife Conservation Society, and World Wildlife Fund, attempting to conserve the country's unique terrestrial and marine biodiversity (Barnes and Rawlinson 2009). There are 171 IUCN protected areas established within Madagascar (Barnes and Rawlinson 2009). These protected areas cover about 3.3% (49,947 km^2) of Madagascar's 1.2 million km^2 exclusive economic zone (EEZ) (Ratsimbazafy et al. 2016, MPAtlas 2022). Madagascar's EEZ extends 200 miles in all directions from the 5,600 km^2 of coastline and is home to 4,500 km^2 of mangroves and reefs (Barnes and Rawlinson 2009), including the Toliara reef system along the southwestern coast (see Appendix Figure A). The Toliara reef hosts over 6,000 species, including many endangered and threatened species, as well as many endemic species to Madagascar (Fricke et al. 2018). Of these 6000 species, there are 752 fish species, 340 coral species and at least six different octopi species (McKenna and Allen 2003). Rasolofonirina et al. (2004) found 25 different species of sea cucumbers that are fished including *Holothuria scabra, Holothuria nobilis, Holothuria fuscogilva,* and

Thelenota ananas. In addition to the high levels of biodiversity in Malagasy waters, in an assessment of 58 countries' reef shark conservation potential, Madagascar was named one of six countries with the highest conservation potential but also lacking set management schemes (Barnes and Rawlinson 2009). This combination suggests that Madagascar can serve as a test case for other countries facing environmental change and fishing pressures by determining which conservation management strategies are most likely to preserve marine biodiversity. In order to do that, a deeper understanding of Malagasy local traditional fisheries is needed including those that occur within the boundaries of the MPAs. Here we provide a case study, focusing on an area of Madagascar that has not been formally evaluated before and is part of a MPA. The goals of this case study are two-fold: 1) characterize the fisheries and 2) analyze the impacts of these fisheries to the reef communities within the boundaries of the MPA/LMMA Soariake.

Methods and Materials

Study Area

Soariake is a Category VI MPA, along the coast of southwest Madagascar and encompasses 443 km^2 (Figure A). Delineated as a MPA in 2008, and officially recognized as such in 2015 (Rasolomanana 2015) the main aim of Soariake is to help to conserve the Toliara Reef System, especially the second barrier reef which has shown great potential as a place for coral replenishment (Barnes and Rawlinson 2009). As a Category VI MPA, sustainable uses are permitted within Soariake. Further, Soariake also is classified as an LMMA due to the high levels of community involvement and regulated by the dina. For this reason, the terms LMMA and MPA are interchangeable within this study unless noted otherwise. Although there are many temporal and species-specific closure periods in Soariake, as well as some permanent small no-take zones (M. Baker-Médard, personal comm.), there is little publicly available information regarding these periods and reserves; therefore, these closures are not taken into account in this study (M. Baker-Médard, personal comm.).

Soariake supports small-scale, commercial fisheries. Gear types used include hook and line, gill net, beach seine, and speargun (Barnes and Rawlinson 2009), as well as low- and sub-tidal hand foraging. Fishing vessels used are typically pirogues or “lakas,” 3-8 m long boats with an outrigger and a sail (Barnes and Rawlinson 2009). In some cases, the water is low enough that fishers, especially women and children, can walk out to the reefs and fish instead of using a laka (Humber et al. 2006; Gough et al. 2009). In southwestern Malagasy fisheries, known target species for export include sea cucumbers, branched murex

(*Chicoreus ramosus*), tulip snail (*Fasciolaria trapezium*), and the common octopus (*Octopus vulgaris*) (Barnes and Rawlinson 2009). Sharks and many fishes also are targeted (M. Baker-Médard 2017).

Data Collection in Madagascar

Many fishers from Salary venture out to fish on MPA Soariake's reefs to harvest products for their own consumption, but also to sell to local brokers for profit. The catch is sold to "sous-collectors" or brokers, residents of their respective towns who serve as middlemen between local fishers and larger fisheries companies which primarily export to European and Asian markets (Humber et al. 2006). Brokers may collect the products on the beach, in their homes, or from returning boats. The marine organisms then are divided into different categories, individuals in each product category counted, a total weight recorded, and fishers paid by the brokers. Since 2010, some of these brokers who sell to the companies supplying the European export market have shared catch data with Dr. Merrill Baker-Médard (Middlebury College, VT). As of October 2022, data sharing continues and has expanded to include additional information (Table 2, see Appendix Table A). The dataset now includes not only the date of landing, fishing location, marine organism category, marine organism count, and total marine organism weight, but also time spent fishing (effort), name and gender of the fisher, how many people participated in the fishing, gear type used, other catch not sold to the broker, and occasionally common names of the marine organisms. Data recorded during 2010 -2011, 2015-2016, and 2019- 2021 by the brokers were forwarded to Charlotte Nagnisaha, the in-country Regional Research

Assistant, who oversaw the data input by local university students before forwarding the data to Dr. Baker-Médard.

Table 2. Categorical fishing trip data collected in Salary and consistency collected by year; 2010 (n=1012 trips), 2011 (n=1490 trips), 2015 (n=1858 trips), 2016 (n=518 trips), 2019 (n=1147 trips), 2020 (n=800 trips), and 2021 (n=5149 trips). Consistency collected: 5 – 100% collected; 4 – ≥90% collected; 3 – ≥70% collected; 2 - ≥40% collected; 1- >0% collected. 0 – not collected at all. Original Malagasy headers with translations can be found in Appendix Table A.

	2010	2011	2015	2016	2019	2020	2021	ALL
TRIP DATE	**5**	**5**	**3**	**5**	**4**	**5**	**4**	**4**
NAME OF FISHER	**4**	**4**	**4**	**5**	**4**	**3**	**3**	**4**
SEX OF FISHER	**2**	**2**	**1**	**2**	**4**	**3**	**3**	**3**
NUMBER OF FISHERS ON TRIP	**0**	**0**	**0**	**0**	**4**	**3**	**3**	**2**
FISHING SITE	**4**	**4**	**5**	**5**	**5**	**5**	**5**	**4**
MARINE ORGANISMS SOLD	**4**	**5**	**4**	**5**	**3**	**4**	**4**	**4**
NUMBER OF MARINE ORGANISM LANDED	**5**	**4**	**4**	**3**	**4**	**4**	**4**	**4**
TOTAL WEIGHT OF MARINE ORGANISM CATEGORY (KG)	**5**	**5**	**3**	**2**	**3**	**4**	**4**	**3**
PRICE PAID TO FISHER (AR)	**4**	**4**	**0**	**0**	**4**	**4**	**4**	**3**
TIME DEPARTED	**0**	**2**	**3**	**5**	**4**	**3**	**3**	**3**
TIME RETURNED	**2**	**4**	**3**	**5**	**4**	**3**	**3**	**3**
LANDINGS NOT SOLD TO BROKER	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
GEAR TYPE USED	**0**	**0**	**0**	**0**	**0**	**3**	**4**	**2**

Data Preparation

Raw data were analyzed in R version 4.0.2 (R Core Group 2016). The data were grouped according to fishing site, marine organisms caught, and gear types used for spatial and temporal analysis. Because Malagasy is a phonetic language, multiple spellings occurred for the same category, so data were grouped and then translated into English (see Appendix Tables B, C, D). To determine the proper groupings of the fishing sites, all the names of fishing sites were organized according to similarities in spelling, ignoring prefixes like “An.” All groupings were verified by Dr. Baker-Médard who has substantial knowledge of the Malagasy language and Malagasy culture. Fishing site names that were unable to be grouped, such as those entries that were too vague like “Amba” meaning “North” or words that were not known fishing areas, were placed into the “Other” category. A “Blank” category was created for when the fishing site was left blank, either because data were not collected or the fisher was not willing to share where they fished. A similar grouping process was used for organizing the marine organisms. Due to the level of catch information collected for the majority of the dataset, species-specific information was unavailable and, thus, marine organisms were grouped into large marine organism categories (i.e., Fish, Octopus, Squid, etc.; see Appendix Table C).

Occasionally species level information was collected throughout the years, the majority in 2021 per the request of Dr. Baker-Médard. For those data that included more specific names than just “Fish” or “Octopus,” FishBase (Frose and Pauly, 2022) was used to match the Malagasy common names to the scientific names (see Appendix Table E). In some cases, multiple possibilities were found and both options were included (see Appendix Table E).

In the original dataset, if multiple species were landed on the same trip, the fishing site and the name and gender of fisher were included only with the entry of the first species landed. In these cases, the fishing site and the name and gender of fisher were copied and transferred into a new data column so that this information corresponded to all catch within each trip. This allowed the data to be sorted by both number of trips to a fishing site and where marine organisms were caught.

Numerical values for the number and total weight of marine organisms were not always present in the dataset. The word "marobe," meaning "many," was used multiple times. For the analysis of the total weights and average weight per individual organism, these data were removed as they could not be quantified. Other removed data included entries that incorporated decimals into the count data (i.e., 10.5 Fish or 0.6 Squid).

Data Analysis

To characterize the fisheries, we first determined where the majority of the fishing occurred, what the landed marine organism categories were, and what gear types were used for fishing. The total number of trips to each fishing site was calculated, first by year and then overall for the dataset (see Appendix Table F). The percentages for each site were achieved by using the sum of each site divided by the sum of all of the trips (n=11,974, see Appendix Table F). Each site that accounted for at least 5% (arbitrarily chosen to ensure enough data existed for further analyses) across all years of the data was considered a highly exploited site, then analyzed more in depth. As these percentages were taken over the entire dataset, the proportionate number of visits to each of the six main fishing sites for each year of data collection were also analyzed to identify if rotational fishing was used throughout time.

To better define the sites (n=6) that accounted for more than 5% of fishing trips, ArcGIS (ESRI, Redlands CA, USA) was used to map and visually describe the site locations.

Image J was used to calculate distances (km) from the town of Salary to the six fishing sites and to calculate the areas (km^2) of the main fishing sites using the hand drawn maps compiled into Appendix Figure A by Dr. Baker-Médard. As the fishing sites were defined by hand drawn maps, the distances (km) and areas (km^2) were not used for statistical analysis, but rather as descriptive information about sites that would not be commonly known to those outside of this fishing community in Salary and surrounding villages.

Defining the next part of these fisheries, the landed marine organism categories for the entirety of the dataset (2010-2021) were analyzed. The number of trips with landings for each category were summed. These sums were then used to calculate the proportion of each category with respect to all of the categories. Furthermore, the proportions of landings for each year of data collection were calculated. Both number of trips with landings and total weight of each category were also summed and proportions were calculated by using the following equations: $(\frac{total\ landings_{organism\ category}}{total\ landings_{all\ categories}})$ and $(\frac{total\ weight_{organism\ category}}{total\ weight_{all\ categories}})$. The categories with the highest proportions were then prioritized for further analysis. This protocol was repeated for landings from the main fishing sites.

For the final step of characterizing the fisheries, gear types were analyzed. Gear type data were only collected in 2020 and 2021. All data that did not have an entry for gear were excluded from analysis. The gear types were grouped, and the number of times summed that they were used that resulted in a landing for each marine organism category. Metal rods and sticks were grouped together since both are used similarly to dig to find, probe, and pry an organism out of the water, and/or hit the marine organism until stunned or dead (M. Baker-Médard, personal comm.). The “Other” category for gear consisted of gear types that were not translatable from Malagasy into English. The gear type of “Hook” which occurs in the dataset is referred to as “Hook and Line” in this analysis. Within each marine organism category, the number of gear type occurrences were totaled and those sums were used to calculate the proportion of the usage of each gear type for landing each category; $\frac{total\ frequency_{gear\ category}}{total\ frequency_{all\ categories}}$. This process was repeated for the main marine organisms in the main fishing sites. A Kruskal-Wallis rank sums test was used to determine if gear type varied significantly by landed marine organism category.

To explore the potential negative consequences of these fisheries in the MPA/LMMA Soariake, the two highest proportionally landed marine organism categories were analyzed further: Fish and Octopus. The total landings (number of individuals), total biomass (kg), and average individual weight (count/kg) of Fish and Octopus were tracked temporally by season and year. Due to the sporadic nature of the data collection, to complete a temporal analysis, we identified specific seasons of two- or three-month periods that reoccurred in the data collection across the years. “Winter” included July, August, and September. “Summer” included November and December. We selected three years for each season representing the fisheries at the beginning, middle, and end of the dataset to track trends in catch: Winter 2011, 2015, and 2019 and Summer 2010, 2015, and 2020. Generalized linear models with a Poisson error distribution were used to determine if Fish or Octopus landings (or removals) from all main fishing sites (total) and from individual fishing sites in Winter or Summer varied significantly over time. Linear regressions were used to determine if landed Fish or Octopus total weight and average weight from all main fishing sites (total) and from individual fishing sites in Winter or Summer varied significantly over time. For all regression models, the residual plots were verified (see Appendix Figure B-CG).

Results

Characteristics of the Fisheries

Locations of Fishery

Fifty-one (51) unique fishing sites were identified in the MPA/LMMA Soariake in addition to the "Blank" and "Other" categories (Figure 1). The number (n) of trips to these 51 sites varied from one to 2,408 (Figure 1). Six major fishing sites were identified using an arbitrarily chosen 5% threshold. These six major fishing sites were Ananganose (n=1,116), Andambe (n=830), Anjokozoko (n=686), Belamera (n=2,408), Nandoa (n=586), and Nanohofa (n=1,426) (Figure 1). The arbitrarily chosen 5% threshold was used to determine if a site qualified as a major fishing site for these analyses and help to ensure enough data for analyses (Figure 1). Together the visits to these six main sites accounted for 62.3% of the total number of fishing trips (n=11,268). All six fishing sites lie within 5 km of the town of Salary (Figure 2, Table 3). Some sections of the backreef, reef crest, or forereef of Soariake are called slightly different names by different fishers, thus reflecting how these place names are dynamic instead of fixed socio-ecological space. While small alternate spellings were accounted for in our analysis, some of the smaller sites that are mapped, all of which account for less than 5% of total fishing trips, have some degree of spatial uncertainty associated with them.

The most frequented fishing site was Belamera, accounting for 21.4% of all fishing trips and was the highest proportionally visited site for all years except for 2011 (Figure 3). Belamera lies 4.16 km from shore, directly west of Salary, and is the second smallest site with an area of 0.24 km^2 (Table 3). Belamera is located on a strip of outer reef, surrounded by deeper waters on three sides (Figure 2).

The second most frequently visited site was Nanohofa, accounting for 12.7% of all trips. Nanohofa lies about 3.31 km from Salary, slightly north of Belamera, and encompassing 0.91 km^2 of the reef (Figure 2, Table 3). Like Belamera, Nanohofa is on an outer stretch of reef, exposed to the more open ocean and currents (Figure 2).

Anananose accounting for 9.9% of all fishing trips is the furthest site at 4.96 km and is the smallest of the fishing sites at only 0.14 km^2 (Table 3). Anananose was the highest proportionally visited site in 2011 (Figure 3). Anananose is the most northern site, surrounded by deeper waters and the open ocean (Figure 2). The name “Anananose” translates to “at the island.”

Andamabe, accounting for 7.4% of all fishing trips, is the closest of the sites to Salary, 2.01 km from the shore (Table 3). Andamabe, encompassing 0.70 km^2, is the only main fishing site that lays on the inner reef with no exposure to deeper waters (Table 3, Figure 2).

Anjokozoko, accounting for 6.1% of all visits, is 4.53 km from Salary and encompasses 0.61 km^2 (Table 3, Figure 2). Anjokozoko has two exposed sides to deeper waters (Figure 2). One side is the outer fringe of the reef facing the open ocean while the southern side faces a deeper channel in between Anjokozoko and the next strip of reef (Figure 2). Anjokozoko and Belamera are sites that have had documented rotational closures.

The final of the six sites, Nandoa, accounting for 5.2% of all fishing trips, is 4.26 km from Salary and encompasses 0.49 km^2 (Table 3, Figure 2). Nandoa lies on a middle segment of an outer fridge of reef westward of Andamabe, with Belamera to the north, and Anjokozoko to the south (Figure 2).

All six sites were visited within each year of data collection. The highest frequented site of Belamera had annual visits that ranged from 46.9%-22.1%. The second highest frequented site of Nanohofa had annual visits that ranged from 29.5%-17.4%. Anananose had annual visits that ranged from 18.6%-8.1% and Andamabe had annual visits that ranged from 27.3%-0.8%. Anjokozoko annual visits ranged from 16.2%- 2.6% and Nandoa had annual visits that ranged from 17.4%-2.7% (Figure 3).

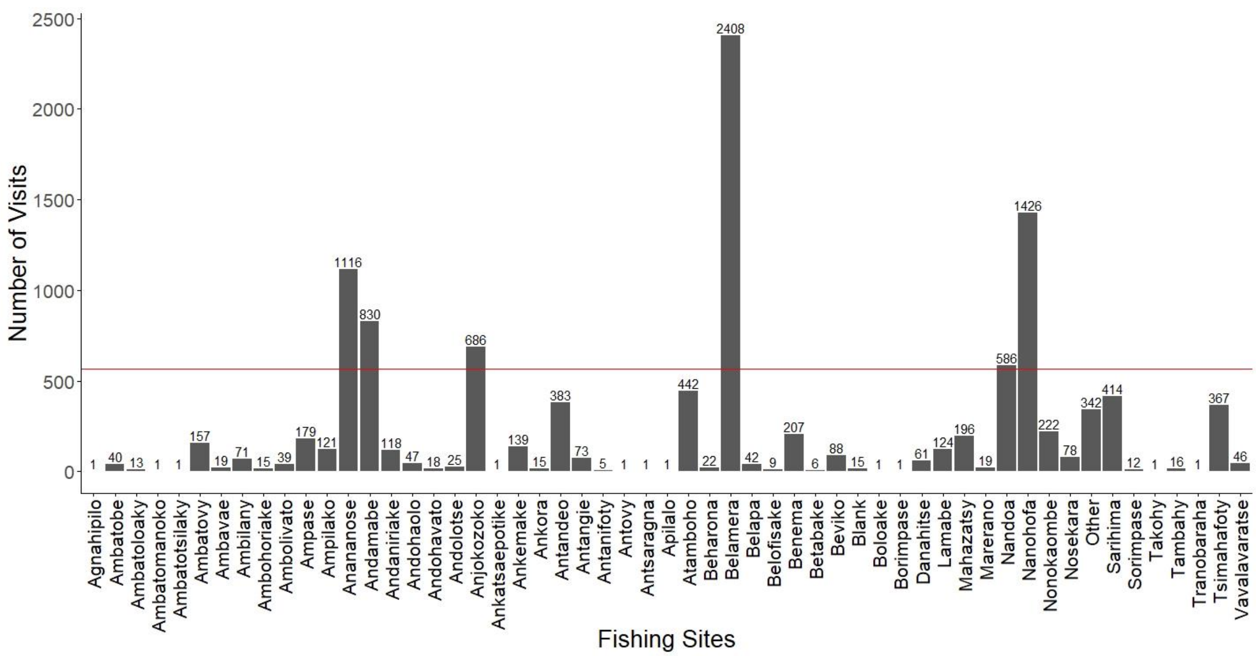


Figure 1. Total number of fishing trips to all fishing sites reported to data collectors in Salary, Madagascar during 2010-2021. The red line indicates the minimum threshold (n=5%) for specific fishing sites to be categorized as “main fishing sites.” “Blank” indicates data entries for which the name of a specific fishing site was not recorded. “Other” accounts for those visits where an unidentifiable name was recorded for fishing site.

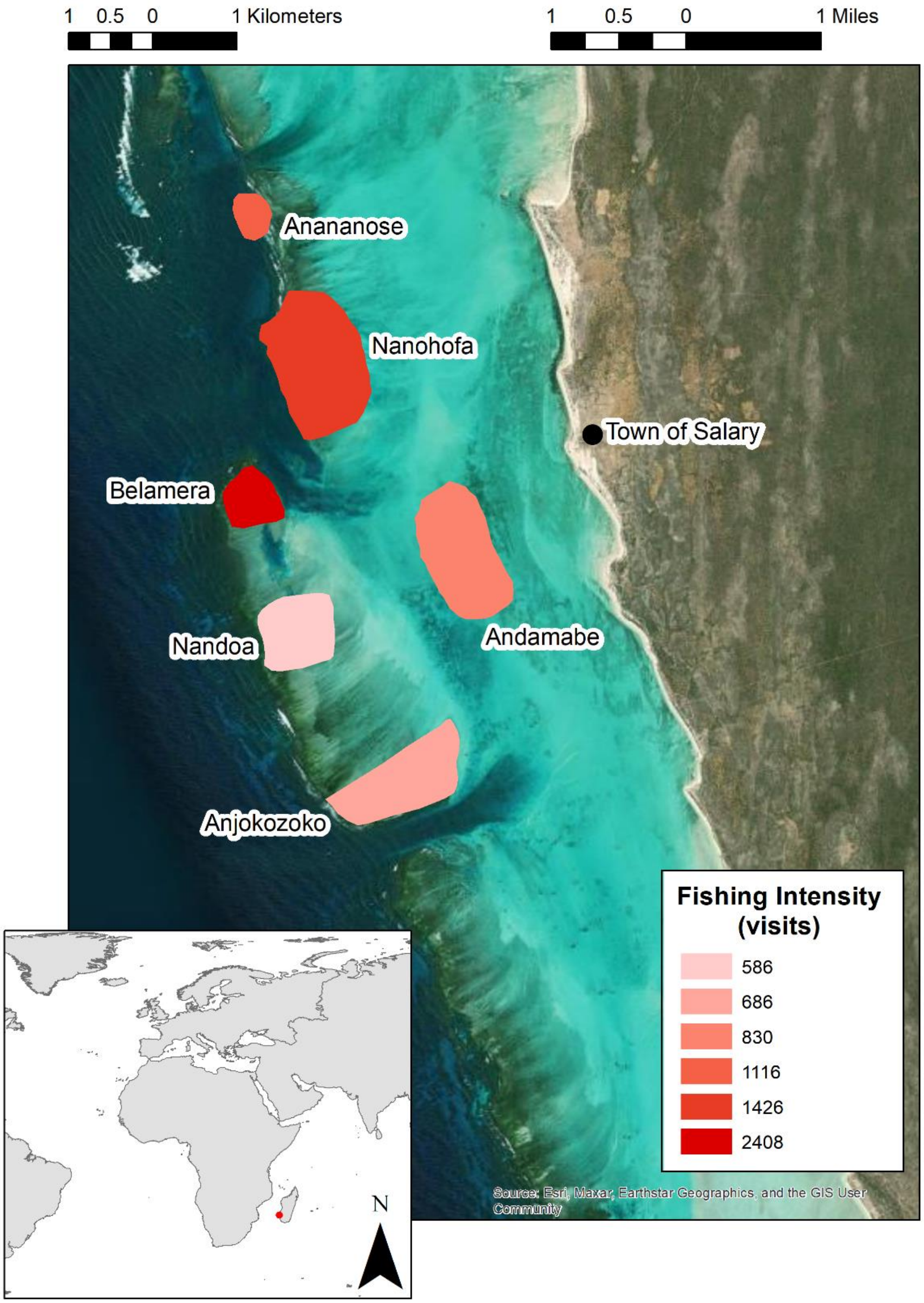


Figure 2. Location of the six main sites (Belamera, Nanohofa, Ananaose, Andamabe, Anjokozoko, and Nandoa) fished from the town of Salary on the southwestern coast of Madagascar. The color of each site corresponds to how often the site was frequented, with the darker color representing the highest intensity and the lightest color representing the lowest intensity.

Table 3. Characteristics of the six main fishing sites frequented from Salary, Madagascar during 2010-2021.

Fishing Site	Total Number of Trips	Distance from Salary (km)	Area of Site (km^2)
Belamera	2,408	4.16	0.24
Nanohofa	1,426	3.31	0.91
Anananose	1,116	4.96	0.14
Andamabe	830	2.01	0.70
Anjokozoko	686	4.53	0.61
Nandoa	586	4.26	0.49

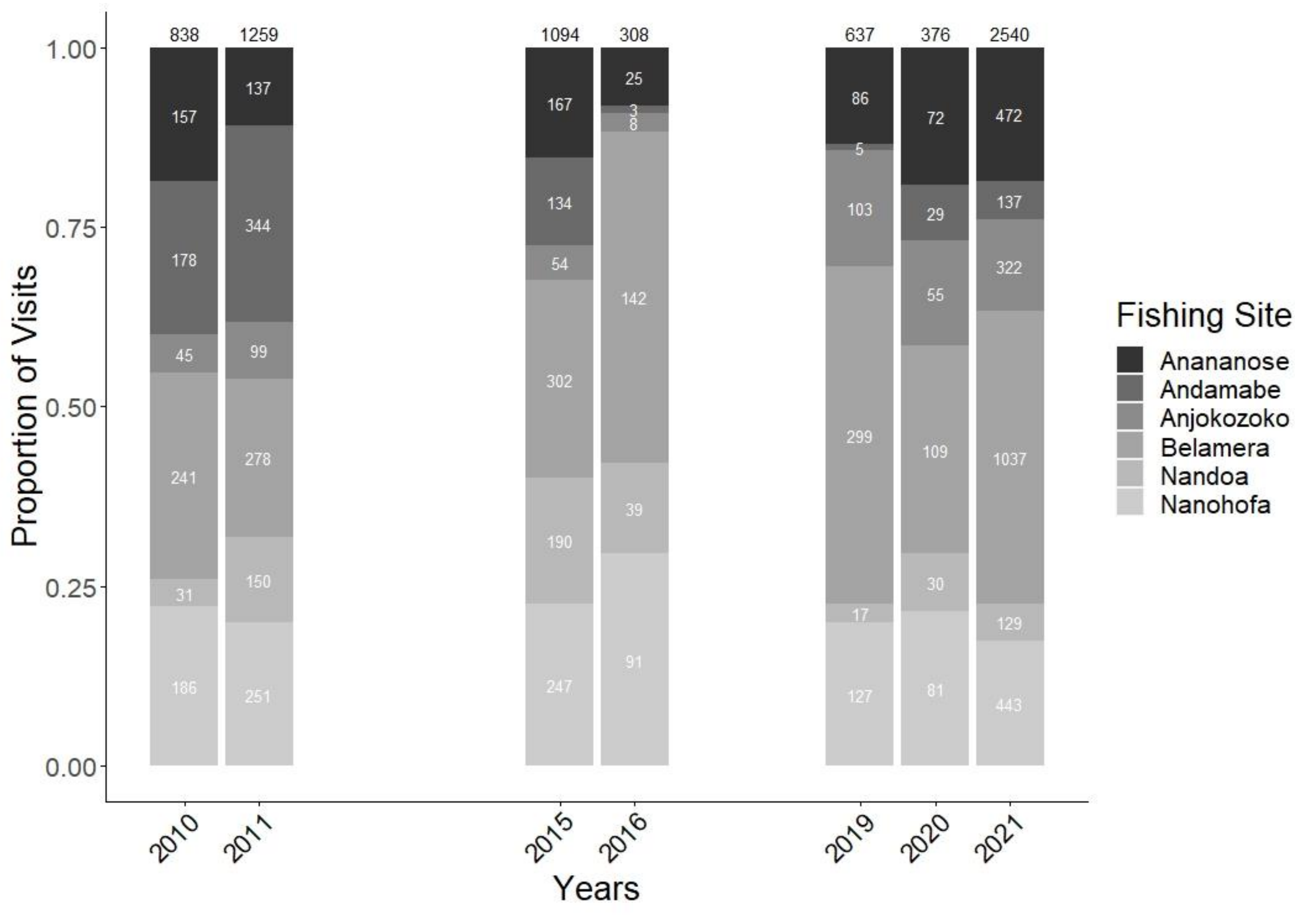


Figure 3. The proportion of visits to each of the six main fishing sites (Anananose, Andamabe, Anjokozoko, Belamera, Nandoa, and Nanohofa) in each year of data collection (2010- 2011, 2015- 2016, 2019-2021). The number of fishing trips to each site are included on the respective bar with the total annual trips reported above.

Landings of Fisheries

Marine organisms landed from fishing trips to the reef adjacent to Salary were within the following 11 categories: Eel, Fish, Gastropod, Lobster/Crab, Octopus, Sea Cucumber, Seahorse, Seaweed, Squid, and Other Organisms (Figure 4). Of the 11,268 fishing trips recorded during 2010 to 2021, Fish, Octopus, Gastropod, Squid, Sea Cucumber, and Eel accounted for 48.7%, 23.3%, 9.4%, 6.7%, 5.9%, and 0.9% of all landings, respectively (Figure 4). Other Organisms, Lobster/Crab, Seaweed, and Seahorse accounted for a combined total of 5.1% of landings (Figure 4).

A total of 46,234.4 kg of marine organisms were recorded in our dataset as landed in Salary during 2010 to 2021 (Table 4). Weight of Fish accounted for 49.3% of landings, weight of Octopus accounted for 37.0% of landings, weight of Gastropod accounted for 5.8% of landings, weight of Squid accounted for 4.4% of landings, and weight of Eel accounted for 0.9% of landings (Figure 5). The combined total weight of Other Organisms, Sea Cucumber, Lobster/Crab, and Seaweed accounted for 2.6% of landings (Table 4). Although Seahorse were landed (Figure 4), there were no recorded weights for Seahorse landings (Table 4). Although Sea Cucumbers and Other Organisms did not account for much of the landings by weight in these analyses, the weights were only recorded 8.0% and 11.8% of the time for these categories, respectively (Table 4).

Eel, Fish, Gastropod, Octopus, Sea Cucumber, and Squid proportionately dominated the landings totaling 94.9% of fishing trips to all fishing sites and 99.2% of fishing trips made to the main six fishing sites (Figure 4, Figure 5). For the main six fishing sites, Octopus were landed on 49.5% of all fishing trips, Fish were landed on 29.8% of fishing trips, Squid were landed on 7.0% of fishing trips, Gastropods were landed on 5.5% of fishing trips, Sea Cucumbers were landed on 5.1% of fishing trips, and Eels were landed on 2.3% of fishing trips (Figure 5).

Eel, Fish, Gastropod, Octopus, Sea Cucumber, and Squid also proportionately dominated the recorded amount of 25,378.7 kilograms, encompassing 54.9% of the total weight of landings (Table 5). Weight of Octopus accounted for 49.7% of landings, weight of Fish accounted for 39.7% of landings, weight of Gastropod accounted for 5.8% of landings, weight of Squid accounted for 4.4% of landings, weight of Eel accounted for 0.9% of landings, and weight of Sea Cucumber accounted for 0.4% of landings (Table 5). However, Sea Cucumbers had a recorded weight for only 8.0% of the landings (Table 5).

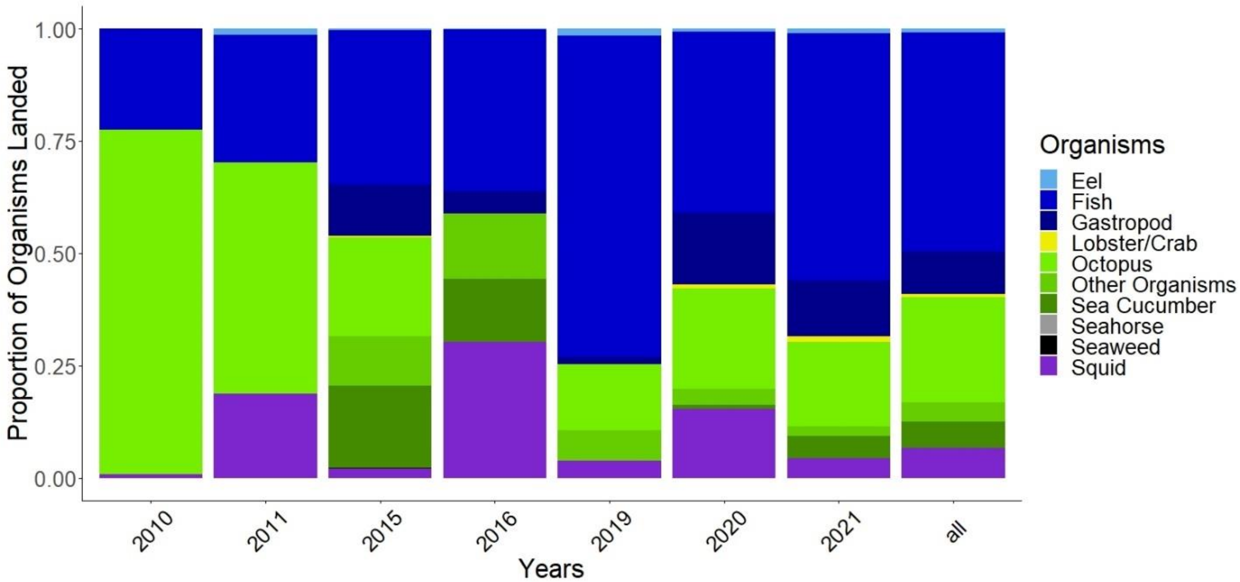


Figure 4. Proportional abundance of all marine organism categories (Eel, Fish, Gastropod, Lobster/Crab, Octopus, Sea Cucumber, Seahorse, Seaweed, Squid, and Other Organisms) landed from the main fishing sites throughout the years of the dataset (2010- 2021).

Table 4. Total landings (inclusive of all fishing sites) for each marine organism category landed in Salary, Madagascar as recorded in the dataset from 2010 to 2021: total number of trips, total number of trips with no record for weight, and total proportion of organism category weight landed. *Four recorded weights of sea cucumbers were not included in the proportion as they were deemed inaccurate.

Organism Category	Total Trips Landed	Trips with no Recorded Weight	Proportion of Total Weight Landed (kg)
Eel	264	6	0.0092
Fish	3,355	98	0.4926
Gastropod	624	63	0.0582
Lobster/Crab	51	0	0.0040
Octopus	5,572	25	0.3704
Other Organisms	737	650	0.0179
Sea Cucumber	578*	532*	0.0040
Seahorse	3	3	NA
Seaweed	5	3	0.0002
Squid	785	7	0.0435

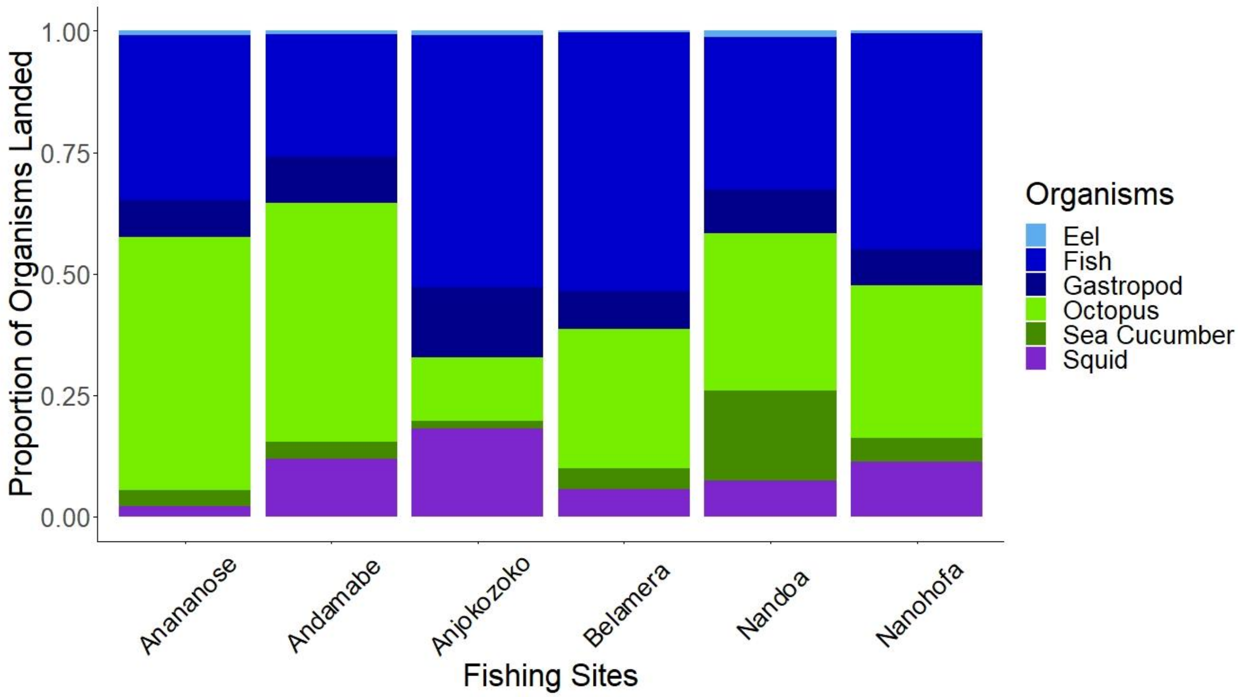


Figure 5. Proportional abundance of main marine organisms (Eel, Fish, Gastropod, Octopus, Sea Cucumber, Squid) landed from the main fishing sites throughout all years of the dataset (2010- 2021).

Table 5. Total landings of each marine organism category landed from the six main fishing sites off of Salary, Madagascar as recorded in the dataset from 2010 to 2021: total number of trips, total number of trips with no record for weight, and total proportion of organism category weight landed. *Two recorded weights of sea cucumbers were not included in the proportion as they were deemed inaccurate.

Organism Category	Total Trips Landed	Trips with no Recorded Weight	Proportion of Total Weight Landed (kg)
Eel	114	2	0.0075
Fish	1,886	45	0.3972
Gastropod	293	35	0.0456
Octopus	3,905	16	0.4969
Sea Cucumber	369*	339*	0.0044
Squid	490	3	0.0485

Main Landings of Fishery

Overall, the categories of Fish and Octopus were landed the most numerically and volumetrically from the six main fishing sites (Figure 5, Table 5). Together they accounted for 79.2% of the catch and 89.4% of the recorded weight landed from all fishing trips. Totaling the proportional abundance of Fish and Octopus, they account for 99.0% (2010), 79.8% (2011), 64.9% (2015), 32.2% (2016), 87.7% (2019), 69.7% (2020), and 80.3% (2021) of the catch each year.

The number of Octopus landings accounted for 76.2% of total landings in 2010 and 51.6% of total landings in 2011 (Figure 6, Table 6). Octopus accounted for 26.2% of landings in 2015 (Figure 6, Table 6). Only one octopus was landed in 2016 accounting for less than 0.1% of total landings (Figure 6, Table 6). In 2019, 2020, and 2021, Octopus held proportional landings percentages of 23.6%, 36.4%, and 33.4%, respectively (Figure 6, Table 6).

Weight was not always recorded but for the recorded weights in 2010, Octopus landings accounted for 82.5% of the weight (Figure 6, Table 6). For the recorded weights in 2011, Octopus accounted for 65.7% (Figure 6, Table 6). In 2015, Octopus landings accounted for 47.0% of the landed weight (Figure 6, Table 6). Similar to the drop in the number of landings in 2016, Octopus landings accounted for 0.12% of the total weight. In 2019, the Octopus weight accounted for 50.5% of landings (Figure 6, Table 6). The Octopus landings weight accounted for 39.2% of total recorded landed weight (Figure 6, Table 6). Octopus landings accounted for 40.0% of the recording landings in 2021 (Figure 6, Table 6).

Fish accounted for 22.8% of total landings in 2010 and 28.2% of total landings in 2011 (Figure 6, Table 6). Fish accounted for 38.7% of landings in 2015 and 32.2% of landings in 2016 (Figure 6, Table 6). In 2019, Fish accounted for 64.1%, in 2020 Fish accounted for 33.3% of total landings, and in 2021 Fish accounted for 46.9% of total landings (Figure 6, Table 6).

In 2010, Fish accounted for 16.9% of the recorded weight (Figure 6, Table 6). For 2011, Fish landings were 23.4% of the recorded weight (Figure 6, Table 6). In 2015, Fish landings accounted for 49.0% of the total recorded weight and in 2016, the highest percentage for fish, 64.3% (Figure 6, Table 6). For 2019, Fish landings accounted for 39.7% of the weight of the recorded landings, and 44.6% in 2020 (Figure 6, Table 6). The Fish landings accounted for 46.5% of recorded weight (Figure 6, Table 6).

In 2016, one octopus was landed in our data resulting in a 0.05% of the total landings for the year (Figure 6, Table 6). Data collection occurred only during the month of January until February 6th. There is a nationwide regional closure for octopi fisheries on the southwest coast of Madagascar from December 15th to January 31st (Aina 2010). This was the only year that neither Fish nor Octopus were the highest landing percentages and the only year that the combined percentages did not exceed two-thirds of the total landings. However, these data represent only a portion of the town's fisheries from select brokers who export products mainly to European markets.

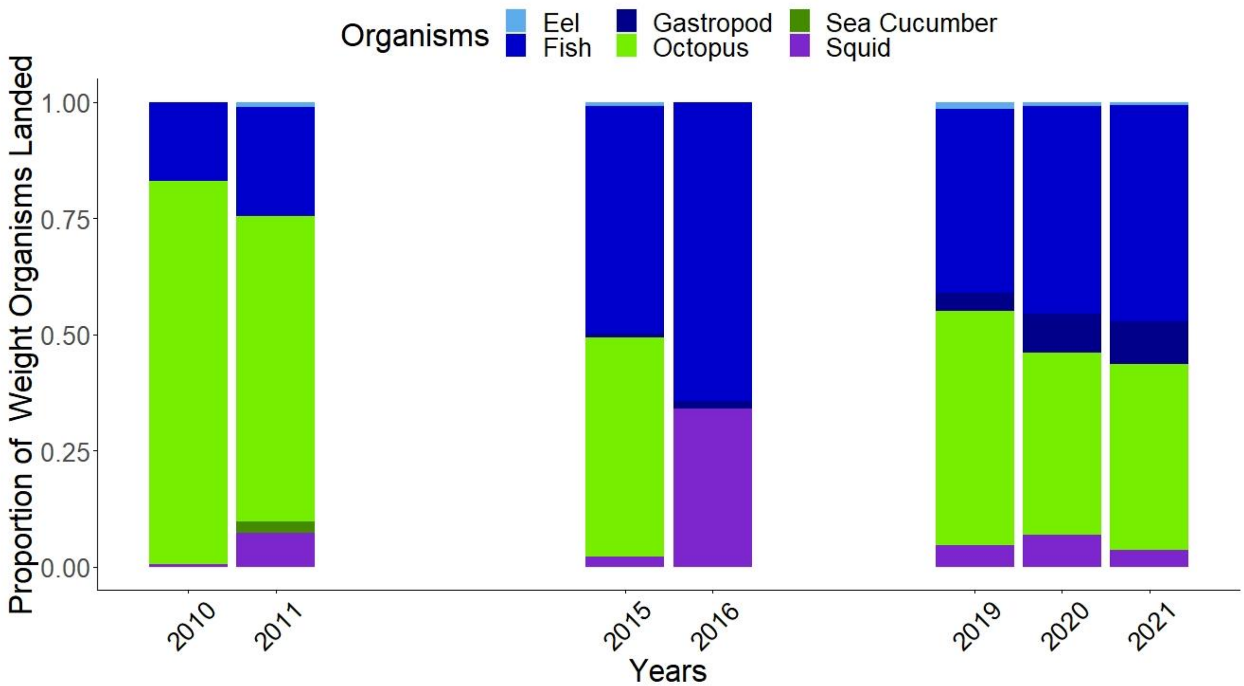


Figure 6. Proportional weight landed of main marine organisms (Eel, Fish, Gastropod, Octopus, Sea Cucumber, Squid) landed from the main fishing sites throughout all years of the dataset (2010- 2021). No landings were recorded 2012-2014 and 2017-2018.

Table 6. Total annual landings by count and weight (kg) of Octopus and Fish from the main fishing sites from 2010 - 2021. These totals only include survey data with both numerically valid count data and weights. For months included in each year, refer to Appendix Table G.

	2010	**2011**	**2015**	**2016**	**2019**	**2020**	**2021**
Fish Landings	899	1,506	2,608	620	2,968	770	10,258
Fish Total Weight (kg)	503.5	958.4	1,856.5	537.5	704.7	443	3,873.2
Octopus Landings	2,998	2,757	1,930	1	1,071	802	5,379
Octopus Total Weight (kg)	2,451.3	2,701.6	1,972.9	1	897.3	627.8	3,958.7

Fishing Methods

From 2020 to 2021, seven gear types were identified by fishermen harvesting organisms adjacent to Salary: Hand, Hook and line, Metal rod/Stick, Net, Spear, Spear Gun, and Other (Figure 7). There were no data collected on gear types for the marine organism category of Seahorse (Figure 7).

In reference to all of the fishing sites, Spears were used most frequently (n=1,398) to catch the six main organism categories and resulted in an average of 5.18±0.19 landings per trip (Figure 8). Hook and line were the second most utilized gear type (n=613) and 10.16±0.36 organisms were landed on average per trip. Spear guns (n=589) averaged 6.63±0.45 landings per trip (Figure 8). Nets (n=94) had the highest average landings for the gear types with 38.12±5.43 landings per trip. These four gear types were considered the main gear types for these fisheries (Figure 8).

The proportional frequency of gear usage and the resulting total of landings from the six main fishing sites were examined for variation (Figure 8). Nets and spear guns did show a proportional change when landing Fish (Figure 8). Nets were used for Fish only 9.5% of fishing trips but landed 30.8% of abundance of Fish in comparison to spears which were used on 8.3% of the fishing trips and landed 6.4% of abundance of Fish (Figure 8). Spears were used to land Gastropods for 15.9% of trips but resulted in the abundance of 28.9% landings of the Gastropods (Figure 8). Spears were used for fishing Sea Cucumbers for 68.4% of trips but resulted in the abundance of 87.5% of Sea Cucumbers landings (Figure 8).

When fishers used a net to land Fish (n=85 trips), they averaged 39±6 Fish per trip. These net trips landed significantly more Fish per trip than any other gear type ($p < 0.001$) but were not the most commonly used gear type (Figure 8). Hook and line (n=388) were the most commonly used gear for landing Fish and landed an average of 12±0.5 Fish (Figure 8). Spears were used most frequently to land Octopus (n=1243 trips) with an average landing of 4±0.1 per trip (Figure 8). Hook and line were used most frequently to land Squid (n=194 trips) and averaged 7±0.4 landings per trip (Figure 8). Hook and line resulted in the highest average landings of Gastropod (n=14 trips) with 25±4 per trip, however spear guns were used most frequently (n=115 trips) resulting in 9±1 average landings per trip (Figure 8).

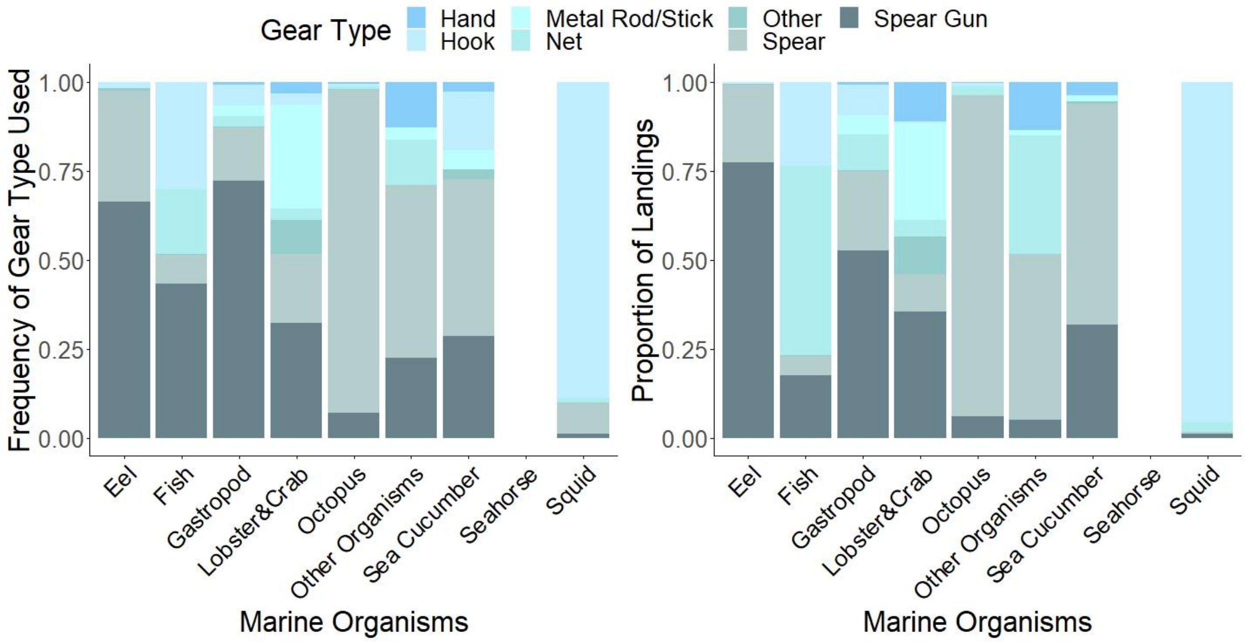


Figure 7. (Left) The proportional frequency of fishing trips that used each gear type (Hand, Hook, Metal Rod/Stick, Net, Other, Spear, Spear Gun) resulting in landings of each of the marine organism categories (Eel, Fish, Gastropod, Lobster/Crab, Octopus, Other Organisms, Sea Cucumber, Seahorse, and Squid) across all fishing sites. **(Right)** For each of the marine organism categories (Eel, Fish, Gastropod, Lobster/Crab, Octopus, Other Organisms, Sea Cucumber, Seahorse, and Squid) the proportional number of landings resulting from each gear type (Hand, Hook, Metal Rod/Stick, Net, Other, Spear, Spear Gun).

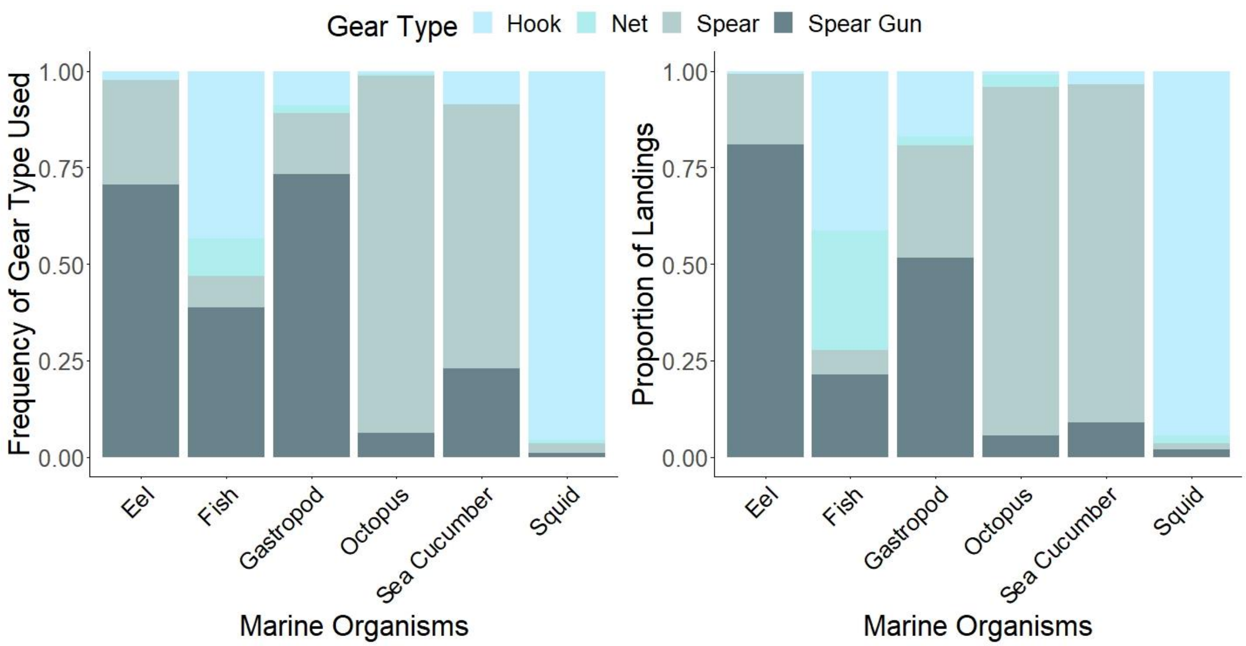


Figure 8. (Left) The proportional number of fishing trips that used the predominant gear types (Hook, Net, Spear, Spear Gun) resulting in landings of each of the marine organism categories (Eel, Fish, Gastropod, Octopus, Sea Cucumber, and Squid) across the main six fishing sites. **(Right)** For each of the marine organism categories (Eel, Fish, Gastropod, Octopus, Sea Cucumber, and Squid) the proportional number of landings resulting from each gear type (Hook, Net, Spear, Spear Gun).

Analysis of Potential Impact of Fisheries to MPA

Fish

Fish landing trends were similar for both Winter and Summer. For both seasons, we found significant increases in the number of landings over time, but no significant differences were found for either the total weight of landings or the average weight of the individual fish landed, which remained stable throughout the time series (Figure 9, Figure 10, Table 7, Table 8). For the Winter months, we found landings significantly increased ($p = 0.0226$; Figure 9, Table 7), with an increasing slope of 1.12 (Figure 9, Table 7). There were no significant differences for either the total weight of the landings ($p = 0.65$, Figure 9) or the average individual weight of the landings ($p=0.76$, Figure 9). Landings of Fish significantly increased during the Summer months ($p<0.001$, Table 8, Figure 10), with an increasing slope of 1.01 (Figure 10, Table 7). Again, there were no significant differences in Summer for the total weight of landings ($p=0.92$, Figure 10, Table 8) or the average weight of the individual Fish ($p=0.76$, Figure 10, Table 8).

For the Winter months, when the individual sites were analyzed, we saw that Andamabe (slope= 0.448, $p = 0.016$), Anjokozoko (slope= 1.233, $p<0.001$), Belamera (slope= 1.053, $p = 0.001$), Nandoa (slope= 1.443, $p<0.001$), and Nanohofa (slope= 1.132, $p<0.001$) followed the significant increase in landings as seen when all sites were combined, whereas Anananose (slope= 0.007, $p=0.716$) landings did not significantly increase over time (Figure 9, Table 7). Differing from the overall findings, landings from both Andamabe (slope= -0.153, $p<0.001$) and Nanohofa (slope= -0.070, $p = 0.008$) significantly decreased in average individual weight (Figure 9, Table 7). Furthermore, the weight of landings per trip from Andamabe significantly increased over time (slope= 0.333, p=0.008) (Figure 9, Table 7).

For the Summer months, the number of landings from Anananose (slope= 1.035, p=0.008), Andamabe (slope= 1.283, p<0.001), and Anjokozoko (slope= 1.086, p<0.001) significantly increased over time similar to the combined data (Figure 10, Table 8). However, Belamera (slope= -0.973, p= 0.004) significantly decreased in total number of landings per trip and both Nandoa (slope= 1.021, p= 0.746) and Nanohofa (slope= 1.019, p= 0.210) remained constant over time (Figure 10, Table 8). We also saw an increase in the total weight of landings that were sourced from Andamabe (slope =0.504, p= 0.035) but not from any of the other sites (Figure 10, Table 8). The average weight per fish from each of the sites landed during the summer months did not change over time (Figure 10, Table 8).

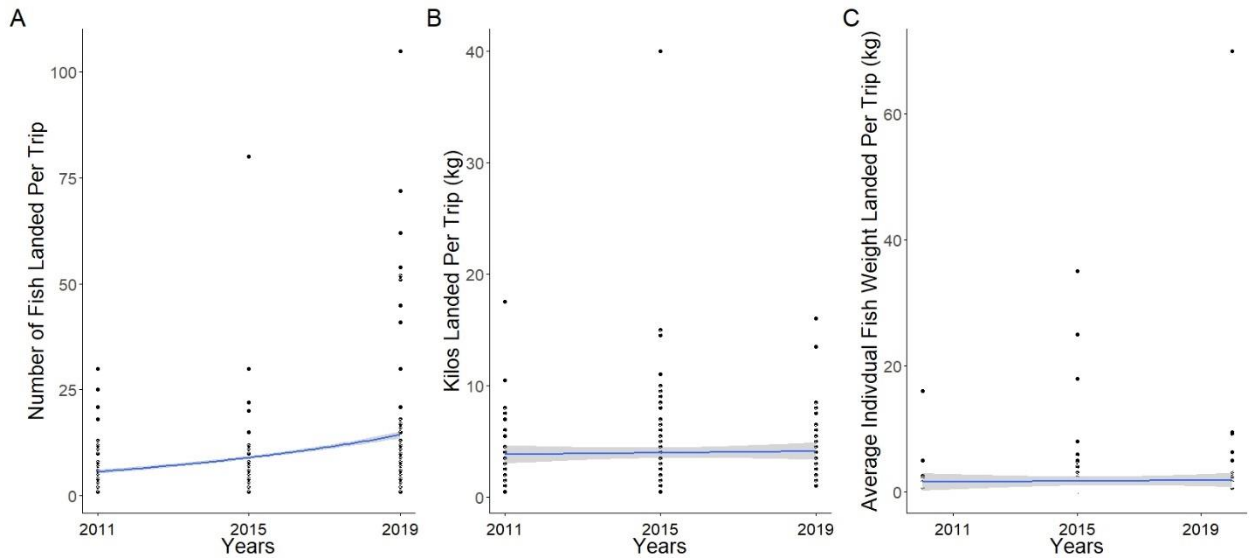


Figure 9. Temporal analysis of landings of Fish in Winter months (July, August, and September) within the six main fishing sites during 2011, 2015, and 2019. A) Number of Fish landed per trip via a generalized linear model with a Poisson error distribution (slope= 1.124, p<0.001). B) Total weight (kg) of Fish landed per trip (slope = 0.037, p= 0.654). C) Average weight of individual Fish caught per trip (kg) (slope = -0.003, p= 0.914). Gaussian linear regressions were used to test for significant changes over time of both total Fish weight and average individual Fish weight. Errors bars represent a 95% confidence interval.

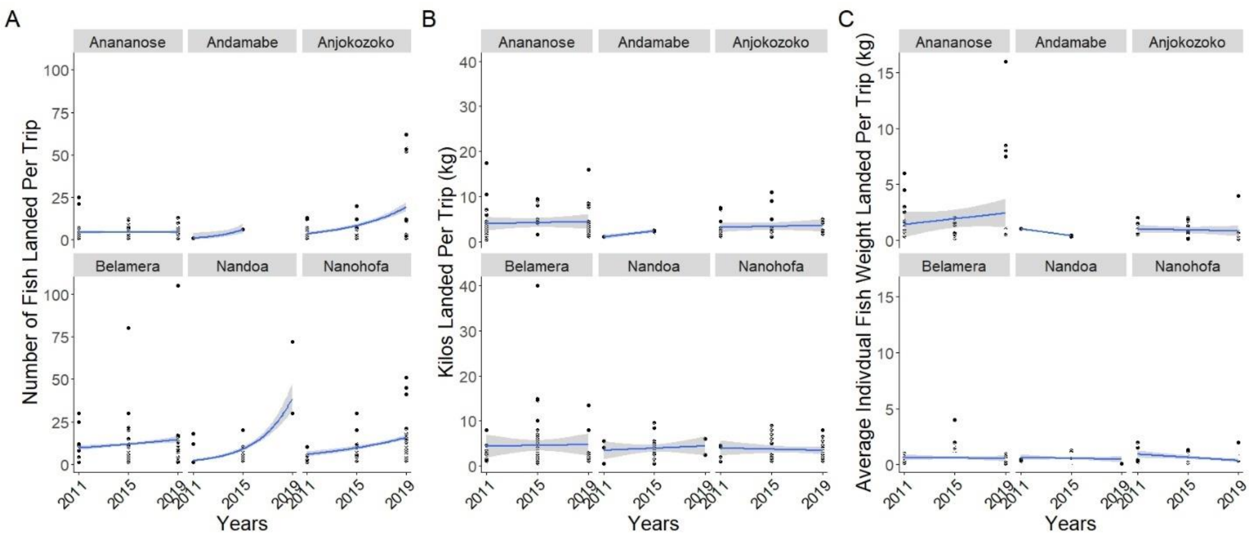


Figure 10. Temporal analysis of landings of Fish in Winter months (July, August, and September) within the six main fishing sites during 2011, 2015, and 2019. A) Number of Fish landed per trip via a generalized linear model with a Poisson error distribution. B) Total weight (kg) of Fish landed per trip. C) Average weight of individual Fish caught per trip (kg). Gaussian linear regressions were used to test for significant changes over time of both total Fish weight and average individual Fish weight. Errors bars represent a 95% confidence interval. See Table 7 for summary statistics.

Table 7. Summary statistics of changes in Fish landings, caught from each of the six main fishing sites as well as all sites combined, during Winter (July, August, and September) over time (2011 to 2019). A generalized linear model with a Poisson error distribution was used to analyze number of Fish landed. Gaussian linear regressions were used to test for significant changes over time of both total Fish weight and average individual Fish weight. "*" indicates significance ($p<0.05$).

	Number Landed (Poisson)			**Weight Landed**		**Average Individual Weight**	
	Slope (log)	*Slope (exp)*	*p Value*	*Slope*	*p Value*	*Slope*	*p Value*
Anananose	0.007	1.007	0.716	0.058	0.693	0.127	0.261
Andamabe	0.448	1.565	0.016*	0.333	0.008*	-0.153	<0.001*
Anjokozoko	0.209	1.233	<0.001*	0.056	0.631	-0.023	0.564
Belamera	0.052	1.053	0.001*	0.045	0.871	-0.012	0.687
Nandoa	0.367	1.443	<0.001*	0.121	0.607	-0.022	0.475
Nanohofa	0.124	1.132	<0.001*	-0.067	0.603	-0.070	0.008*
All Sites	0.117	1.124119	<0.001*	0.037	0.654	-0.004	0.914

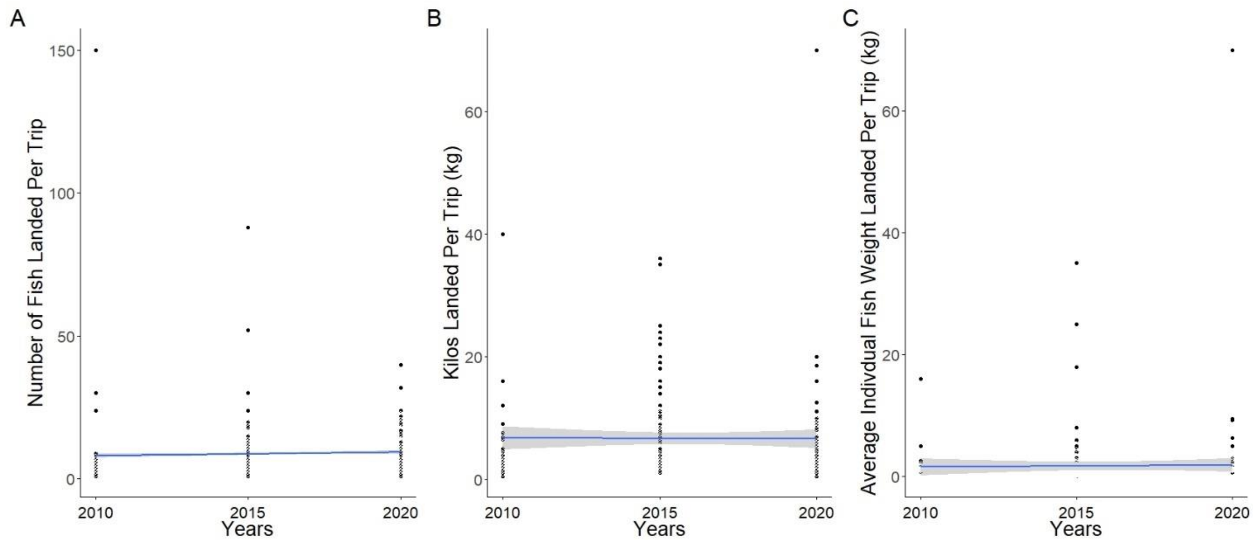


Figure 11. Temporal analysis of landings of Fish in Summer months (November and December) within the six main fishing sites during 2010, 2015, and 2020. A) Number of Fish landed per trip via a generalized linear model with a Poisson error distribution (slope = 0.015, p= 0.023). B) Total weight (kg) of Fish landed per trip (slope = -0.015, p= 0.919). C) Average weight of individual Fish caught per trip (kg) (slope = 0.032, p= 0.763). Gaussian linear regressions were used to test for significant changes over time of both total Fish weight and average individual Fish weight. Errors bars represent a 95% confidence interval.

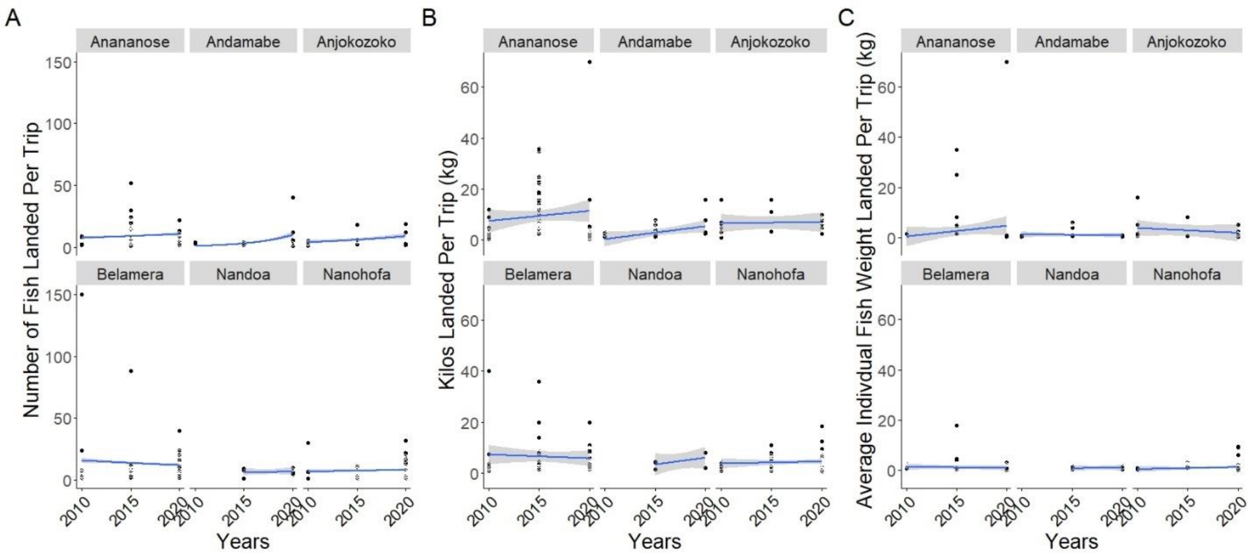


Figure 12. Temporal analysis of landings of Fish in Summer months (November and December) within the six main fishing sites during 2010, 2015, and 2020. A) Number of Fish landed per trip via a generalized linear model with a Poisson error distribution. B) Total weight (kg) of Fish landed per trip. C) Average weight of individual Fish caught per trip (kg). Gaussian linear regressions were used to test for significant changes over time of both total Fish weight and average individual Fish weight. Errors bars represent a 95% confidence interval. See Table 8 for summary statistics.

Table 8. Summary statistics of changes in Fish landings, caught from each of the six main fishing sites as well as all sites combined, during Summer (November and December) over time (2010 to 2020). A generalized linear model with a Poisson error distribution was used to analyze number of Fish landed. Gaussian linear regressions were used to test for significant changes over time of both total Fish weight and average individual Fish weight. ”*” indicates significance ($p<0.05$).

	Number Landed (Poisson)			**Weight Landed**		**Average Individual Weight**	
	Slope (log)	*Slope (exp)*	*p Value*	*Slope*	*p Value*	*Slope*	*p Value*
Anananose	0.035	1.035	0.008*	0.397	0.314	0.429	0.212
Andamabe	0.250	1.283	<0.001*	0.504	0.035*	-0.032	0.735
Anjokozoko	0.083	1.086	<0.001*	0.036	0.892	-0.190	0.427
Belamera	-0.027	-0.973	0.004*	-0.148	0.587	-0.053	0.563
Nandoa	0.021	1.021	0.746	0.533	0.293	0.042	0.745
Nanohofa	0.019	1.019	0.210	0.075	0.562	0.080	0.293
All Sites	0.015	1.015	0.023*	-0.015	0.919	0.032	0.763

Octopus

For the Octopus fisheries when all sites were aggregated, Winter landings significantly decreased by number (slope= - 0.97, p<0.001, Figure 11, Table 9) and total weight landed (slope= -0.12, p<0.001, Figure 11, Table 9) per trip over time within the six main fishing sites. However, there was no significant change in the average weight of individual Octopus landed during Winter over time (p=0.786, Figure 11, Table 9). Summer Octopus catches remained stable over time; the number of Octopus landed (p= 0.77), the total weight landed (p= 0.95), and the average individual Octopus weight (p= 0.32) did not significantly differ from 2011-2019 (Figure 11, Figure 12, Table 10).

For the Winter months, when the individual sites were analyzed for trends in Octopus landings, only the sites of Anananose and Belamera followed similar trends. For the overall decrease in the number of landings Anananose showed a significant decrease (slope= -0.945, p= 0.001), as well as Belamera (slope= -0.971, p= 0.023) (Table 9, Figure 14). The sites of Andamabe (slope= -0.967, p= 0.416), Anjokozoko (slope= -0.970, p= 0.296), Nandoa (slope= -0.996, p= 0.866), and Nanohofa (slope= -.0995, p= 0.709) remained constant. For the overall weight trends, Anananose significantly decreased (slope= -0.339, p= 0.045) along with Belamera (slope=-0.241, p<0.001). Similar to the number of Octopus landed, Andamabe (slope= -0.123, p= 0.370), Anjokozoko (slope= -0.104, p= 0.280), Nandoa (slope= 0.067, p= 0.292), and Nanohofa (slope= -0.010, p= 0.895) (Table 9, Figure 14). The average individual weight of Octopus landed from Belamera also were significantly smaller over time (slope=-0.049, p=0.006) (Figure 14, Table 9).

There were site-specific differences in the Octopus fisheries during the Summer months. Anananose and Andamabe both had significant change to the total number of Octopus landed. Anananose (slope= 0.962, p<0.001) significantly decreased and Andamabe (slope= 1.050, p= 0.001) significantly increased in the number of landings (Table 10, Figure 16). The sites of Anjokozoko (slope= -0.080, p= 0.259), Belamera (slope= -0.056, p= 0.206), Nandoa (slope= -0.034, p= 0.736), and Nanohofa (slope= -0.118, p= 0.106) remained constant for the total number of landings per trip (Table 10, Figure 16). Andamabe also significantly increased (slope= 0.140, p= 0.025) in the total weight of landings (Table 10, Figure 16). The sites of Anananose (slope= -0.080, p= 0.259), Anjokozoko (slope= 0.218, p= 0.316), Belamera (slope= -0.056, p= 0.206), Nandoa (slope= -0.034, p= 0.736), and Nanohofa (slope= -0.118, p= 0.106) remained constant for the total number of landings per trip (Table 10, Figure 16). Only, Belamera significantly decreased (slope=-0.026, p=0.039) in average individual body weight, with all other sites showing no significant trends (Figure 16, Table 10).

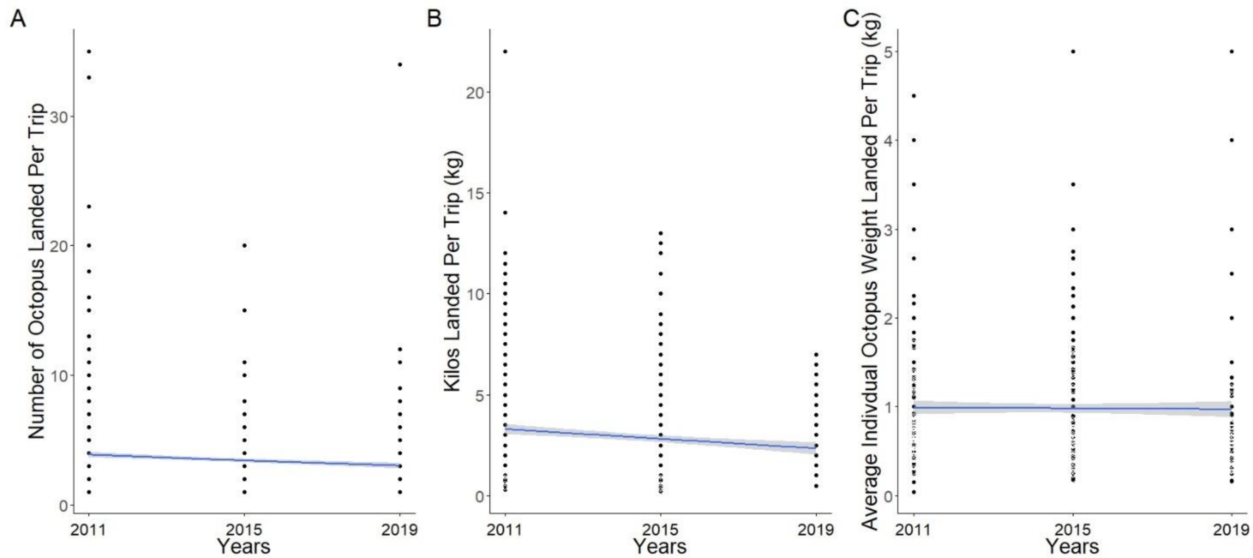


Figure 13. Temporal analysis of landings of Octopus in Winter months (July, August, and September) within the six main fishing sites during 2011, 2015, and 2019. A) Number of Octopus landed per trip via a generalized linear model with a Poisson error distribution (slope= -0.969, p< 0.001). B) Total weight (kg) of Octopus landed per trip (slope= -0.1194, p< 0.001). C) Average weight of individual Octopus caught per trip (kg) (slope=-0.002, p= 0.786). Gaussian linear regressions were used to test for significant changes over time of both total Octopus weight and average individual Octopus weight. Errors bars represent a 95% confidence interval.

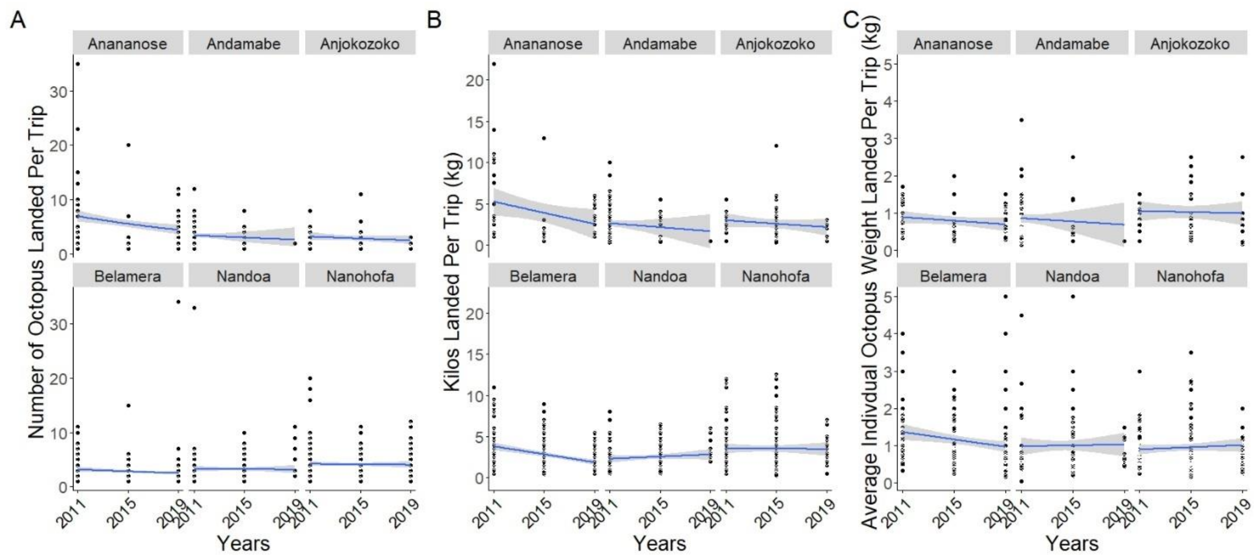


Figure 14. Temporal analysis of landings of Octopus in Winter months (July, August, and September) within the six main fishing sites during 2011, 2015, and 2019. A) Number of Octopus landed per trip via a generalized linear model with a Poisson error distribution. B) Total weight (kg) of Octopus landed per trip. C) Average weight of individual Octopus caught per trip (kg). Gaussian linear regressions were used to test for significant changes over time of both total Octopus weight and average individual Octopus weight. Errors bars represent a 95% confidence interval. See Table 9 for summary statistics.

Table 9. Summary statistics of changes in Octopus landings, caught from each of the six main fishing sites as well as all sites combined, during Winter (July, August, and September) over time (2011 to 2019). A generalized linear model with a Poisson error distribution was used to analyze number of Octopus landed. Gaussian linear regressions were used to test for significant changes over time of both total Octopus weight and average individual Octopus weight. "*" indicates significance (p< 0.05).

	Number Landed (Poisson)			**Weight Landed**		**Average Individual Weight**	
	Slope (log)	*Slope (exp)*	*p Value*	*Slope*	*p Value*	*Slope*	*p Value*
Anananose	-0.057	-0.945	0.001*	-0.339	0.045*	-0.024	0.155
Andamabe	-0.034	-0.967	0.416	-0.123	0.370	-0.022	0.584
Anjokozoko	-0.031	-0.970	0.296	-0.104	0.280	-0.007	0.810
Belamera	-0.030	-0.971	0.023*	-0.241	<0.001*	-0.049	0.006*
Nandoa	-0.004	-0.996	0.866	0.067	0.292	0.006	0.851
Nanohofa	-0.005	-0.995	0.709	-0.010	0.895	0.014	0.396
All Sites	-0.031	-0.970	<0.001*	-0.119	<0.001*	-0.002	0.786

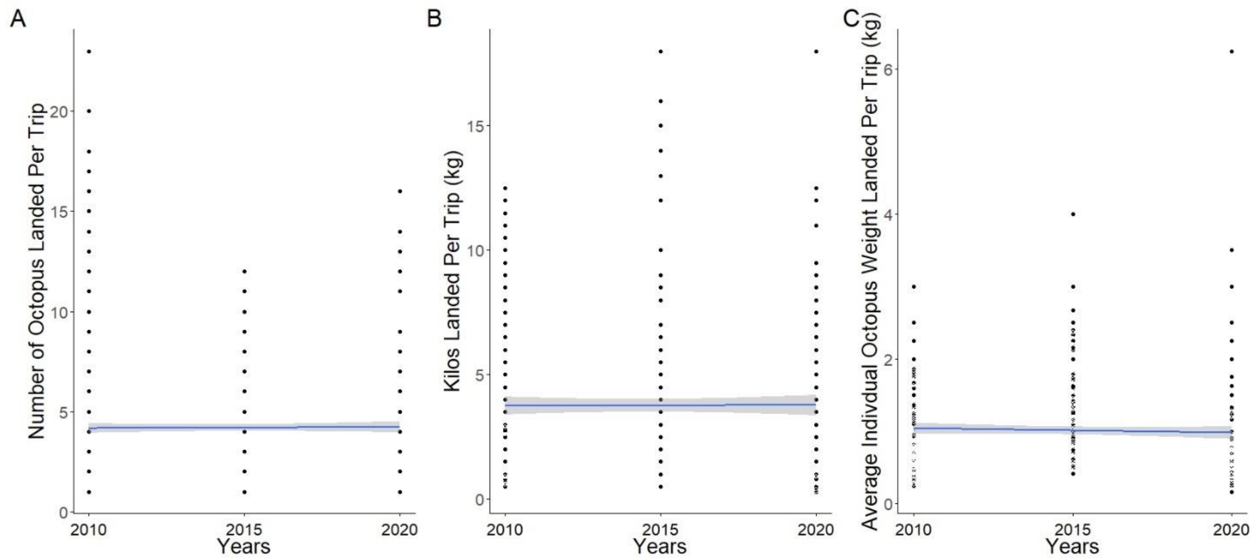


Figure 15. Temporal analysis of landings of Octopus in Summer months (November and December) within the six main fishing sites during 2010, 2015, and 2020. A) Number of Octopus landed per trip via a generalized linear model with a Poisson error distribution (slope= 1.001, p= 0.766). B) Total weight (kg) of Octopus landed per trip (slope = 0.002, p= 0.951 C) Average weight of individual Octopus caught per trip (kg) (slope = -0.006, p=0.320). Gaussian linear regressions were used to test for significant changes over time of both total Octopus weight and average individual Octopus weight. Errors bars represent a 95% confidence interval.

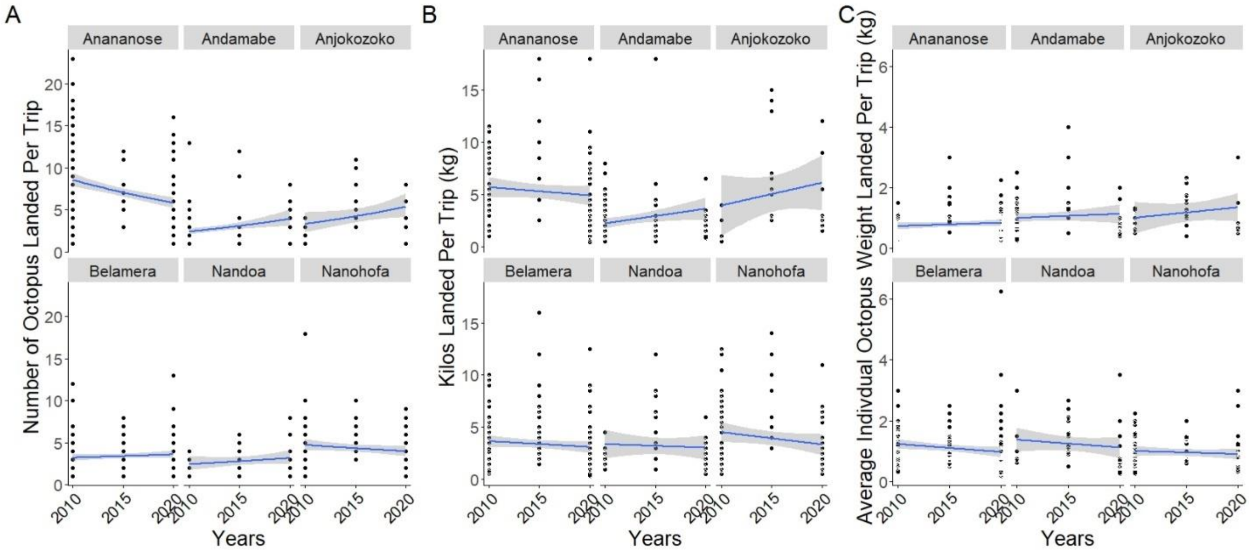


Figure 16. Temporal analysis of landings of Octopus in Summer months (November and December) within the six main fishing sites during 2010, 2015, and 2020. A) Number of Octopus landed per trip via a generalized linear model with a Poisson error distribution. B) Total weight (kg) of Octopus landed per trip. C) Average weight of individual Octopus caught per trip (kg). Gaussian linear regressions were used to test for significant changes over time of both total Octopus weight and average individual Octopus weight. Errors bars represent a 95% confidence interval. See Table 10 for summary statistics.

Table 10. Summary statistics of changes in Octopus landings, caught from each of the six main fishing sites as well as all sites combined, during Summer (November and December) over time (2010 to 2020). A generalized linear model with a Poisson error distribution was used to analyze number of Octopus landed. Gaussian linear regressions were used to test for significant changes over time of both total Octopus weight and average individual Octopus weight. "*" indicates significance (p< 0.05).

	Number Landed (Poisson)			**Weight Landed**		**Average Individual Weight**	
	Slope (log)	*Slope (exp)*	*p Value*	*Slope*	*p Value*	*Slope*	*p Value*
Ananarose	-0.038	-0.962	<0.001*	-0.080	0.259	0.011	0.193
Andamabe	0.049	1.050	0.001*	0.140	0.025*	0.013	0.453
Anjokozoko	0.048	1.049	0.052	0.218	0.316	0.034	0.372
Belamera	0.011	1.011	0.219	-0.056	0.206	-0.026	0.039*
Nandoa	0.027	1.027	0.258	-0.034	0.736	-0.026	0.377
Nanohofa	-0.017	-0.983	0.117	-0.118	0.106	-0.010	0.427
All Sites	0.001	1.001	0.766	0.002	0.951	-0.006	0.320

Table 11. Statistics for Figures 9, 10, 11, and 12. A generalized linear model with a Poisson error distribution was used to analyze the count data represented in the first panel of all three figures. Poisson for count data, A Gaussian linear regression was used to test the significance of the findings for the total and average weight. "*" indicates significance (p<0.05).

	Number Landed (Poisson)			**Weight Landed**		**Average Individual Weight**	
	Slope (log)	*Slope (exp)*	*p Value*	*Slope*	*p Value*	*Slope*	*p Value*
Summer Fish	0.015	1.015	0.023*	-0.015	0.919	0.032	0.763
Summer Octopus	0.001	1.001	0.766	0.002	0.951	-0.006	0.320
Winter Fish	0.117	1.124	<0.001*	0.037	0.654	-0.004	0.914
Winter Octopus	-0.031	-0.969	<0.001*	-0.119	<0.001*	-0.00229	0.786

Discussion

Madagascar is a hot spot for conservation research, but the phonetic nature of the native language can be confusing for those unfamiliar. Some NGOs working in Madagascar have publications that can help translate the native phenetic language to English, (e.g., Gough et al. 2009), but there are still not enough resources available for non-French or -Malagasy speaking scientists. This study made use of opportunistically collected data through the brokers and is an example of what is possible with the fragmented data that comes with opportunistically collected data. This study also illustrates the limitations of this type of incomplete data collection. The phonetic grouping and translation work executed within this thesis, as documented in Appendix Tables A-E, can help not only streamline the continuing analyses of Salary's fisheries, but serve as a linguistic resource for other southwestern Malagasy towns.

Fishing pressure is one of the major sources of anthropogenic impacts to coastal ecosystems (Stewart et al. 2010), but it can also fuel local coastal economies and livelihoods. Fisheries monitoring starts by understanding the basics of the fisheries. In the case of the fisheries in Salary, we found 51 unique fishing sites with the majority of fishing (63.3%) occurring in six main fishing sites. Belamera, Nanohofa, Ananose, Andamabe, Anjokozoko, and Nandoa (Figure 1). Identifying the locations of the fishing is the first step in examining the extent of how the community's fishers are interacting with the environment. Ratsimbazafy et al. (2016) identified the majority of fishing sites in MPA Velondriake by Global Positioning System (GPS). The data for these analyses were opportunistically collected and are only from one town, but GPS locations of all fishing sites within MPA Soariake were documented. Ratsimbazafy et al. (2016) documented 312 fishing sites in MPA Velondriake utilized by 13 different villages indicating that there are more fishing sites in MPA Soariake than those used by Salary's fishers.

We investigated the annual consistency of fishing sites that were visited the most frequently (Figure 3). Examining the annual consistency showed that the Salary fishers are not annually rotating where they are fishing, but instead that each of these six sites are consistently under fishing pressure (Figure 3). While the percentages of each year's site visits vary, the specific differences in these variations might vary due to when data were collected for that year. These data were sporadically collected during different months and the number of collection days varied from year to year (see Appendix Table G). The most inclusive year of data collection was 2021(see Appendix Table G) with 10 months and the least inclusive year was 2016 with only 2 months.

Specific fishing spots can be highly frequented for a multitude of reasons including productivity, location, and previous catch success. The physical location of the six most visited fishing sites were further investigated (Belamera, Nanohofa, Anananose, Andamabe, Anjokozoko, and Nandoa) for potential reasons why they were highly frequented (Figure 2). In a community that is confined to lakas or walking, distance of travel can be an influencing factor to the fishers. All six of the main fishing sites are relatively close to Salary, with the furthest about 5 km away. Andamabe is the closest site at 2 km away and the only one of the six that is not exposed to the open ocean (Table 2, Figure 1). The location of the fourth most visited site, Andamabe (830 trips), lacks the same type of exposure to currents and possible fish congregations as the other five fishing sites might have so there must be a different reason for the number of fishing trips it attracts. Andamabe's distance to shore, as well as the reef stretching between shore and Andamabe's boundaries, might allow increased access to fishers as visiting Andamabe might not require a laka during low tide as Humber et al. (2006) observed in a MPA north of Salary. Humber et al. (2006) recorded a few reefs that were able to be fished by women and children during spring tides when the water levels are low enough for the reef to be walkable, similar to Andamabe. There is documentation of women landing Fish, Squid, and Octopus from Andamabe during 2010, 2011, and 2015. It also is possible that women and children that may have ventured out during spring tides in 2020 and 2021 did not sell their landings to our collectors. I would like to acknowledge that gear data were the most limited of these analyses and further collection might reveal different patterns than what is documented in 2020-2021.

The most common landed marine organism categories from the Salary region of Soariake were Eel, Fish, Gastropod, Octopus, Sea Cucumber, and Squid, with Octopus and Fish landed the most. Octopus historically has been one of the highest landed and most exported organisms in Madagascar (Humber et al. 2006; Aina and Arnason 2010; Raberinary and Benbow 2012; Westerman and Benbow 2014; Oliver et al. 2015), so it was expected that Octopus would dominate the landings from MPA Soariake. However, we found a proportional shift in the highest landed organisms from the beginning of the dataset to the more recent years (Figure 3) contradicting the historic findings. As hypothesized, Octopus dominated all other organisms landed in 2010 and 2011 (Figure 4) and continued to be high in 2015 but was not the most landed category again until 2019 (Figure 5). In should be noted that in 2016, when only one Octopus was landed, the data were collected during January and February when the Octopus fishery has a nationwide closure, December through mid-January (Aina and Arnason 2010). Fish was the highest landed category for every year that Octopus was not the highest.

Our findings showed an overall significant decrease in the total number of Octopus landings ($p < 0.001$) and total weight of Octopus landings ($p < 0.001$) in the Winter months of July, August, and September and no significant changes in the Summer months of November and December ($p=0.766$, $p=0.951$) for all of the sites combined. However, at the fishing site of Belamera, we found significantly decreased average body size in both Summer and Winter fishing (Figure 14, Table 9). Additionally, during the Winter months at Belamera, there was a significant decrease in the total number being landed and the total weight landed (Figure 14, Table 9). These trends indicate that Belamera might be frequented to the point of overfishing but without further detail (e.g., knowledge of species of octopus) in the level of data collection, we cannot conclusively say overfishing has or is occurring.

In Madagascar, *Octopus cyanea* is considered to be the most dominant species of octopus within the fisheries (Andriamaharo et al. 2009). The other two species found in these fisheries are *O. aegina,* and *O. macropus* (Andriamaharo et al. 2009). Examining the *O. cyanea* life cycle in southwest Madagascar, there are two peaks of recruitment that occur 5-6 months after spawning, one in June and the second in December, as indicated by an increase of juvenile landings in Andavadoaka, a town approximately 50-km north of Salary (Raberinary and Benbow 2012). With a new cohort of juvenile octopus ready to be fished every December due to the recruitment period, the population could be considered relatively consistent within our Summer months from year to year. With the other recruitment period occurring one month prior to the start of our Winter landings data, it is possible that the decrease in landings in Winter could be due to higher effort in June when recruitment of the population is at its peak. The Vezo may target and land more octopus during June making landing octopus more difficult in the subsequent months (July, August, and September). The peaks of recruitment and consequential effort can partially explain why landings decreased through time (Figure 11). The number of landings can also vary due to interannual recruitment differences from year to year. For both overall temporal analyses, the average size of the individual octopus landing per trip was about 1 kg, consistent with *O. cyanea* at about six months of age, indicating that the majority of the landings were these new juveniles (van Heukelem 1976). Further investigation is needed to know if decreases in Octopus landings is due to their population size shrinking or a difference in timing of peak recruitment into the fishery versus when landing data were collected. For the fishing site of Belamera, further investigation could determine if Belamera is experiencing any overfishing as both site-specific analyzes showed significant decreases in the average weight of Octopus being landed per trip. Belamera might benefit from rotational closures that has been experimented with as a way of managing the fishery in other MPAs (Humber et al. 2006).

Madagascan fishers are generally opportunistic. In the past, the demand for octopus in the area has been high as it could be dried and sold locally as well as exported to foreign markets. With a historically higher demand, the octopi's populations might be lower (Aina and Arnason 2010), causing the opportunistic nature of the Salary fishers to shift to target, and thus land, more fish.

For the category of Fish, there are not just three species that dominate the fishery like in the Octopus fishery, but a diverse list of possible species (see Appendix Table E). This variability limits the amount of confidence of these analyses, as well as the conclusions that can be drawn. Proportionally, we see that there is a shift towards Fish in the catch data, but what does that mean for the impacts to the fishery? In both of the overall temporal analyses for Fish, there is a significant increase in the number of Fish caught throughout the years (Summer $p=0.0226$; Winter $p< 0.001$). However, there is not a significant change in the total weight of Fish being landed (Summer $p=0.919$; Winter $p=0.654$) nor in the average individual size of the landings (Summer $p=0.763$; Winter $p=0.914$; Table 7). An increase in the number of Fish landings could be an indicator of overfishing, but on its own is not conclusive evidence. We also found a decrease in average body size with Fish landings from Andamabe ($p< 0.001$) and Nanohofa ($p= 0.008$) for Winter Fish landings (Figure 10, Table 7), but this was not consistent with Summer Fish landings (Figure 12, Table 8). A decline in average body size or weight could also indicate that larger individuals have been removed indicating that the population structure of the communities have changed (Haedrich and Barnes 1997), also known as fishing down marine food webs. Fishing down marine food webs can lead to ecosystem collapse, causing trophic levels to become unbalanced with disproportionate pressure (Branch et al. 2010). However, in this study, without confirmation of species landed, we do not know if these changes are indications of differences in landings within trophic levels or a result of something else (e.g., climate change, sampling design). Due to this inconclusive evidence, it is unknown if fishing down marine food webs is occurring.

It is important to remember that the data used in this analysis consist of products landed and collected by the "sous-collectors" or brokers who then export them to European-based markets. These data do not account for all landings by each person, meaning there are organisms landed that are not sold to the brokers and even some fishers that may not interact with these brokers at all. For example, even within these survey data, there are some recordings of other landings, but as they were not quantified, they were excluded from these analyses (see Appendix Table A).

Salary, like many other towns in Madagascar, has been experimenting with different management styles on a local level to determine what might work best for their needs (M. Baker-Médard, personal comm.). Some of the management styles in southwest Madagascar include species-specific fishery closures, like with octopus (Aina and Arnason 2010; Raberinary and Benbow 2012; Oliver et al. 2015), and others focus on location-based closures (Humber et al. 2006; Harris 2007). Oliver et al. (2015) found that fishing effort increased directly following a species-specific closure in Velondriake, an MPA/LMMA that lies just north of MPA/LMMA Soariake. Humber et al. (2006) saw an increase in effort for octopus fishing after a no-take zone (NTZ) of MPA/LMMA Velondriake, Nosy Fasy, reopened. Salary has tried to implement a NTZ in Anjokozoko, one of the main fishing sites as determined by this analysis. While there are no publicly available data or way to corroborate the exact timing of closures in Anjokozoko at this time, it is known that Anjokozoko has been closed to fishing for at least some period of time (M. Baker-Médard, personal comm.). It could be possible that, like with Nosy Fasy, fishers concentrate effort in areas that are rotational NTZs or have been NTZs in the past because NTZs are typically established in productive areas (Sanchirico et al. 2006). There are fluctuations between the earlier and later years in the data with the proportional amount of visits to Anjokozoko peaking at 7.9% between 2010-2016 and a high of 16.2% for 2019-2021. It is possible that the earlier years had limited visitations because of closures, but that is unconfirmed. One indication of a closure of Anjokozoko could be that it was not visited in February in any of the years, yet landings occurred for the other sites in February of 2016 and 2021. We did not have any recorded data for 2016 after February, but in March of 2021, there were 20 recorded trips to Anjokozoko. Any closures that were portions of one or multiple months would be hard to identify within these data without outside confirmation. Gathering exact closure dates, both past and future, is a key focus for future research regarding these data.

The reefs where Salary fishers fish are more conducive to those gear types that are predominantly used. For fishers, fruitful fishing has a favorable catch per unit effort (CPUE) ratio. This means that for low amounts of effort or time spent fishing, there is a high number of landings. While the CPUE ratio for using nets is more favorable, used on 18.0% of trips, and accounting for 53.1% of landings, spear guns (43.4%) and hook and line (30.2%) were used much more frequently (Figure 6). While we do not have details on each of the types of nets used, Gough et al. (2009) suggests that many of the nets that are used by Vezo are gill nets, catching fish that are drawn in by the splashes made by the fishers slapping the water with sticks and then becoming entrapped and unable to pass through the netting. Depending on the net type used, it could include multiple people in the laka or even multiple lakas (Gough et al. 2009). Spear and spear guns allow more control over what marine organisms are landed. The coral and rocky bottoms allow hidings places that marine organisms can take advantage of to avoid capture. Hook and Line can be deployed from the boat and only needs one fisher as they would not leave the boat. The gill nets, requiring more than one fisher, can snag and tear during deployment or retrieval, adding expenses or loss of fishing days to the fisher for repairing nets. The Vezo have lived off the sea for many years and will use gear types that are more conducive to the places they are fishing and the potential profits that can be made.

MPA/LMMA Soariake as defined by the IUCN allows the use of the resources within its boundaries, but only in a sustainable manner (Table 1, Barnes and Rawlinson 2009). By analyzing the annual temporal trends of the most landed marine organism categories, we aimed to see if the fishing inside the boundaries of MPA Soariake is sustainable. It should be noted that while we examined the trends from one fishing town, Salary's harvesters are not the only ones who have access to and visit these reef sites. For example, fishers from the town of Tsiandamba, just south of Salary, also visit some of these sites (unpublished data, see Appendix Figure A). Another source of marine organism removal from these waters is the international fishing vessels that have access in Madagascar's EEZ due to government level decisions (Carver 2019). While foreign fishing vessels are not supposed to fish within 12 nautical miles of the shore, they have been documented doing so and even fishing within two more northern MPAs, Barren Islands and Ambodivahibe, from 2012 to 2020 indicating that these restrictions are not always followed (White et al. 2022).

Edgar et al. (2014) describes five key factors that can help create a successful MPA: no take, well enforced, old (>10 years), large (>100km^2), and isolated by geographical features. Edgar et al. (2014) continues to say that at least four of the five factors are typically present for a successful MPA. MPA Soariake has been following the MPA guidelines for more than 10 years and is greater than 100km^2, but it is not isolated or entirely a no take MPA. The level of enforcement within MPA Soariake is unknown at this time. The cultural needs and habits of the Vezo people prevent a large no take area, instead requiring a multi-zoned MPA that allows fishing in some areas. Most studies evaluating the timeline of effectiveness of MPAs are usually performed on MPAs that allow no or extremely limited fishing rather than the more open fisheries that are seen in this study (Guidetti et al. 2008; García-Rubies et al. 2013; Fraser et al. 2019). Since this study did not have a NTZ for comparison to previous studies like Guidetti et al. (2008), García-Rubies et al. (2013), and Fraser et al. (2019), ten years may not be enough of an ecological time scale to interpret MPA effectiveness.

Within these analyses, one site out of the six showed signs of potential overfishing for one of the two marine organism categories that were temporally investigated, octopus fishing in Belamera. With inconclusive evidence of trends of either overfishing or ecosystem recovery for both Octopus and Fish fishing from Anananose, Andamabe, Anjokozoko, Nandoa, and Nanohofa or all sites combined, it appears to be too soon to know how the establishment of the MPA is impacting the fishing reefs of Salary. These fisheries are not a complete inventory of all the marine organisms being landed from the reefs which may also provide more information about trends in the area. While 11 years might be enough time for an ecosystem to rebound without any fishing, it appears more years are needed or more holistic data collection from all fisheries with actively fished areas to more fully understand if the MPA is impacting the area. An evaluation too soon after a MPA is established may result in premature non-significant results (Guidetti et al. 2008) and probability of positive impacts of an MPA only increases with time (Fraser et al. 2019).

Limitations of This Study

This study has many limitations to the information it provides. The source of these data is limited to exporters, primarily focused on the European market. The landings that are sold to Asian exporters, a market than can differ in demand and thus influence prices, was not included. It is also unknown which exporting market has a higher demand, which would influence how fishers might sell their catch for more profit or how that would change the initial intentions of the fishers (e.g., location and methods of fishing). It is unknown if the data collection was consistent throughout all years of the data. No year of data collection includes data from all twelve months. It is unclear if data were recorded every time the fishers sold landings to these town brokers or if data were more haphazardly collected based on convenience to the local brokers.

Gear data were not collected until 2020, meaning the sample size was relatively low, especially for some of the gears reported. It is unclear if some gear reported is not used very frequently or simply at a lower frequency during the data collection period of time. Nets could be easier to use with multiple people, but since the data collection for gear occurred during the SARS COVID-19 pandemic, fishers could have chosen to limit the number of fishers on a boat to limit exposure to others and their chance of catching the virus.

The level of data collection was broad and, thus, limited the analyses. Grouping landed marine organisms into broad categories was a necessity for this project due to the lack of species identification that occurred early on in data collection. In 2010 and 2011, Fish were identified as F1, F2, F3, or simply “Fia” (see Appendix Table C). Only in the later years of the dataset did the brokers start identifying fish species with common Malagasy names. While in most cases we were able to translate the Malagasy name into the English common name or scientific name, there was a large variety of species listed for each common name (Froese and Pauly 2019). With species level identification or even genus or family level identification, combined with weight of the individual, we would have been able to track the average size of the individuals and know with a greater degree of certainty if the marine organism was typically being harvested before or after reaching sexual maturation. If the organism is removed prior to maturing and being able to reproduce, it is unable to contribute to the longevity of the stock. If scientists can track the possible fecundity along with fishing mortality, we can track if the population is considered overfished or not. If too many individuals are being removed prior to maturation, unsustainable fishing practices are occurring within the MPA which would violate the terms as laid out by the IUCN (Table 1; Saborido-Rey and Trippel 2013).

Continuing Studies

There are future studies that can be done with the currently available dataset, but even more with some added levels of data. One of the topics of information this dataset covered is the "Raha Hafa" or "Other Landings." As this analysis attempted to convey, the landings reported here were only those sold to the sous-collectors that recorded these data. These sous-collectors only recorded information about the marine organisms they purchased from the fishers, but the fishers may have not chosen to sell all of their landings to these sous-collectors. "Raha Hafa" attempted to fill in some of the other landings that were not sold, but the addition of a column asking the fishers their intended use of these other landings could help create a more complete picture of these Salary fisheries. For example, if the fisher intended to sell, bring home, or trade these additional landings, we could get a better picture of what might be headed to Asian and other foreign market-based sous-collectors without involving additional collectors.

The dataset included the number of fishers that were involved on each fishing trip. It would be interesting to examine the number of fishers involved when using particular gear types as well as the comparable profits made for one fisher verse multiple. For example, some of the nets require more than one fisher to deploy or collect. While the CPUE is favorable to using nets when landing Fish, it would be interesting to investigate if profit is higher to fish alone and use a spear or spear gun rather than fish with others and have to divide the profits.

Under the guidance of Dr. Baker-Médard, Dr. Fairchild, and Dr. White and funding by the National Science Foundation, research will continue in Salary. These studies will not only investigate the fisheries and the health of the MPA Soariake, but also some of the socio-economic dynamics at play. For the socio-economic studies, surveys given to residents could include the public's perspective of the MPA as well as public knowledge about restrictions and fisheries management plans. We had hoped to include the effects of fishery closures and NTZ's in this study, but due to the lack of publicly available information about Salary's management of their fisheries, this could not be included. If the future socio-economic surveys were able to incorporate the public's knowledge about NTZs and area closures, these data might be more telling of how management is working in the area.

Along with the socio-economic dynamics, the work done within these analyses can help to streamline continued analyses of Salary's fisheries with the translation groupings and prewritten R code to sort future data. The translation work along with the changes made to the survey method will help to continue monitoring these fisheries and MPA/LMMA Soariake. These changes include limiting the phonetic spelling options by providing options to choose from and using both larger categories as well as species level identification.

Another aspect that should be examined is the role of gender within the fisheries. There has been previous evidence of gendered price discrepancy between the male and female fishers of Madagascar (Wosu 2019). There is also research that reveals a difference in access to resources for male verses female fishers (Westerman and Benbow 2014; Baker-Médard 2017; Galappaththi et al. 2022). The 2010-2021 data used in this study could help illustrate these dynamics in Salary. With better information of gender dynamics in Salary's fisheries, future management strategies might be able to be more gender equitable rather than favoring male access to fishing sites (Baker-Médard 2017).

As work on MPA Soariake and the fisheries continues in Salary, the data collected by the sous-collectors should continue with more details to species level identification of the landings. In the future, specific species should be tracked to determine the health of the populations as well as gathering biological information that might be helpful for other research. Through other *O. cyanea* studies in southwest Madagascar, scientists learned that large, mature females like to reside in deeper waters, more difficult for the Vezo to fish them (Raberinary and Benbow 2012). However, the peak of recruitment and consequential landings might be telling of *O. cyanea* habitats in its juvenile life stage, which is not well studied.

These data spanning 11-years are a good start for analyzing an MPA, however our results are unable to determine how the MPA is impacting the area. MPA/LMMA Soariake was established because the area was in need of regulation from overfishing that was occurring (M. Baker-Médard, personal comm.). While we do not see conclusive overall evidence that overfishing is still occurring, we also do not see conclusive evidence the area is rebounding from the previous overfishing. There are less data about how long a Category VI MPA takes to recover versus a more restrictive category of MPAs, but from this study it appears that 11-years is not enough time yet for a conclusive evaluation with these opportunistically collected data. However, this study does provide a baseline that was previously unavailable. If this data collection is able to continue, this study should be reevaluated in another five to ten years.

Conclusion

In this study, we were able to identify 51 fishing sites within MPA/LMMA Soariake's boundaries, including six highly frequented fishing sites. They were, in order of fishing frequency from highest to lowest, Belamera, Nanohofa, Anananose, Andamabe, Anjokozoko, and Nandoa. Furthermore, we were able to identify 11 different categories of marine organisms landed. The most landed marine organism categories were Fish, Octopus, Squid, Sea Cucumber, Gastropod, and Eel. We also assessed the gear types that were used and the frequency of how they were used to land which organisms. The most frequently used gear types were Hook and line, Net, Spear, and Spear Guns.

Through this study we were able to examine both the broad and focused efforts of Salary's fishery. By examining the focused efforts, signs of impacts to the fishing sites and the populations of highly fished marine organisms at those sites can be monitored. By identifying the ways in which gears are used to land the organisms, future studies might be able to better understand the dynamics of these fisheries and the rate at which change might occur. Monitoring is essential to follow the regulations of both MPAs and LMMAs, but also to track the health of these systems that are providing livelihoods to the residents of Salary.

Madagascar is an important country for research as it can be used as a case study for other developing countries. Madagascar has been considered one of the most marine resource rich countries and hopefully active conservation effort will keep those ecosystems intact (Selig et al. 2014). By evaluating the fishing that is being done by the citizens, in an area that has been internationally claimed for conservation purposes, we can have a better understanding if the high biodiversity – low impact fisheries are sustainable (Selig et al. 2014). Although this study is limited in both detail and scope, it can serve as a baseline and resource for future, more detailed, research.

Appendix: Tables

Table A. The headers of the fishing trip dataset from Salary, Madagascar as they appear in Malagasy and translated into English.

Malagasy	English
DATY	Trip Date
ANARANA	Name of Fisher
SEXE / L/V	Sex of Fisher
OLO FIRY	Number of fishers on Trip
TAIA	Fishing Site
KARAZANY	Marine Organisms Sold
ISANY	Number of Marine Organisms Landed
KILO	Total Weight of Marine Organism Category (kg)
VILINY (AR)	Price paid to Fisher (AR)
VILINY (USD)	Price paid to Fisher (USD)
LERA IALANY	Time Departed
LERA IALANY	Time Returned
RAHA HAFA	Landings not sold to Broker
FITOVANA	Gear Type Used

Table B. The complete list of all fishing sites reported to data collectors during 2010-2021 paired with the different ways that they were recorded. Groupings were made under the advisement of and with knowledge from Dr. Baker-Médard. "Other" includes fishing site names that were unable to be grouped. "Blank" includes data collected but the fishing site was not identified or an asterisk "*" was entered for fishing site.

Fishing Site	As Appearing in Data:
Agnahipilo	AGNAHIPILO
Ambatobe	Ambatobe, Ambatobe, AMBATOBE, VATOBE, Batobe
Ambatoloaky	Ambatoloaky, AMBATOLOAKY, Ambatoloake
Ambatomanoko	Ambatomanoko
Ambatotsilaky	Ambatotsilaky, Ambatotsilaky
Ambatovy	Ambatovy, AMBATOVY, Amatovy, Ambatovy , vatovy, Batovy , Abatove
Ambavae	Ambavae, Ambavae, AMBAVAE, Ambavane, Ambavane.B, Avae
Ambilany	Ambilany, AMBILANY, Ambalany, Ambalany, AMBALAVY, AMBALANY, Ambulany, Ampalany
Ambohoriake	Andahariake, Andohariake, ANDOHARIAKE, Ambohoriake, Lohariake
Ambolivato	Ambolivato, Ambolivato
Ampase	Ampase, AMPASE, ampase , Ampase , Ampase, AMPASY, Ampasilava, AMPASILAVA, Ampasilava, PASILAVA
Ampilako	Ampilako, Ampilako, AMPILAKO
Ananose	Anananose , ANANANOSE , Anananose, ANANANOSE, ANANANOSE , Ananosy, ANANANOSY, Ananaosy, Ananosy, Anose, ANOSE, Anose , Anosy, ANOSY, Nanannose, nananose, Nananose, NANANOSE, nananose , Nananose , NANANOSY, Nanonose , Nanose , TANOSE
Andamabe	Andamabe, Andama, Andama , ANDAMA, Andamabe, Andamabe, ANDAMABE, Anadamabe, Andalmabe, Antandama
Andaniriake	Andaneriake, Andanieriake, Andaniriake, ANDANIRIAKE, Andaniriaky, Daniriake, DANIRIAKE
Andohaolo	Andohaolo, Andohahola, Andoha holo, NDOHAOLO, Andohaolo, ANDOHAOLO
Andohavato	Andohavato , Andohavato
Andolotse	Anolotse, ANOLOTSE
Anjokozoko	Anjokozoko, ANJOKOZOKO, Jokojoko, JOKOZKO, jokozoko, Jokozoko, JOKOZOKO, Drokozoko, Ambava jokozoko
Ankatsaepotike	Ankatsaepotike, ANKATSAEPOTIKE
Ankemake	Ankemake, Ankemaky, Ankemake , ANKEMAKE, Ankemoke, Ankenae, Ankenae , Ankamake, ANKENAE, Ankenae
Ankora	Ankora, ANKORA, Ankorake, Ankorake , ANKORAKE

Antandeo	Antandeo, Anandeo, Antandea, Antandebe, Antandeo, ANtandeo, ANTANDEO, Antandeobe, Antaneo, Tandeo, TANDEO, TANDEOBE, Tandeope, Tanndeo
Antangie	Antangie, Antange, Antagie, Antagie , Antangie , Antangie, ANtangie, Tangie, Tangie , TANGIE
Antanifoty	Antanifoty, Tanifoty
Antovy	Antovy, ANTOVY
Antsaragna	Antsaragna, ANTSARAGNA
Apilalo	Apilalo, Apilalo
Atamboho	Atamboho, amboho, Amboho, ABOE, ABOHOE, Amboho , Ambohoe, AMBOHOE, Ambohoe, AMBOHOKE, AMBOHONY, Antabohy, Antamboha, Antamboha , ATAMBOHY, Antamboho, AntambohO, ANtamboho, ANTAMBOHO, ANTAMBOHY, Antamboly, Antanboho, Antanimboho, TAMBOHO, TAMBOHY, Atabohy
Beharona	Beharona, Ambeharona, Beharona, Beharona , BEHARONA, BEHARONGA
Belamera	Belamera, Belameara, BELAMERA, BELAMERA , Belamera , Belamera, belamera, belamela, Ambavabelamera
Belapa	Belapa, Belampa, Belapa , BELAPA, BELOPA, Abelampa
Belofisake	Belofisake, BELOFISA, BELOFISAKE, Abelofisaky
Benema	Benema, Ambemena, Bemena, Bemena , BEMENA, bemena
Betabake	Betabake, BEDABOKE, BETABAKE
Beviko	Beviko, Abeviko, ABEVIKO, BEVIKO, BEVIKO , Beviko
Blank	NA, empty, *
Boloake	Boloake, BOLOAKE
Borimpase	Borimpase, Borimpase
Danahitse	Danahitse, Andaniahitse, Andanahitse, Andanehitse, Danahitse, DANAHITSE, DANIAHITSE, DANOHITSE, Donahitse
Lamabe	Lamabe, Lamabe, Lamabe , LAMABE
Mahazatsy	Mahazatsy, Mazatse, Mahasaha, MAHASAHA, Mahasaha , Mahazatse, Mahazatse , MAHAZATSE, Mahaseha , MAHAZATSY
Marerano	Amarerano, marerano, Marerano, MARERANO, Amarirano
Nandoa	Nandoa, nandoa, Nandoa , NANDOA, N ANDOA, NADOA
Nanohofa	Nanohofa, Nanahofa , MANOFOHA, Nanohfa, nanohofa, Nanohofa , NANOHOFA, Hanohofa
Nonokaombe	Nonokaombe, Nokoabe, Nonokaobe, NONOKAOMBE, NONOKOABE, Nanokaobe , Nanokaobe, Nanokombe, Anonokaombe, Honokaobe, nonokaobe
Nosekara	Nosekara, NOSEKARA, Nosekara , Nosenkara, NOSYKARA, Anosenkara, Anosenkara
Other	AKARA, AMBA, Ambana, Ambavabelona, Andomotse, ANDRANO, Andrefa, ankara, Ankara, Ankara , ANKARA, Ankazo bevohitse,

	Anorake, Anose/Taboly, Antendebe, Antndeo, Atabohy/nanohofa, Ataboly, BADOBE, bakavaratse, Bozike
Sarihima	Sarihima, SAREHIMA, Sarehima, Sarihima, SARIHIMA, Sarihina, Serehima, Sarehima , sarehima
Sorimpase	Sorimpase, Antsrimpase, Antsorimpase, Sarim-pase, Sorimpase, SORIMPASE
Takohy	Takohy, TAKOHY
Tambahy	ANTAMBAHY, TAMBAHY
Tranobaraha	Tranobaraha, TRANOBARAHA
Tsimahafoty	Tsimahafoty, Tsimahafory, Tsimahafot, Tsimahafoty, TSIMAHAFOTY
Vavalavaratse	Vavalavaratse, VAVAE AVARATSE, vavaevaratse, Vavalavaratse, Vavaeavaratse

Table C. The complete list of all organisms landed reported to data collectors in Salary, Madagascar during 2010-2021 paired with the different ways that they were recorded. Groupings were made under the advisement of and with knowledge from Dr. Baker-Médard. "Other Organisms" consisted of organisms that were unable to be translated, multiple organisms listed as a landing, or organisms that did not appear as a landing more than once in the dataset.

Marine Organism Category	**As Appearing in Data:**
Eel (*lamera*)	L, lamera, Lamera, LAMERA, l, L , lamera
Fish (*fia*)	f, F, F , Fia, FIA, FIA , AMBARIAKE, AMBARIAKA, BODOLOHA, FIA ANGY, FIA BANA, FIA BODOLOHA, FIA FITSE, FIA KIMBOROKE, FIA MAINTY, FIA TSONTSO, fia VARILAVA, FIIA TOHO, FIANTSOFA, F,foty, F,Tsifa, F,Tsoraby, F..savesave, F.A.Angy, F.Abitsy, F.aloalo, F.Aloalo, F.aloalo , F.aloalo be, F.aloalo kely, F.ambariake, F.Ambariake, F.Ambatsoy, F.Ambitsozo, F.Ambitsy, F.Amboroy, F.Ambory, F.Amongo, F.Ampase, F.amporama, F.Amporama, F.Ampoza, F.anak'ampoza, F.andrarame, F.angelike, F.Angelike, f.Angerera, F.Angerera, F.angy, F.anterake, F.antisy, F.antseraky, F.antsisy, F.Antsisy, F.antssy, F.Apoza, F.areloha, F.Aterake, F.Babake, F.baboke, F.Baboke, F.be, f.Bemaso, F.bemaso, F.Bemaso Mena, f.Bodoloha, F.bodoloha, F.Bodoloha, F.BOdoloha, F.boloha, F.bondro, F.Bondro, F.Dabandriake, F.fitse, F.Fitse, F.fotihohy, F.Fotihohy, f.foty, F.foty, F.fsifa, F.gogo, F.Gogo, F.joginy, F.Joginy, F.kabo, F.Kabo, F.kapitene, F.kapiteny, F.Kapoake, F.kely terake, F.Kifalaotse, F.kinirike, F.Lafo, F.lamatra, F.Lamatra, F.Lamatra, F.lanilany, F.lanora, F.Lanora, F.lavanify, F.Lavanify, F.Leme, F.leontine, F.llanora, F.lov0, f.lovo, F.lovo, F.lovo , F.lovo sara, F.lovohara, F.Lovohara, F.lovoho, F.lovonakanga, F.Mahaloky, F.mainte, F.mainte , F.mainty, F.maite, F.Malily, F.maliniky, F.mandreandovoke, F.Mandredre, F.Mandrendre, F.Mangerelavenoke, F.Mantafao, F.mante, F.mena, F.Mena, F.Mena , F.Mena , F.MENA BEMASO, F.menasofy, F.Menasofy, F.Molonto, F.Moroy, F.Mpivondrake, F.ongike, F.rara, F.Rara, F.sakavoto, F.sapiata, F.savesae, F.savesave, F.Savesave, F.savesavy, F.savisavy, F.soroboa, F.Soronale, F.tabake, F.Tabake, F.tabike, F.TALANTARA, F.tapaporoha, F.Tapaporoha, F.taramatse, F.Taratake, F.timatipaosa, F.Timatipaosa, f.toho, F.toho, F.Toho, F.Tona, F.Tririmpaosa, F.tsabeake, F.Tsabeake, F.tsabeaky, F.Tsabeaky, F.tsamearene, F.Tsamearene, F.tsameareny, F.tsara, F.Tsara, F.Tsaramatseroke, F.tsfa, f.tsiamearene, F.tsiameareny, F.tsifa, F.Tsifa, F.tsifaH, F.tsikahitse, F.tsipa, f.Tsirimpaosa, F.tsirimpaosa, F.Tsirimpaosa, F.tsiripaosa, F.Tsobariake, F.tsokahita, F.tsokahite, F.tsokahitse, F.Tsokahitse, F.tsoraby, F.Tsoraby, F.tsoy, F.Tsoy, F.tsoy , f.tsoy , F.Tsoy Antsisy, F.Tsoy malinike, F.Tsoy rotse, F.tsoymalinike, F.TsoyMalinike, F.TsoyMaliniky, f.v0ramasake, f.valala, F.valala, F.Valala,

	F.Varavara, F.varevike, F.Varevike, F.varivike, F.vontso, F.voramadake, F.voramasake, F.Voramasake, F.voramasaky, F.Vorramasake, F.Votosaka, f.votsandra, F.votsandra, F.Votsandra, F.Votso, F.Ysifa, F;be, F;bodoloha, F;savesave, F1, F2, F3, Fia, FIA, FIA , FIA ANGY, FIA BANA, FIA BODOLOHA, FIA FITSE, FIA KIMBOROKE, FIA MAINTY, FIA TSONTSO, fia VARILAVA, FIANTSOFA, FIIA TOHO, FITSE, Fmainte, fay, Fay, Fay , Fay , Fay Andema, Fay Foty, fay rara, Fay rara, Fay Rara, FAY RARA, Fay sify, Fay Sify, AKORA, AMATO, AMBARIAKE, ANTSERAKE, BODOLOHA, G, gogo, Gogo, GOGO, JOKO, KABO, lamatra, LAMATSA, LANORA, LOVO, LOVOHARA, TOHO, Varilava, VARILAVA, sampiata, sapiata, SAPIATA, Zamaly Z.M, zamaly Z.M, ZAGO, Zago, ANTSIVA, geba, HOVOHOVO, katsa, LAFO, M.malily, Morosy, MOROY, Naholok, SOROBOA, tabaky, Takalo, TAKALO, TSABEAKE, TSONTSO, VARAVARA, Varilava, VARILAVA, ZAGO, zamaly Z.M, Vary Lary, vary lary, Voramasake, voramasake, Sarigeba, SARIGEBA, F.A.Angy, F.Mainte, fF.Ongike
Gastropod (*bozike*)	b, B, BOZIKE, Beja, BEJA, BETAMPE, BETAMPY, Boz ike, bozike, Bozike, Bozike Joka, Bozike Jonka, Boziky
Lobster/ Crabs	dakake, drakake, Drakake, LANGOUSTA
Octopus (*horike*)	h, H, H-Z, H , H , H nakoho, H nakora, H Nakora, H.F, H.nakoho, H.nakora, H.Nakora, H.Nakorra, H/soroboa, HORITA
Other Organisms	Jarify, JARIFY, NA, *, Bokahi, bokahi, dorilisy, DORILISY, Dorlisy, dorolisy, DOROLISY, Dorilisy, E, Fela, FELA, Gamo, gamo, Joginy, JOGINY, Jonka, JONKA, Kapilany, Kokiazy, KOKIAZY, Lanilany, LANILANY, LANILAY, Liva, LIVA, mabolotsetaly, Mamilaotse, Soronale, SORONALE, SORONALY, T, Tamboky, TAMBOKY, Tsy Misy, Tsy MISY, TSY MISY, Varevek, VAREVEK, Votsanja, VOTSANJA, Zomaly, zomaly, ZOMALY, ZOMALY , Bboziky/joka, Bindra/horita, HIMA, Liva/horita, soke, SOKY, Zanga/Bozike
Sea Cucumber (*zanga*)	Z, ZANGA, zanga, Zanga, zanga , zanga benono, zanga BENONO, Zanga benono, Zanga Benono, ZANGA BENONO, ZANGA BOROSY, Zanga Dorilisy, ZANGA DORILISY, Zanga dorlisy, zanga dorolisy, zanga F.TS, zanga folera, ZANGA FOTITSETSAKE, Zanga foty, Zanga Foty, ZANGA FOTY, ZANGA JOGINY, Zanga kida, zanga mainte, Zanga mainte, ZANGA PITIKE, Zanga potike, ZANGA TRONKENA, zanga tsokena, Zanga tsokena, Zanga Tsokena, zanga Z.M, zanga zomaly, Zanga zomaly, Zanga ZomalyZangambato, Zzanga foty, Benono, benono, BENONO, Tsonkena, TSONKENA, ZANAG, ZANDA DORILISY, Zanga Zomaly, Zangambato, ZangaZomaly
Sea Horses	Lomotse, LOMOTSE
Shimp	Tsitsike, tsitsike, TSITSIKE, Tsiysike
Squid (*angisy*)	a, A, A , ANGISY, Angisy dolo, ANGY

Table D. The complete list of all fishing gear used and reported in Malagasy to data collectors in Salary, Madagascar during 2010-2021 grouped into gear types. Groupings were made under the advisement of and with knowledge from Dr. Baker-Médard.

Gear Group	Recorded in Dataset (Malagasy)
Hand	al tana, antana, Antana, Antana, Nalana antana, Tana, TSY MISY, Antana
Hook	Vintan'Angisy, vin'angisy, vint'angisy, Vint'angisy, vinta, Vinta, VINTA, Vintam-pia, vintampia, Vintampia, VINTAMPIA, vintan'angis, vintan'angisy, Vintan'angisy, VINTAN'ANGISY, Vitam-pia, vitampia, Vitampia, VITAMPIA, vitampoia, vitan'agisy, vitan'angisy, Vitan'Angisy, VITANANGISY, vivtampia, NINTAN'ANGISY
Other Gear	B, ballot, Basy/haato, bvo, bvol, drango, Hj, Mahasaha, Manambaitse, Nikely, Sabora, sabot, Taliraro, Tindriaha, tonotono, Torse, Zanga Trikitera, zanga tsokena, Zanga Zomaly, B , Hj , Mahasaha, Tindriaha
Metal Rod / Stick	Vy, Vy, VY, vy fer, vy frr, vy, Tampa-kazo, Anakavy, Hazokely, Tampa-kazo, Hazokely
Net	harato, Harato, HARATO, Harato, Harato be, harato gogo, Harato gogo, harato malinike, haratobe, palange, PALANGRE, makarakara, Makarakara, HARATOM-PAY, HARATOM-PAY, PALANGRE
Spear	Veloso, voloso, Voloso, VOloso, VOLOSO, voloso, Voloso, VOLOSO/BASIMPIA, Voloso/tana, volosq, Veloso
Spear Gun	Basim-pia, basimpia, Basimpia, BASIMPIA, basimpia, Basimpia, BASIMPIA/ VOLOSO, basy, Basy, bsy

Table E. Marine species reported to data collectors in Salary, Madagascar during 2010-2021 translated from Malagasy into English and Latin mostly by use of FishBase (Froese and Pauly 2019). "*" indicates translations from Andriamaharo et al. (2009). "**" indicates translations from Langley (Langley 2006)."***" indicates translations from Dr. Baker-Médard.

Malagasy Name	Marine Organism Category	Possible Common English Names	Scientific Name
Amato	Fish	Redaxil emperor	*Lethrinus conchyliatus*
Ambariake	Fish	Strongspine silver-biddy	*Gerres acinaces*
Angisy	Squid		
Antsiva	Fish	Katrana	*Rheocles alaotrensis*
Bboziky	Seaweed		
Beja	Gastropod		
Betampe	Gastropod		
Bodoloha	Fish	Blue-barred parrotfish	*Scarus ghobban*
Bozike	Gastropod		
Dakake	Crab		
Dragon	Sea Horse		
Fay	Fish (Ray)		
Fay Foty	Fish (Shark)	Smalltooth sand tiger or Dusky shark	*Odontaspis ferox* or *Carcharhinus obscurus*
Fia Aloalo	Fish	Great barracuda	*Sphyraena barracuda*
Fia Ambitsy	Fish	Spangled emperor or Thumbprint emperor	*Lethrinus nebulosus* or *Lethrinus harak*
Fia Amporama	Fish	One-spot snapper	*Lutjanus fulviflamma* or *Lutjanus monostigma*
Fia Angelike	Fish	Sky emperor	*Plectorhinchus gaterinus* or *Diagramma pictum*
Fia Angerera	Fish	Blackspotted rubberlip or Painted sweetlips	*Plectorhinchus gaterinus* or *Diagramma pictum*
Fia Angy	Fish	Zebra angelfish	*Genicanthus caudovittatus*
Fia Antseraky	Fish	Black-barred halfbeak	*Hemiramphus far*
Fia Areloha	Fish	Goldsilk seabream	*Acanthopagrus berda*
Fia Lafo	Fish	Red lionfish	*Pterois volitans*
Fia Lanora	Fish	Yellowspotted trevally or Giant trevally	*Carangoides fulvoguttatus or Caranx ignobilis*
Fia Leme	Fish	Dusky parrotfish	*Scarus niger*

Fia Soroboa	Fish	Giant guitarfish or Grayspottted guitarfish	*Rhynchobatus dijddensis* or *Acroteriobatus leucospilus*
Fia Tapaporoha	Fish	Thumbprint emperor	*Lethrinus harak*
Fia Taratake	Fish	Blacktip grouper or Brownspotted grouper	*Epinephelus fasciatus or Epinephelus hexagonatus*
Fia Tsabeake	Fish	Ember parrotfish	*Scarus rubroviolaceus*
Fia Varavara	Fish	Mangrove red snapper	*Lutjanus argentimaculatus*
Geba	Fish	Spotted sardinella or Bluestripe herring	*Amblygaster sirm* or *Herklotsichthys quadrimaculatus*
Gogo	Fish	Madagascar sea catfish	*Arius madagascariensis*
Hima	Other	Giant Clam	
Horita	Octopus		
Hovohovo	Fish	Orbicular batfish	*Platax orbicularis*
Kokiazy	Other	Shell	
Lamatra**	Fish	Kanadi kingfish	*Scombermorus plurilineatus*
Lamera	Eel		
Langousta	Lobster		
Lomotse	Seaweed		
Lovo**	Fish	Bluespotted grouper or Coral grouper	*Cephalopholis argus* or *Cephalopholis miniata*
M.malily***	Fish	Black and yellow grouper	*Epinephelus flavocaeruleus*
Morosy***	Fish	Spot-fin porcupinefish	*Diodon hystrix*
Soke	Other	Sea Urchin	
Tabaky	Fish	Ember parrotfish	*Scarus rubroviolaceus*
Takalo***	Fish	Dory snapper or Yellow boxfish or Spotted boxfish	*Lutjanus fulviflamma* or *Ostracion cubicus* or *Ostracion meleagris*
Toho	Fish	Duckbill sleeper or Freshwater goby or Speckled goby	*Butis butis* or *Awaous aeneofuscus* or *Redigobius bikolanus*
Tsitsike***	Lobster		
Tsonkena	Sea Cucumber		
Tsontso	Fish	White-banded triggerfish	*Rhinecanthus aculeatus*

Varavara	Fish	Mangrove red snapper	*Lutjanus argentimaculatus*
Varilava	Fish	Madagascar round herring or Amboaboa round herring	*Sauvagella madagascariensis* or *Sauvagella robusta*
Voramasake	Fish		
Zanga	Sea Cucumber		
Zanga Benono*	Sea Cucumber	White teatfish	*Holothuria fuscogilva*
Zanga Dorilisy*	Sea Cucumber	Pink and Black sea cucumber or Black teatfish	*Holothuria edulis* or *Holothuria notabilis* or *Holothuria sp.*
Zanga foty	Sea Cucumber	Sandfish	*Holothuria scabra*
Zanga Tronkena	Sea Cucumber	Brownfish	*Actinopyga echinites*

Table F. Total number of fishing trips by calendar year for all of the fishing sites reported to data collectors during 2010-2021. "Blank" indicates data were collected but fishing site was not identified.

Fishing Site	2010	2011	2015	2016	2019	2020	2021	Total Trips
Agnahipilo						1		**1**
Ambatobe		3	6	2		1	28	**40**
Ambatoloaky			12				1	**13**
Ambatomanoko							1	**1**
Ambatotsilaky		1						**1**
Ambatovy		14	61	24	1	2	55	**157**
Ambavae			7				12	**19**
Ambilany					7	13	51	**71**
Ambohoriake			2	2			11	**15**
Ambolivato							39	**39**
Ampase			1		51	9	118	**179**
Ampilako						5	116	**121**
Anananose	157	137	167	25	86	72	472	**1116**
Andamabe	178	344	134	3	5	29	137	**830**
Andaniriake	2	15	44	13		2	42	**118**
Andohaolo	12	22	10		1		2	**47**
Andohavato	3	8					7	**18**
Andolotse			16	4		2	3	**25**
Anjokozoko	45	99	54	8	103	55	322	**686**
Ankatsaepotike					1			**1**
Ankemake		8				11	120	**139**
Ankora					3		12	**15**
Antandeo			33	18	57	52	223	**383**
Antangie					10	15	57	**73**
Antanifoty							5	**5**
Antovy			1					**1**
Antsaragna					1			**1**
Apilalo		1						**1**
Atamboho	36	10	28	32	27	53	256	**442**
Beharona					1	3	18	**22**
Belamera	241	278	302	142	299	109	1037	**2408**
Belapa	1	11	15			7	8	**42**
Belofisake			8			1		**9**
Benema	3	14	4	5	2	3	176	**207**
Betabake	1	3	2					**6**
Beviko	3	3	45	30		2	5	**88**
Blank	1	14	194	3	98	96	315	**721**

Boloake			1					**1**
Borimpase							1	**1**
Danahitse	32	8	6	1	1	2	11	**61**
Lamabe			71		31	10	12	**124**
Mahazatsy	6	19	22	2	30	18	99	**196**
Marerano	8		4			2	5	**19**
Nandoa	31	150	190	39	17	30	129	**586**
Nanohofa	186	251	247	91	127	81	443	**1426**
Nonokaombe		2	1		52	19	148	**222**
Nosekara						2	76	**78**
Other	11	16	17	2	53	42	201	**342**
Sarihima	2	8	38	54	63	30	219	**414**
Sorimpase						4	8	**12**
Takohy			1					**1**
Tambahy			16					**16**
Tranobaraha					1			**1**
Tsimahafoty	53	51	98	18	25	8	114	**367**
Vavalavaratse					3	9	34	**46**
All Sites	1012	1490	1858	518	1147	800	5149	**11974**

Table G. Seasonality of data collection of Fish and Octopus landings. "*" indicates only Fish landings recorded for that month.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
2010									X	X	X	X
2011			X	X	X	X	X	X	X	X		
2015							X	X	X	X	X	X
2016	X	X*										
2019					X	X	X	X	X			
2020											X	X
2021	X	X	X	X	X	X	X	X	X	X		

Appendix: Figures

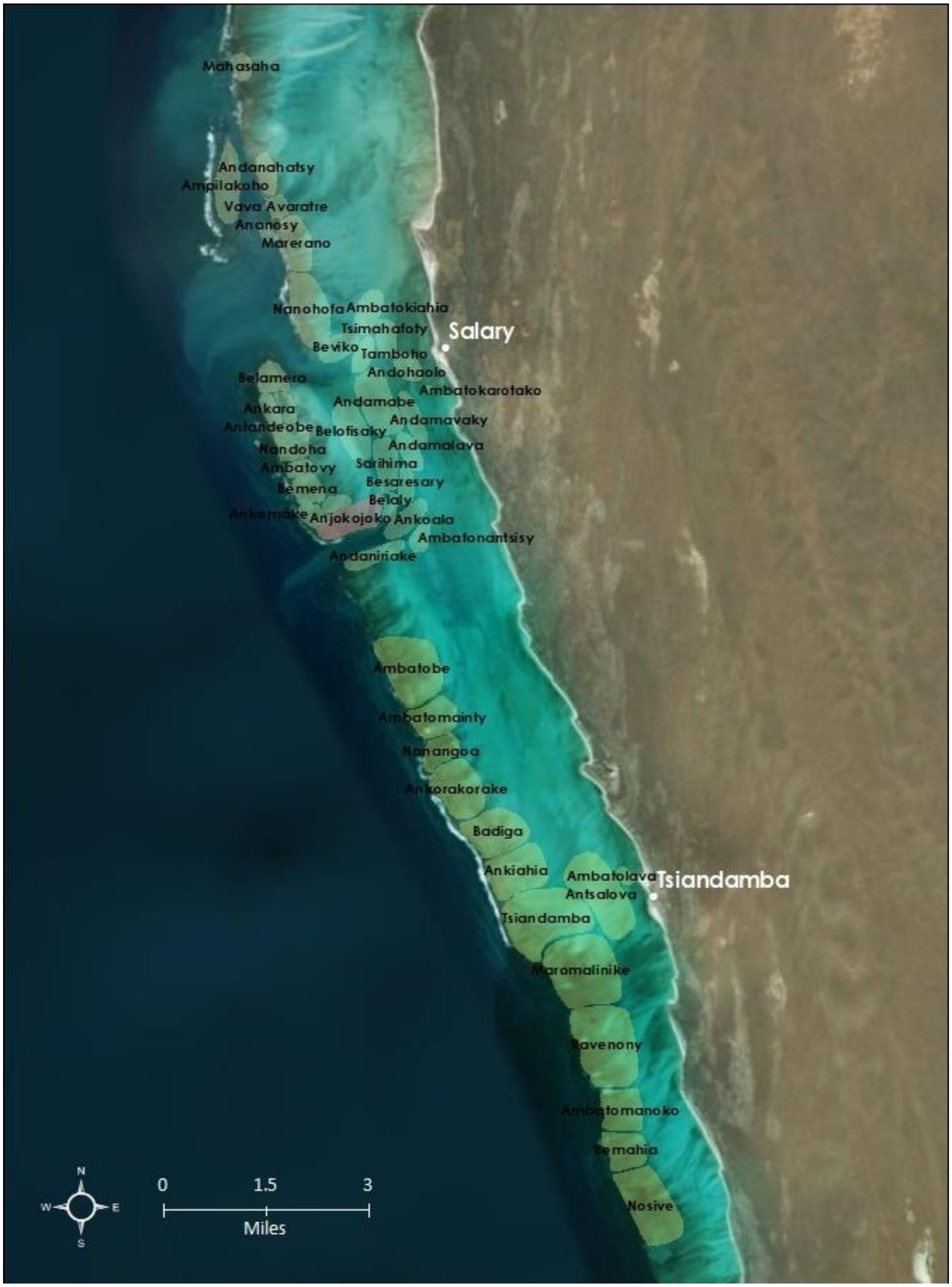


Figure A. Fishing reefs in the Toliara Reef System frequented by the residents of Salary and Tsiandamba in southwestern Madagascar, as communicated orally by local fisher-people. (Source: M. Baker-Médard)

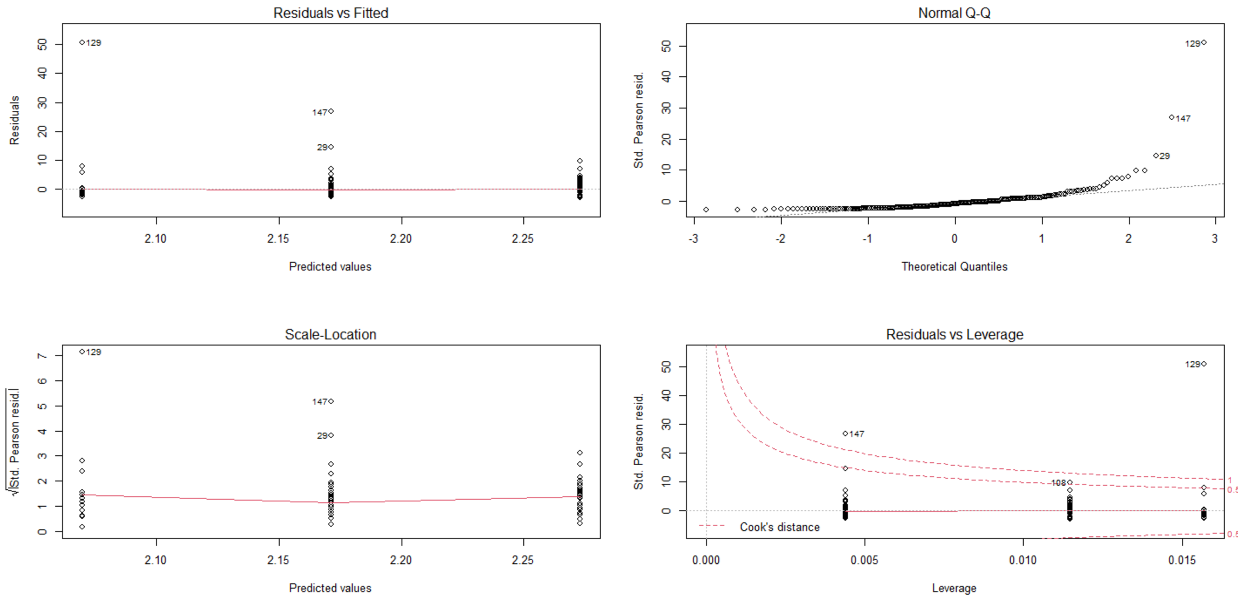


Figure B. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in November and December 2011, 2015, and 2019.

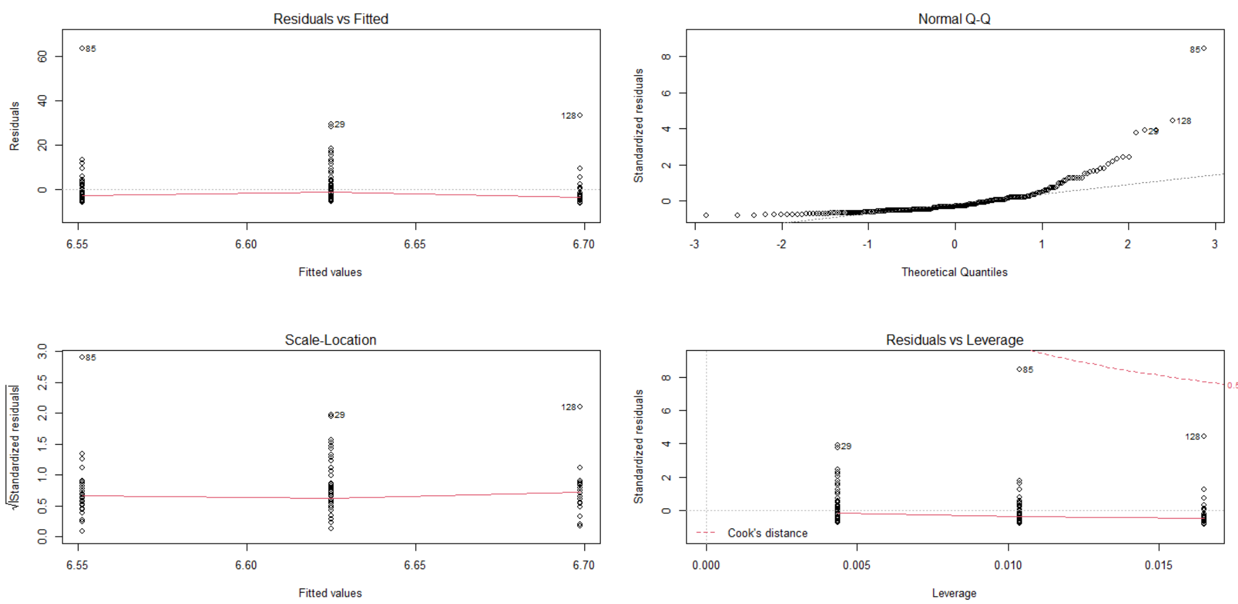


Figure C. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in November and December 2011, 2015, and 2019.

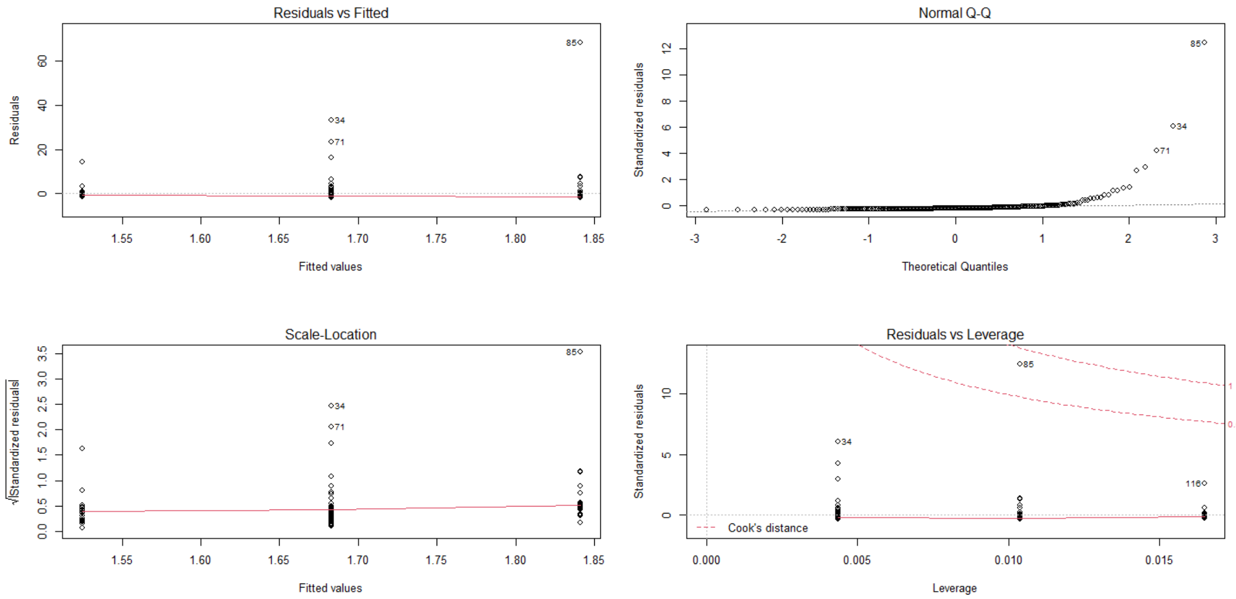


Figure D. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in November and December 2011, 2015, and 2019.

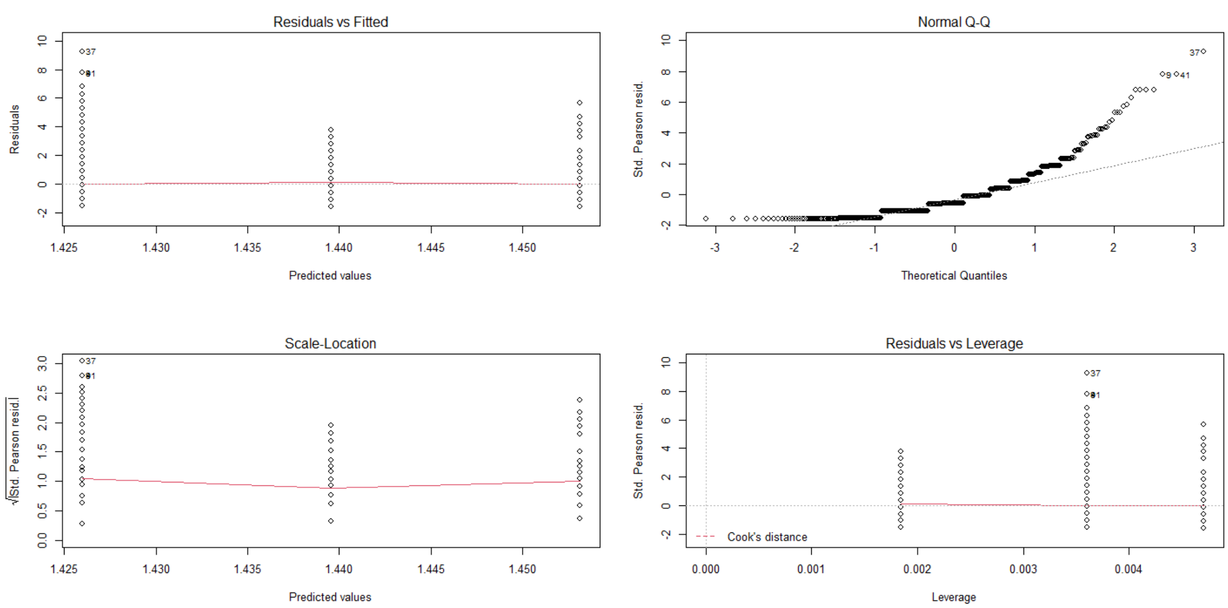


Figure E. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in November and December 2011, 2015, and 2019.

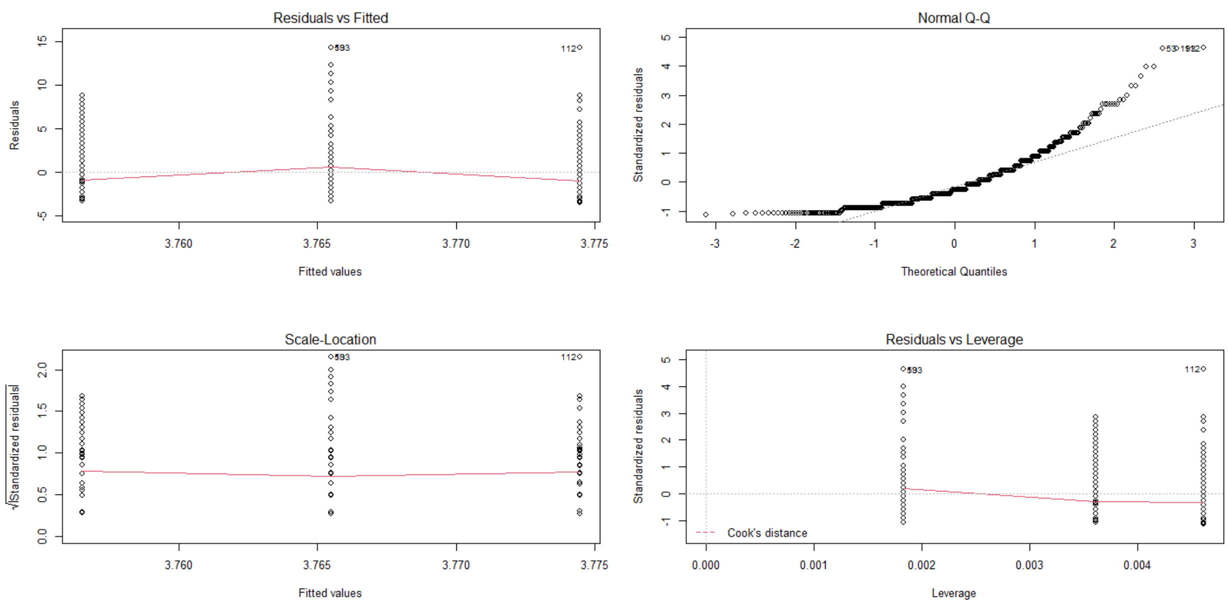


Figure F. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in November and December 2011, 2015, and 2019.

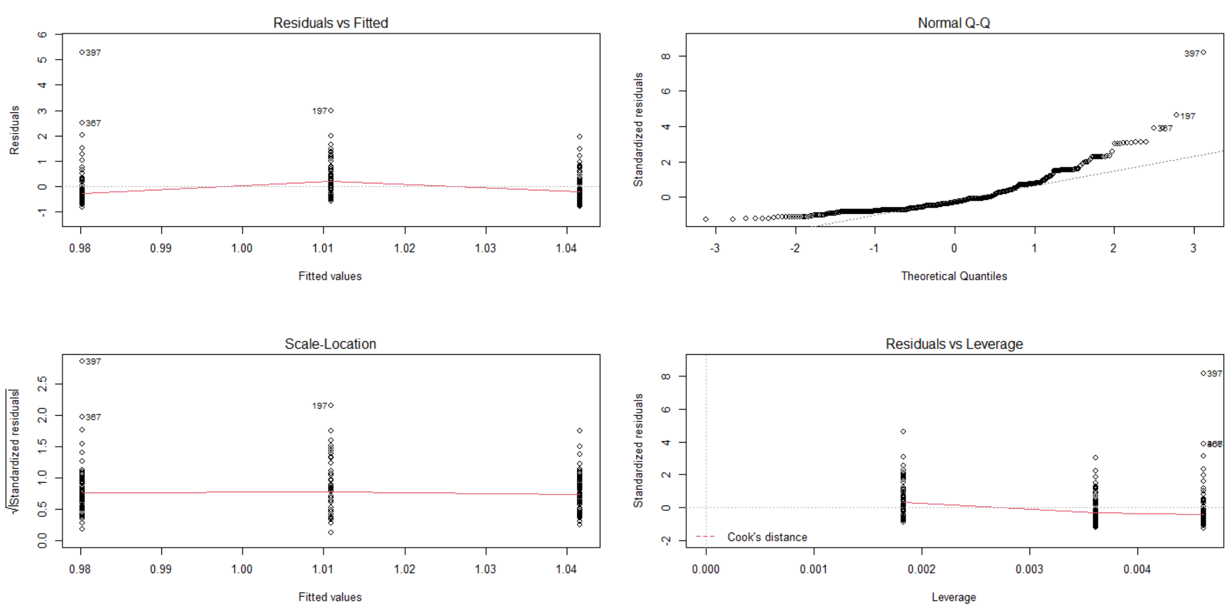


Figure G. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in November and December 2011, 2015, and 2019.

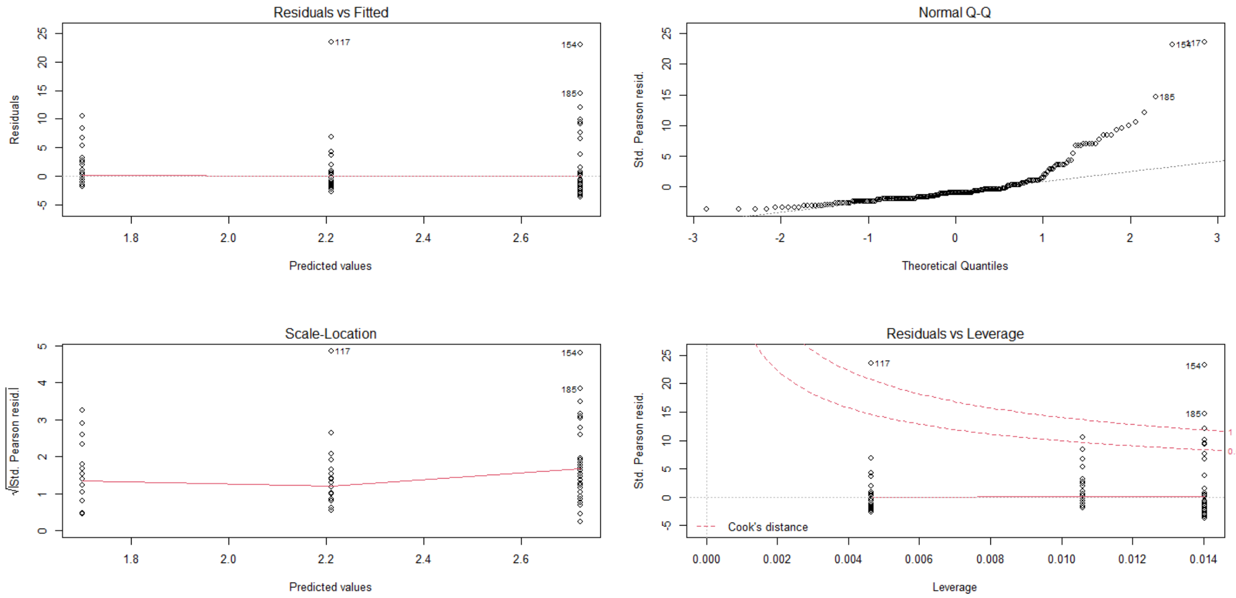


Figure H. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in July, August, September 2010, 2015, and 2020.

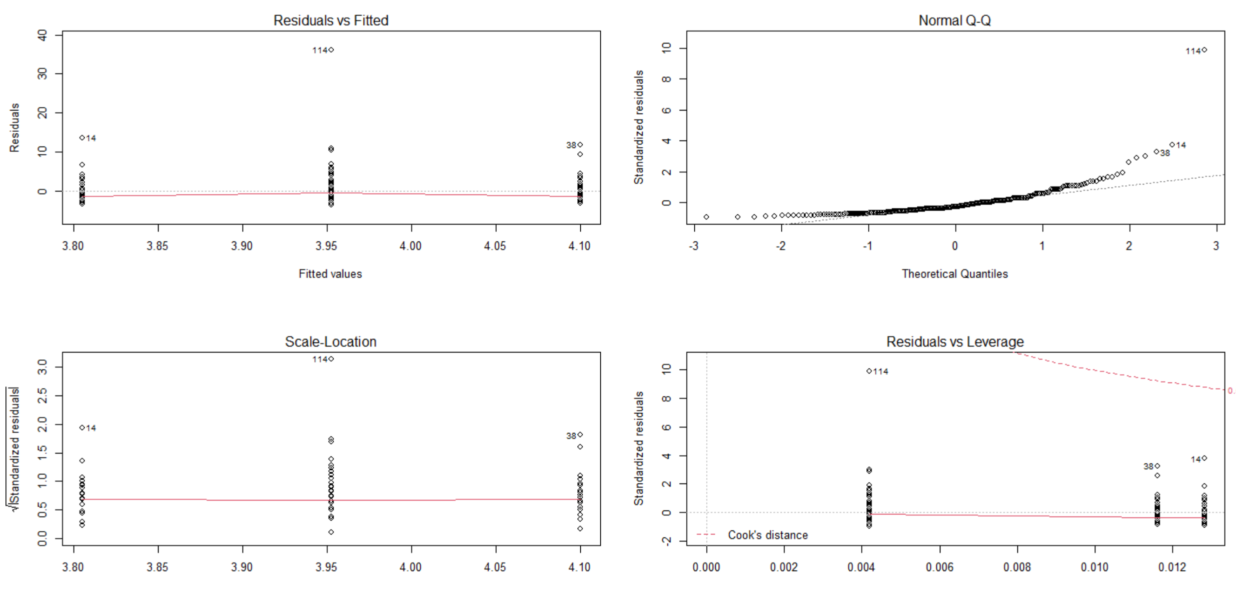


Figure I. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in July, August, September 2010, 2015, and 2020.

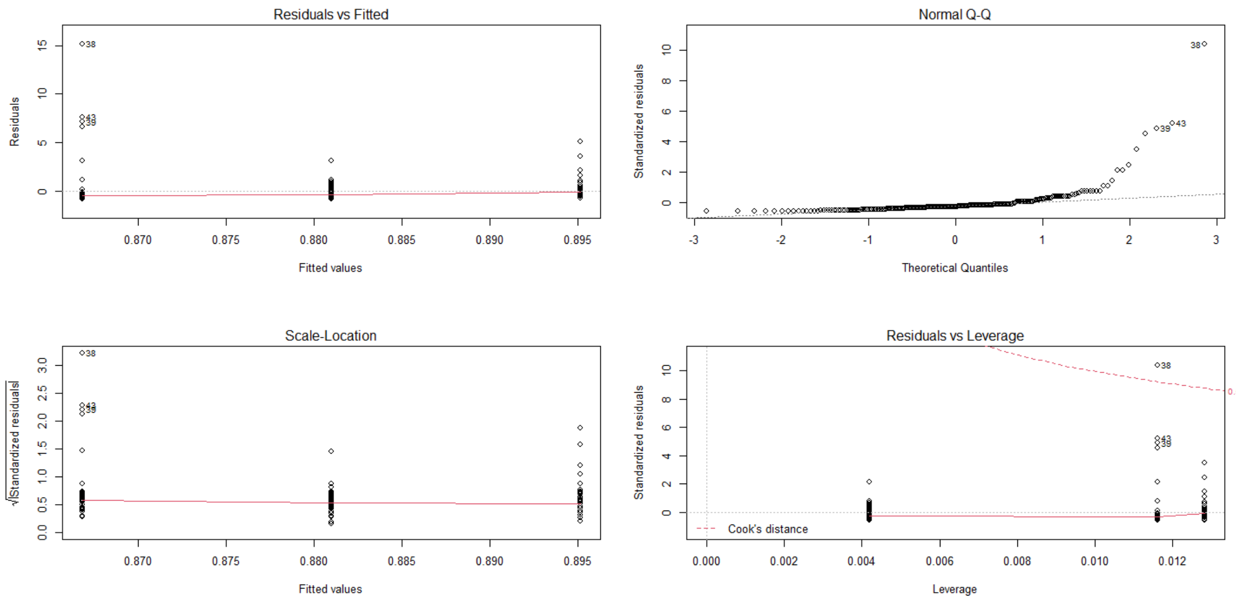


Figure J. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in July, August, September 2010, 2015, and 2020.

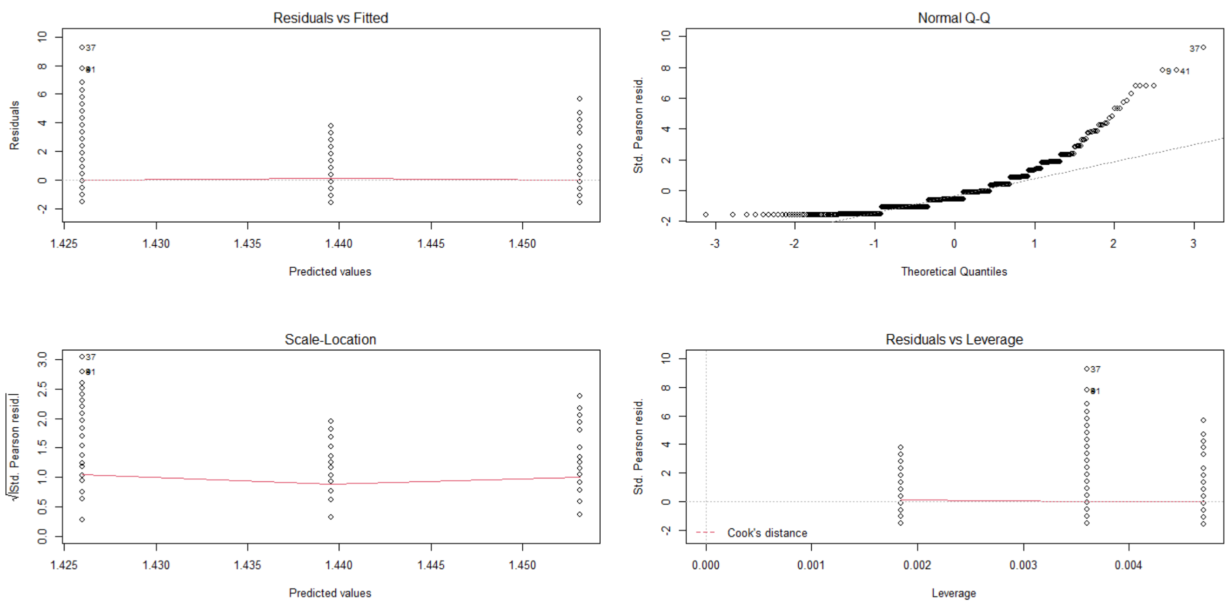


Figure K. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in July, August, September 2010, 2015, and 2020.

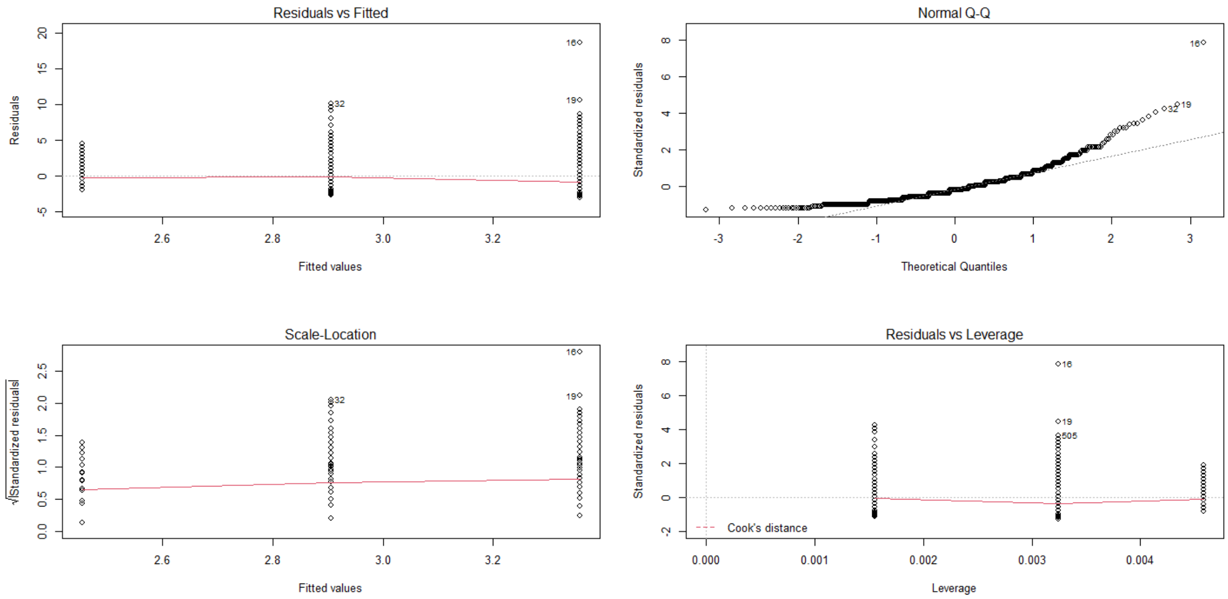


Figure L. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020.

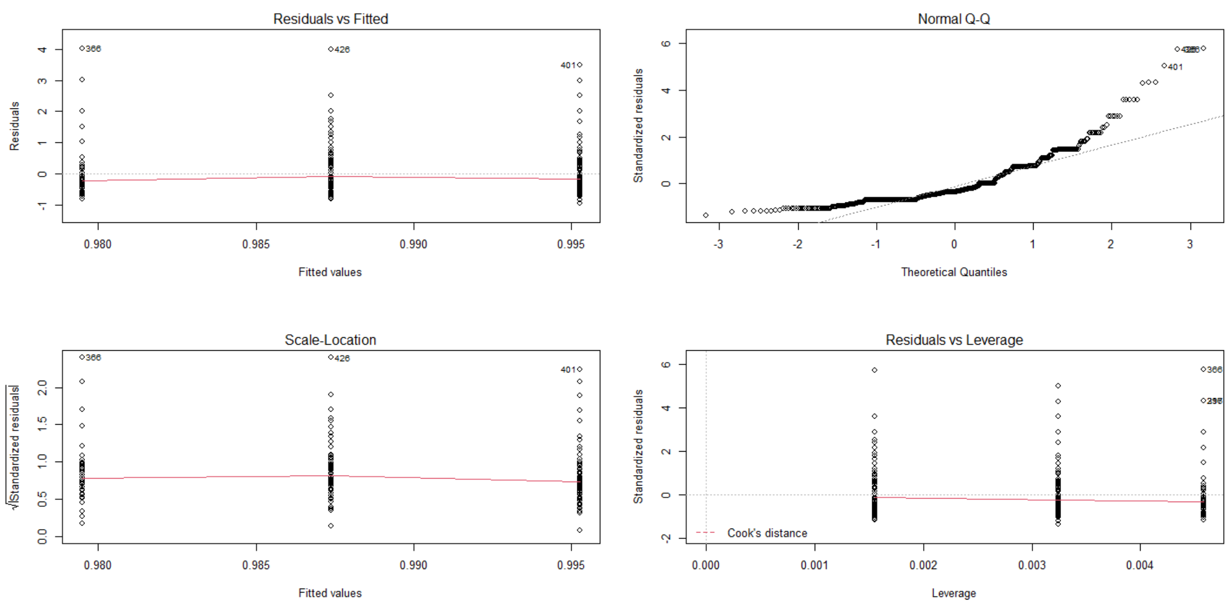


Figure M. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020.

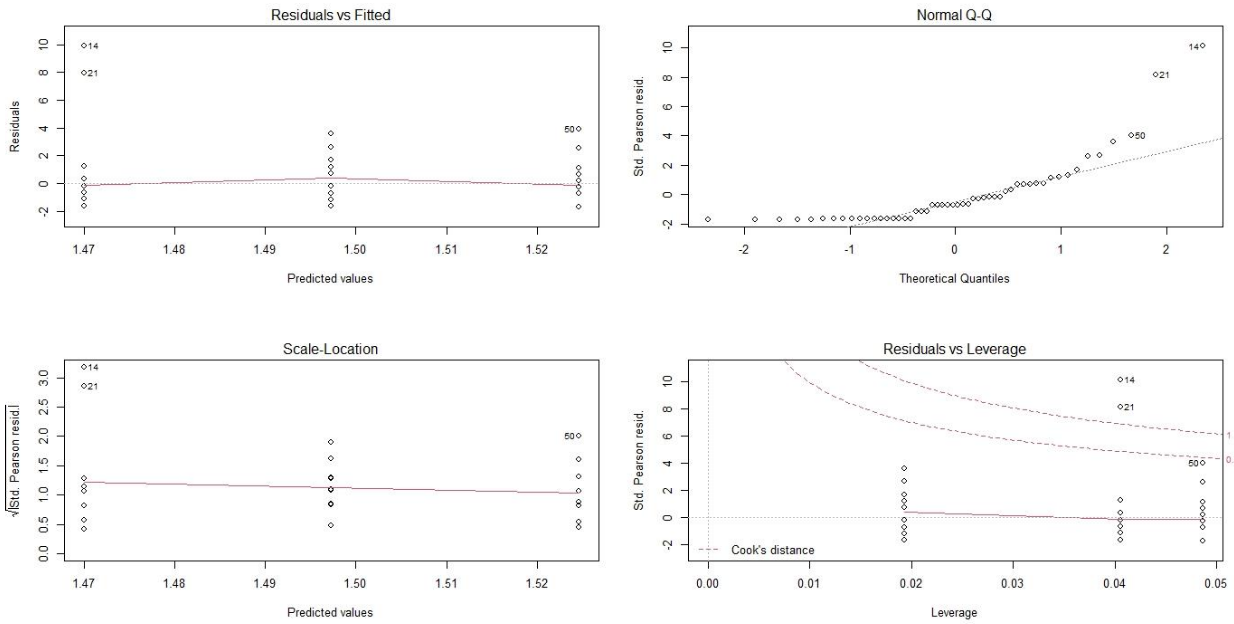


Figure N. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Ananose.

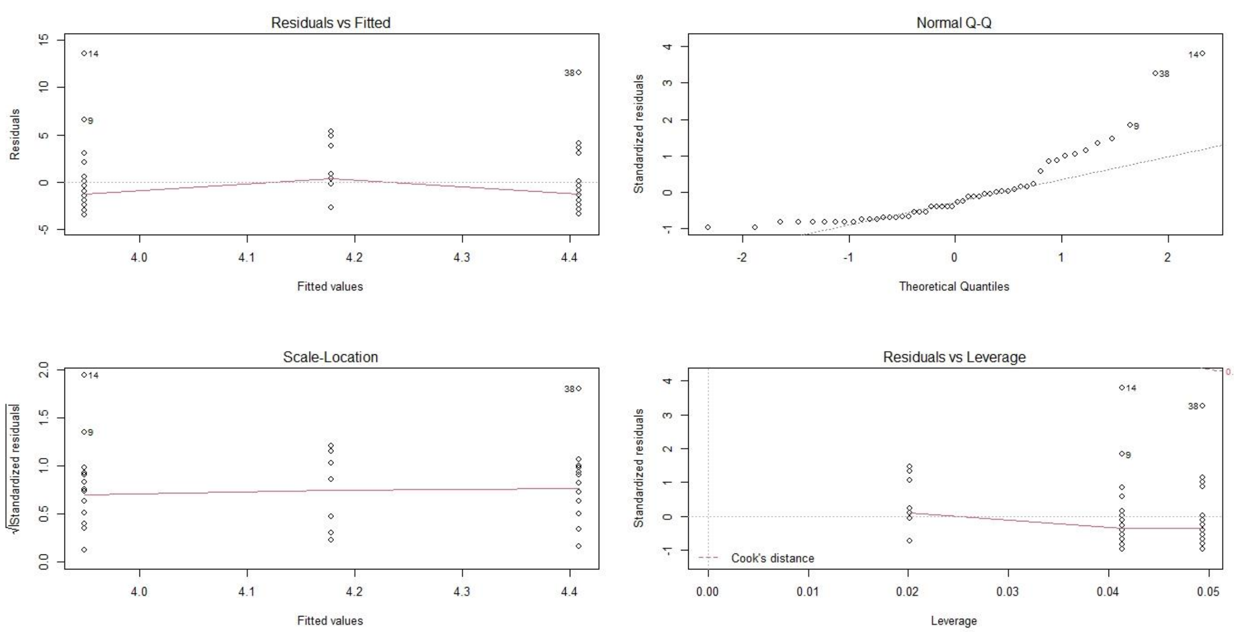


Figure O. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Ananose.

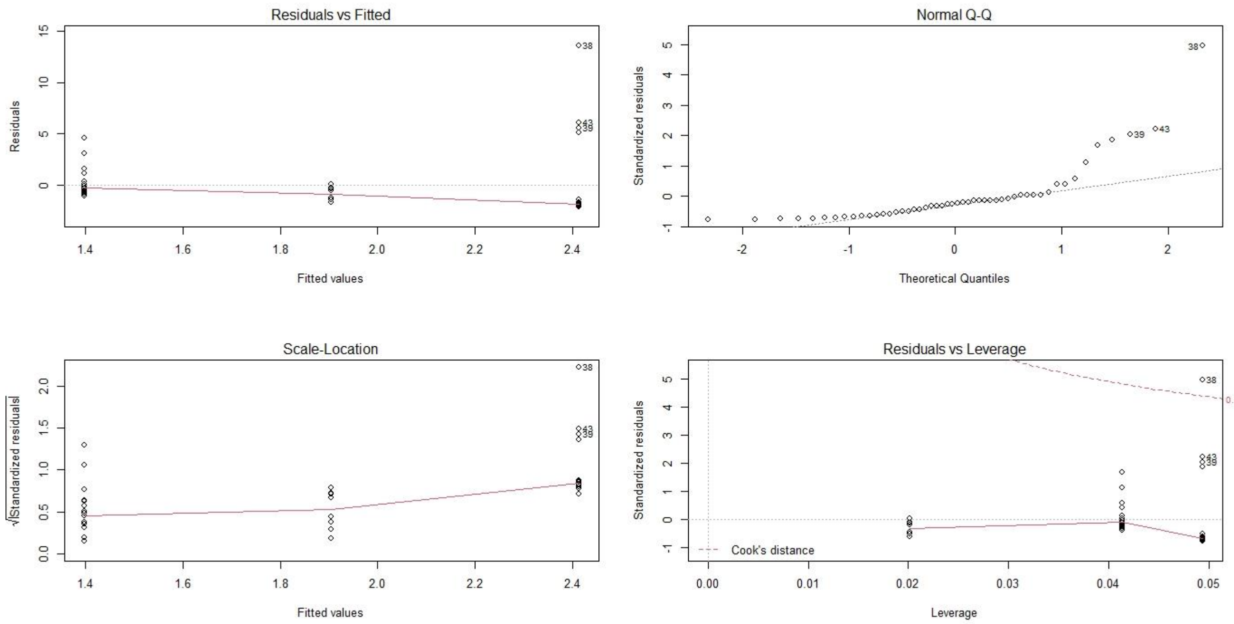


Figure P. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Ananoanose.

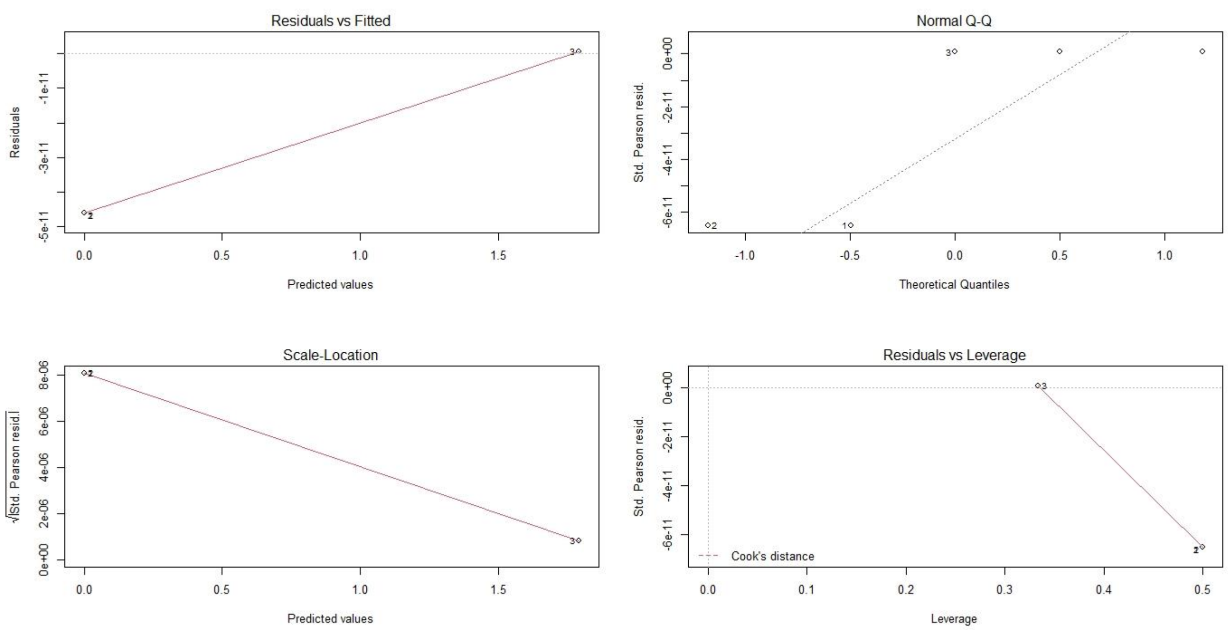


Figure Q. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Andamabe.

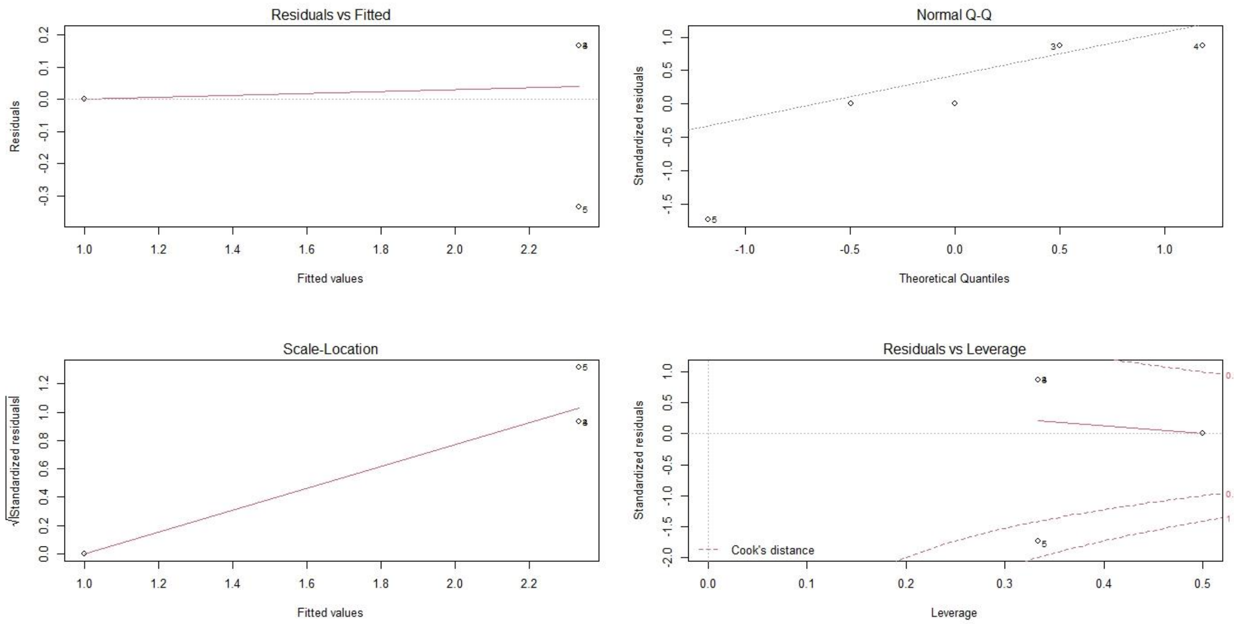


Figure R. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Andamabe.

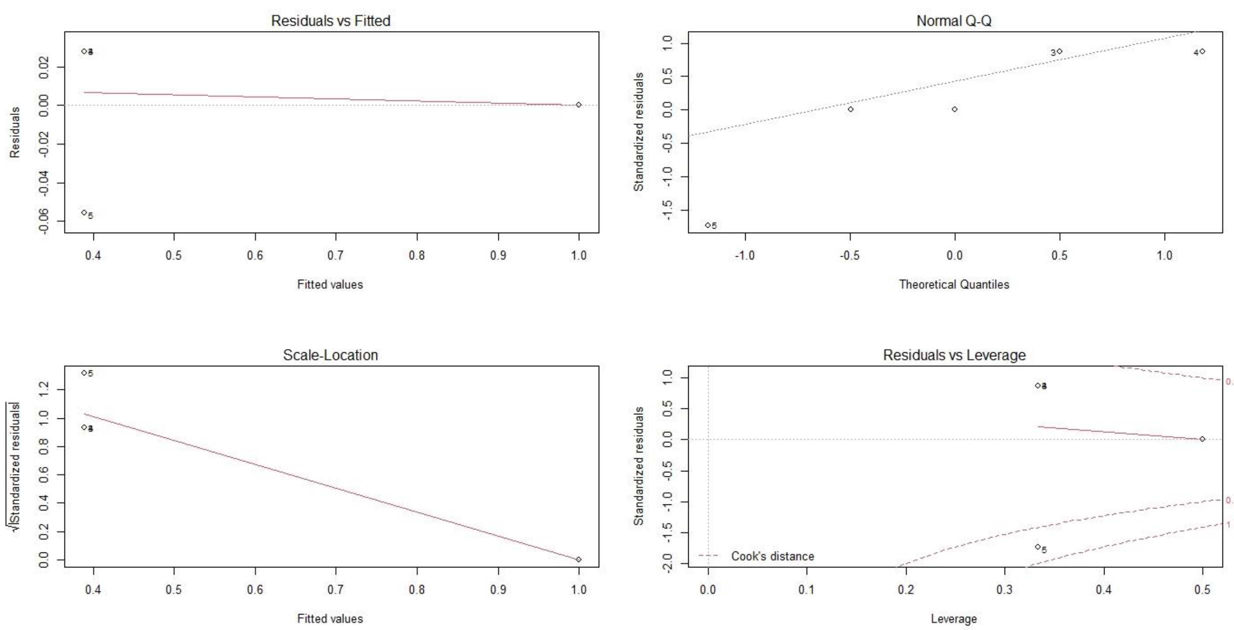


Figure S. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Andamabe.

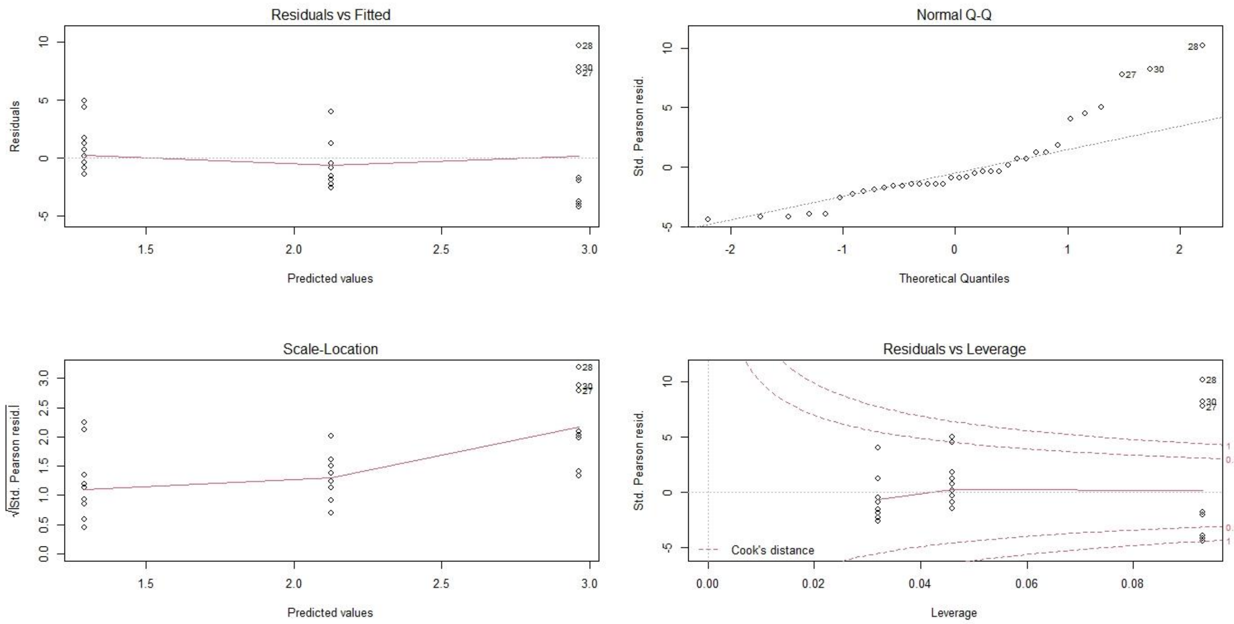


Figure T. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Anjokozoko.

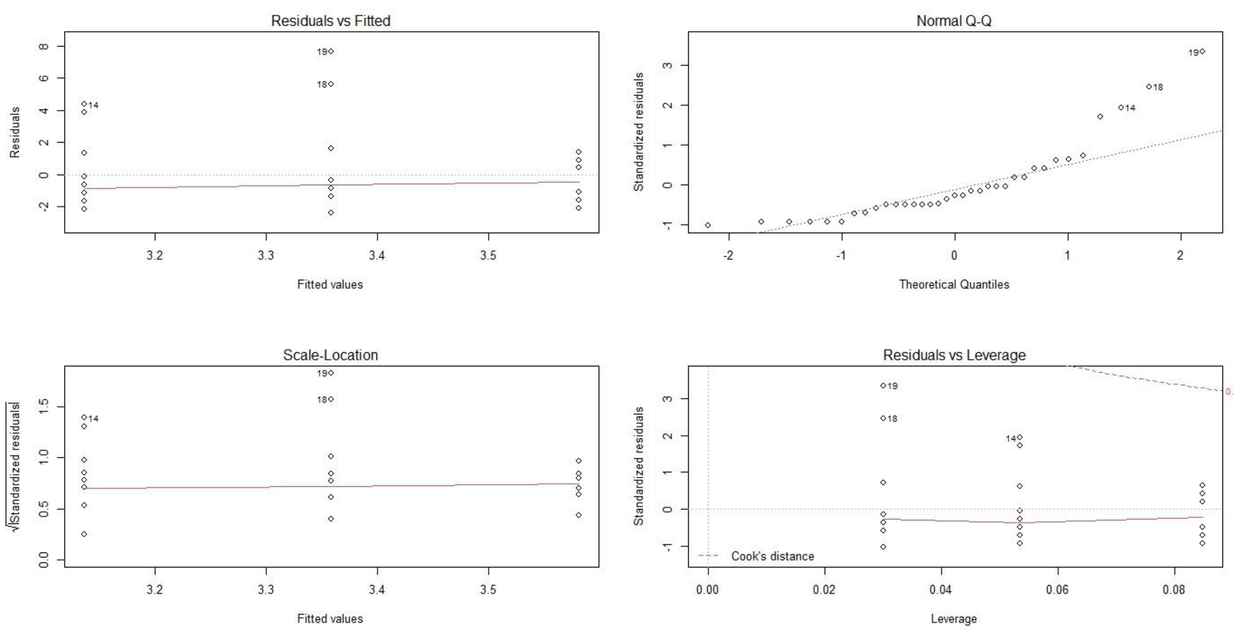


Figure U. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Anjokozoko.

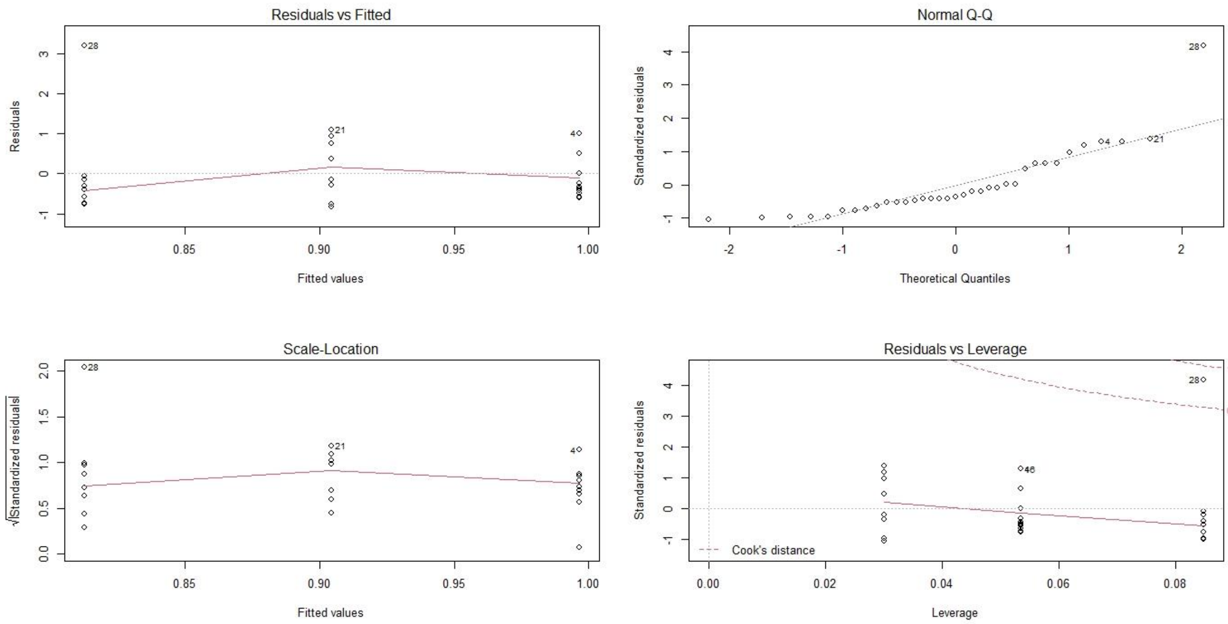


Figure V. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Anjokozoko.

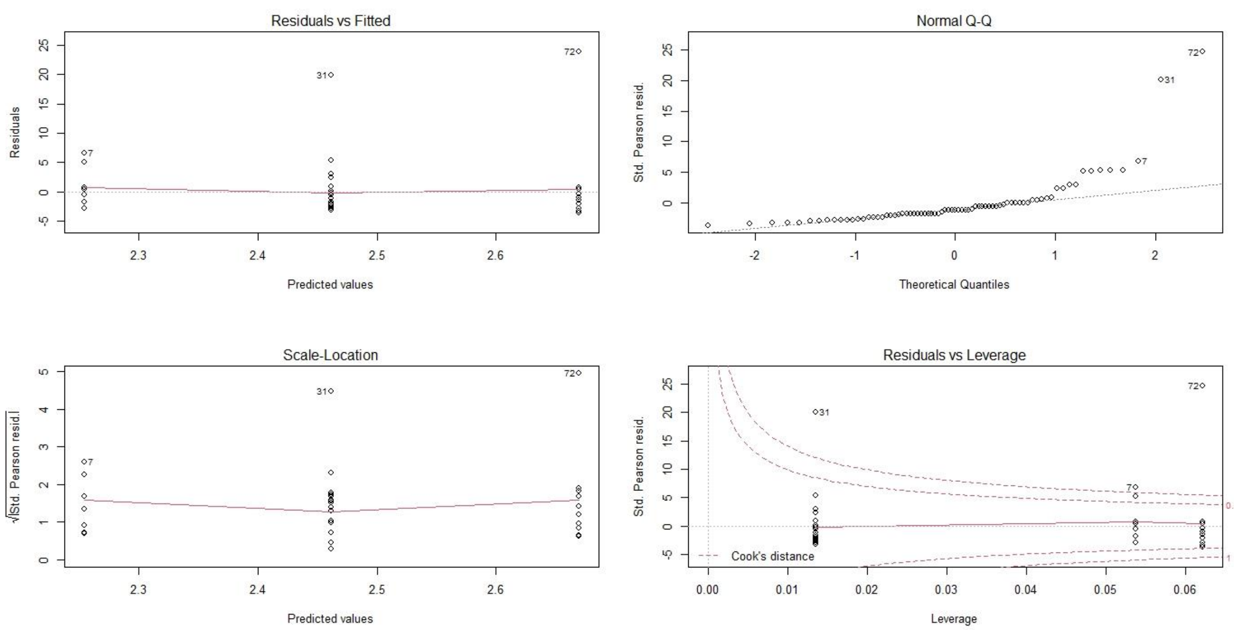


Figure W. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Belamera.

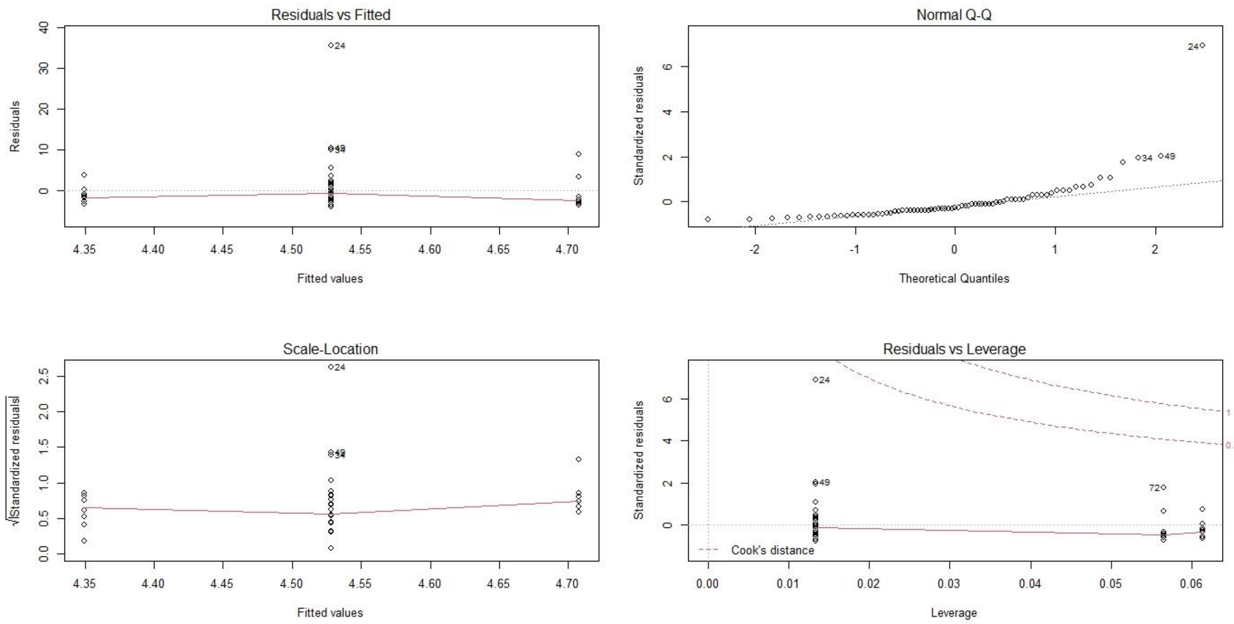


Figure X. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Belamera.

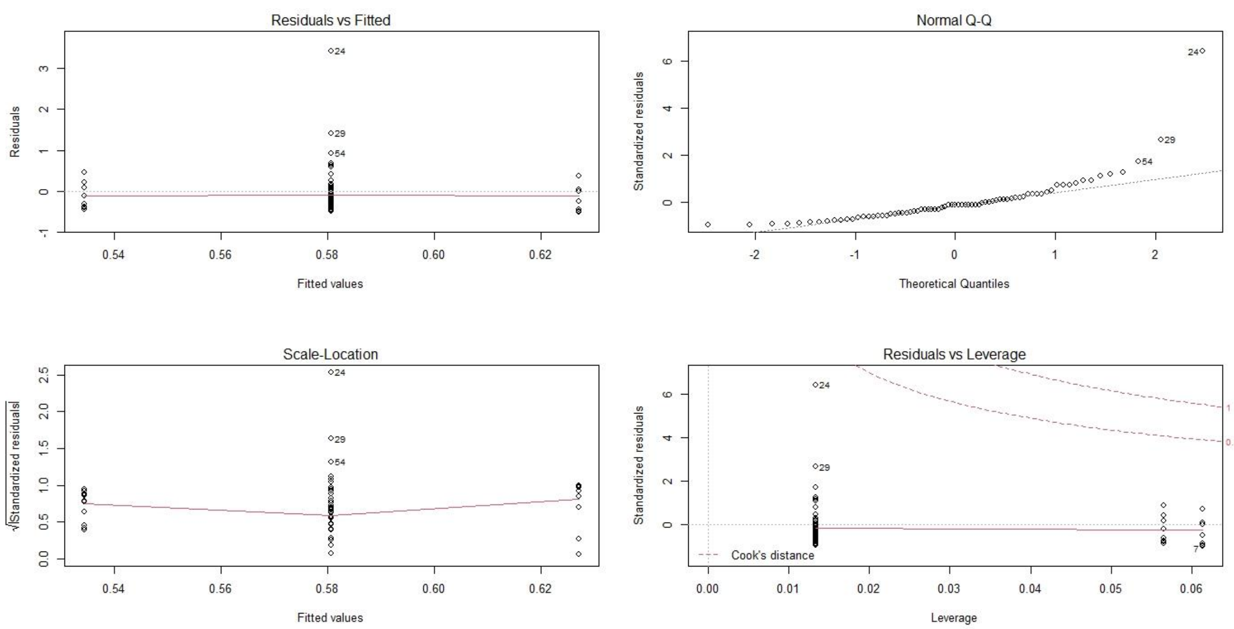


Figure Y. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Belamera.

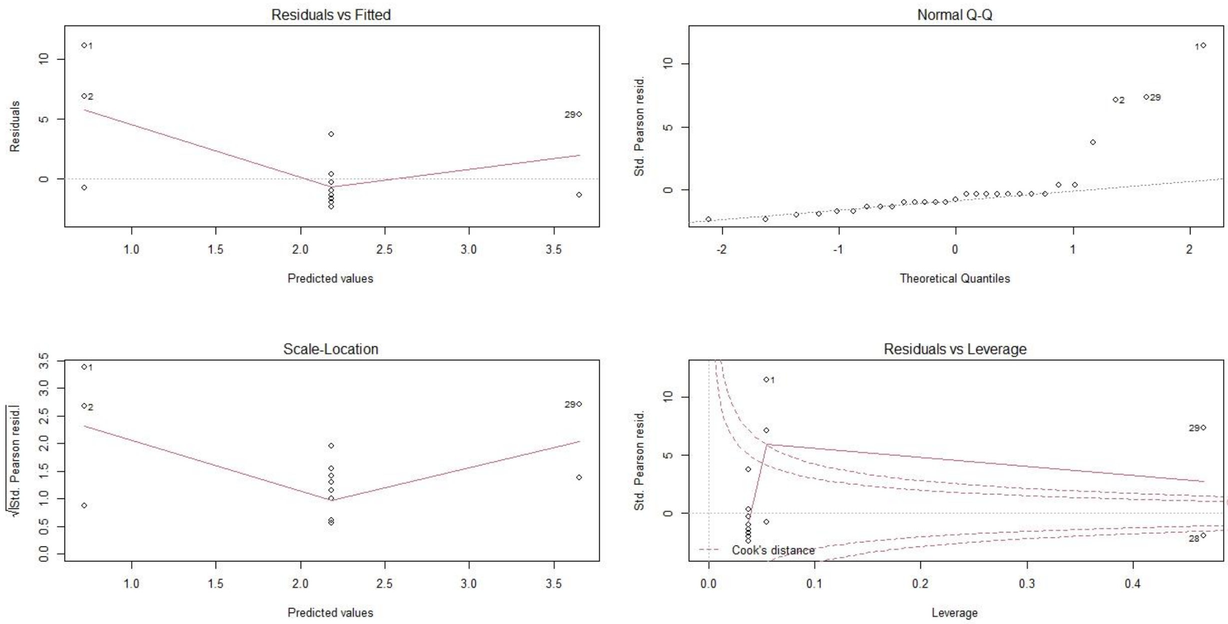


Figure Z. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nandoa.

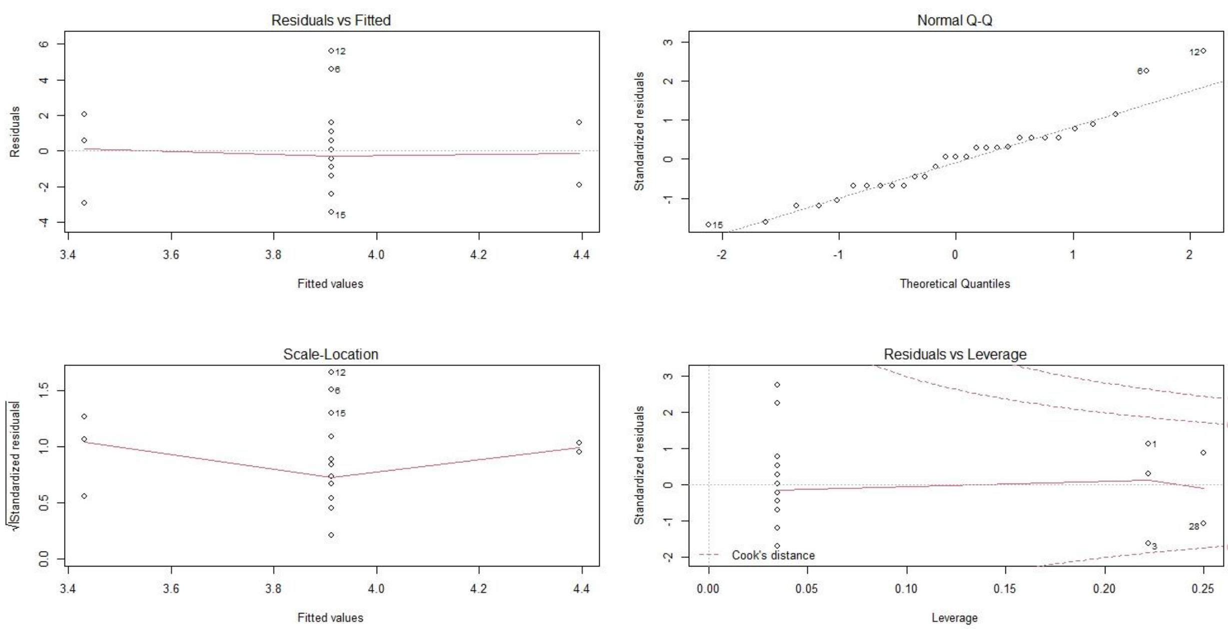


Figure AA. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nandoa.

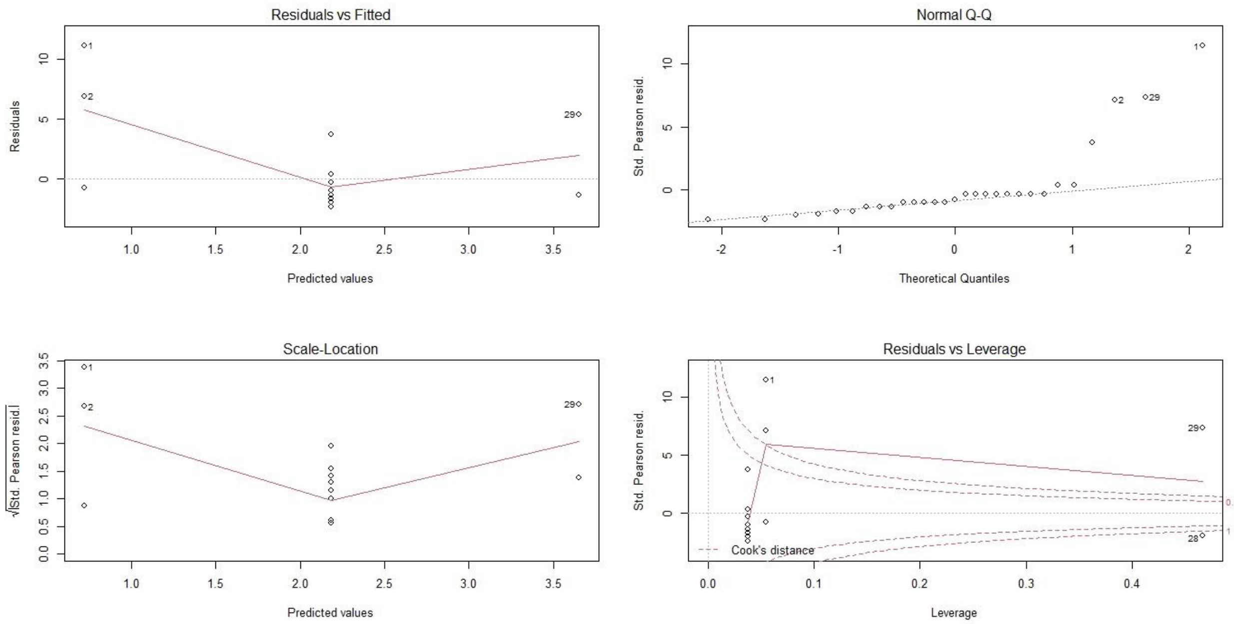


Figure AB. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nandoa.

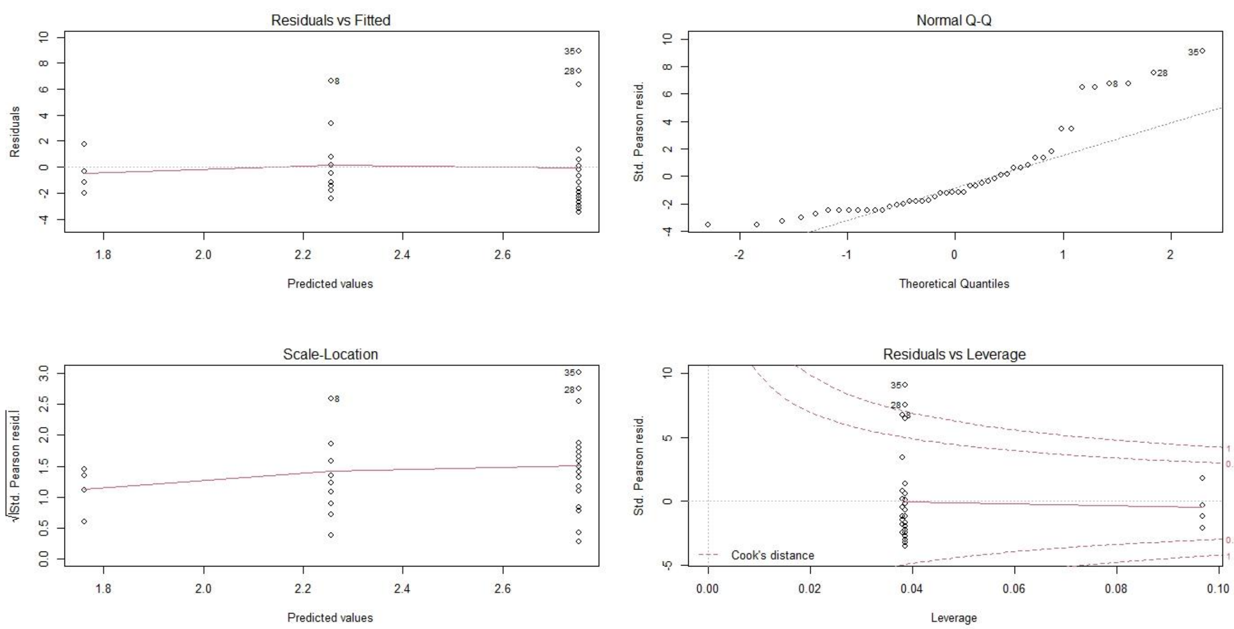


Figure AC. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nanohofa.

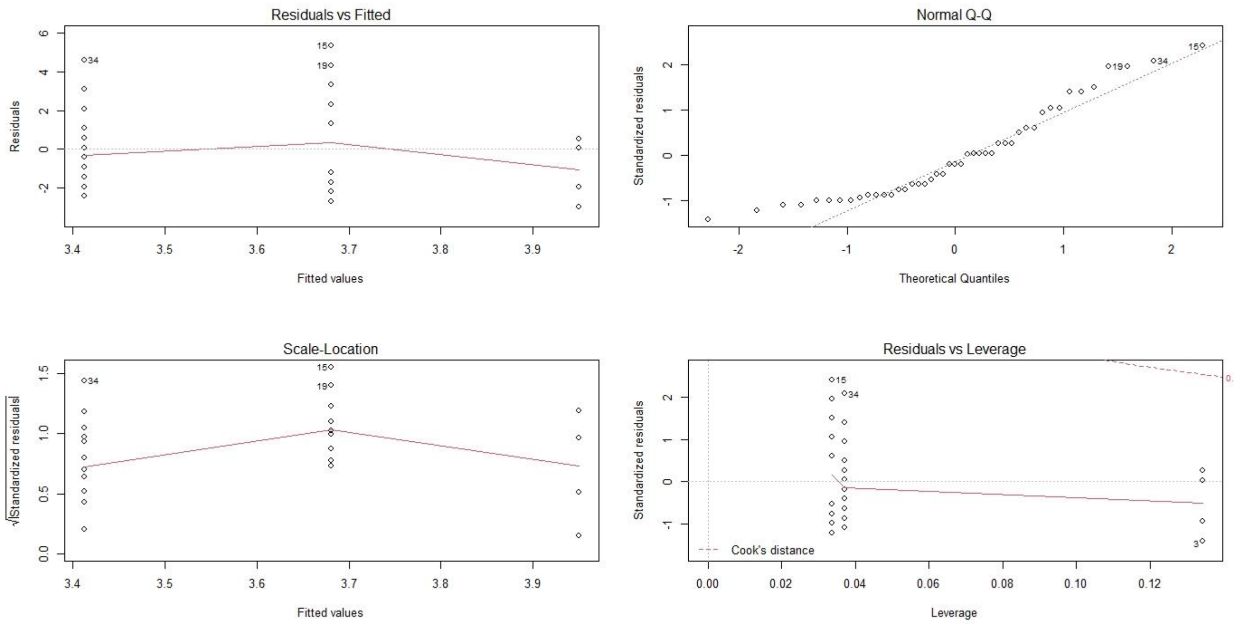


Figure AD. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nanohofa.

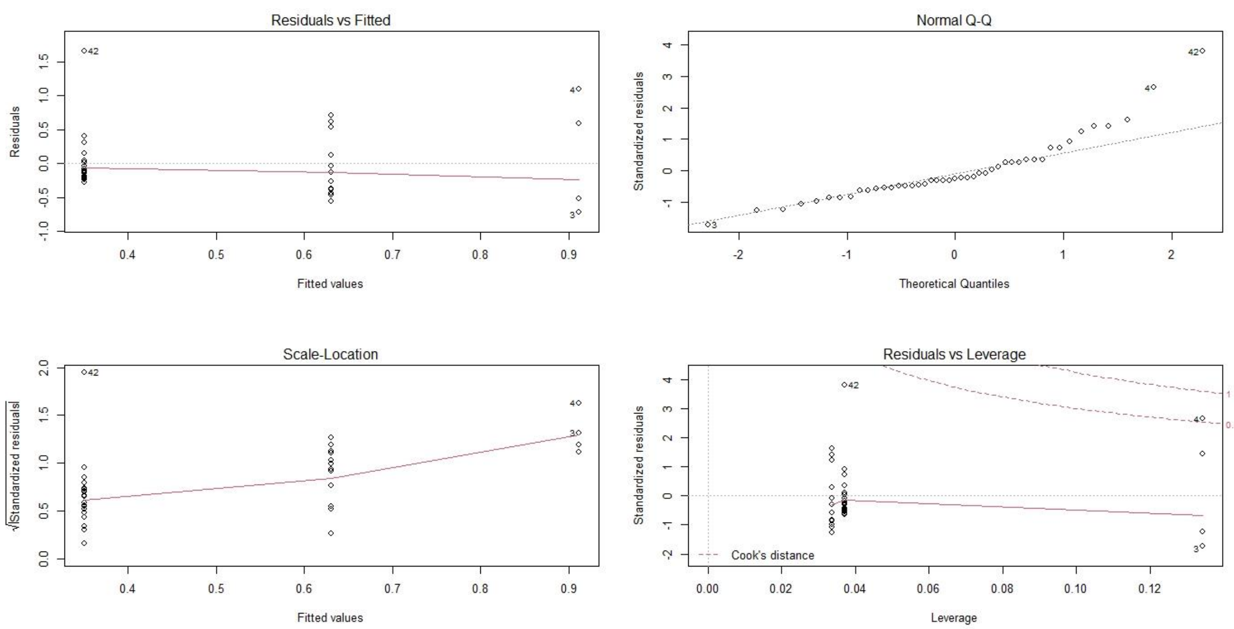


Figure AE. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nanohofa.

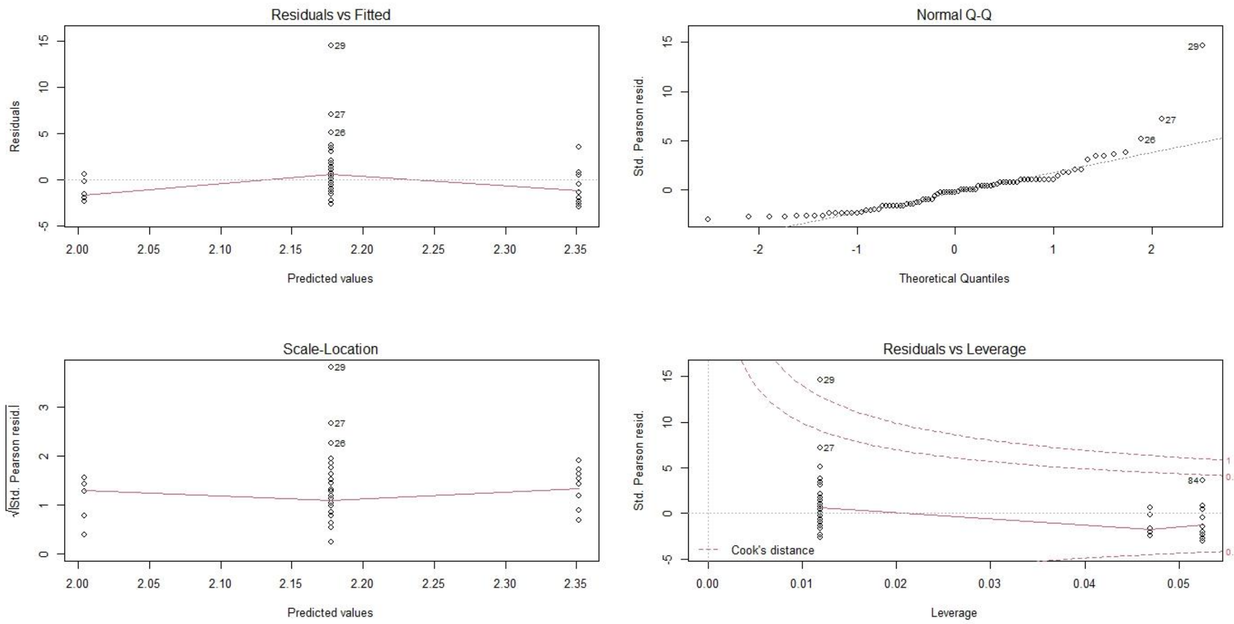


Figure AF. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anananose.

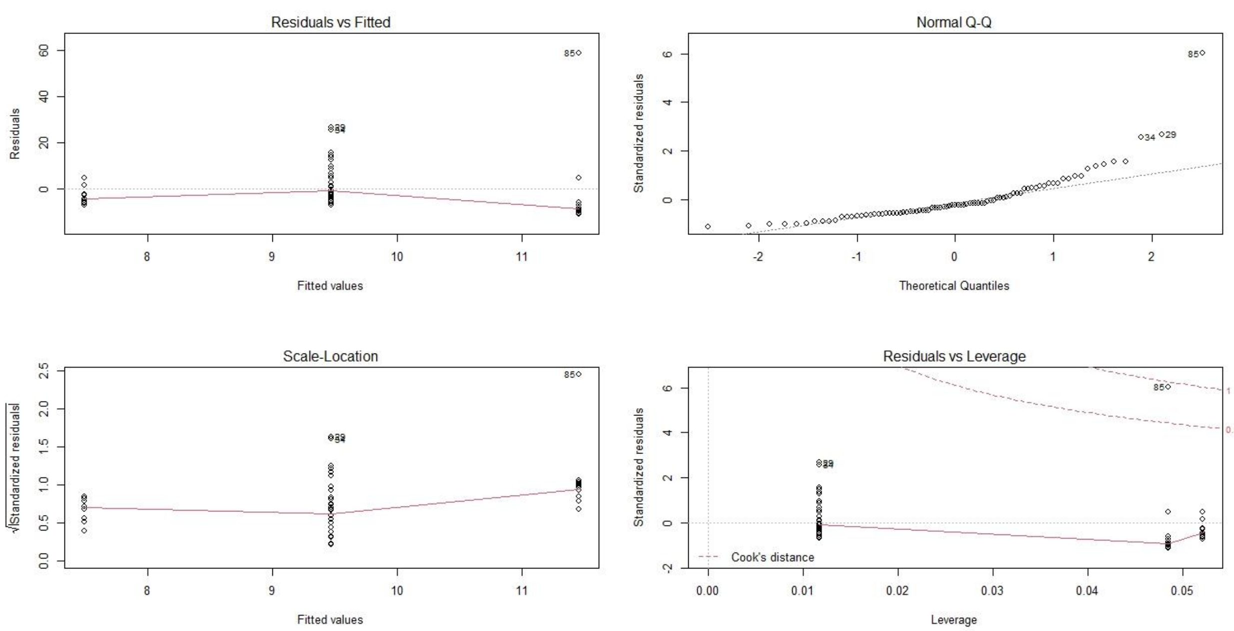


Figure AG. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anananose.

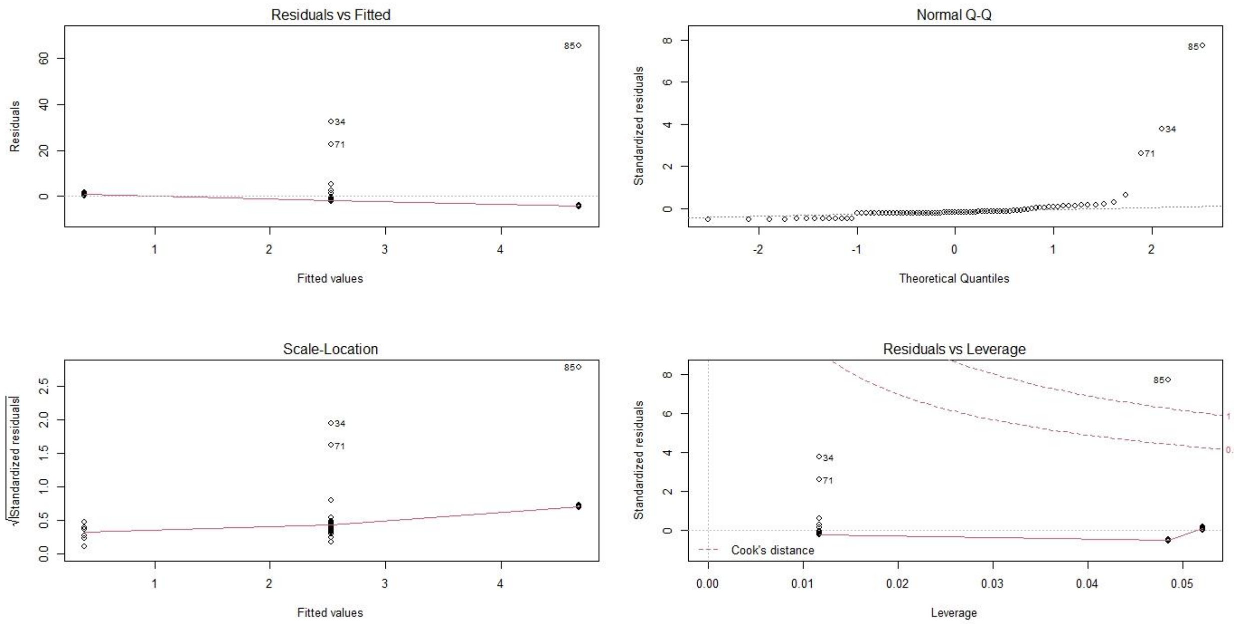


Figure AH. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anananose.

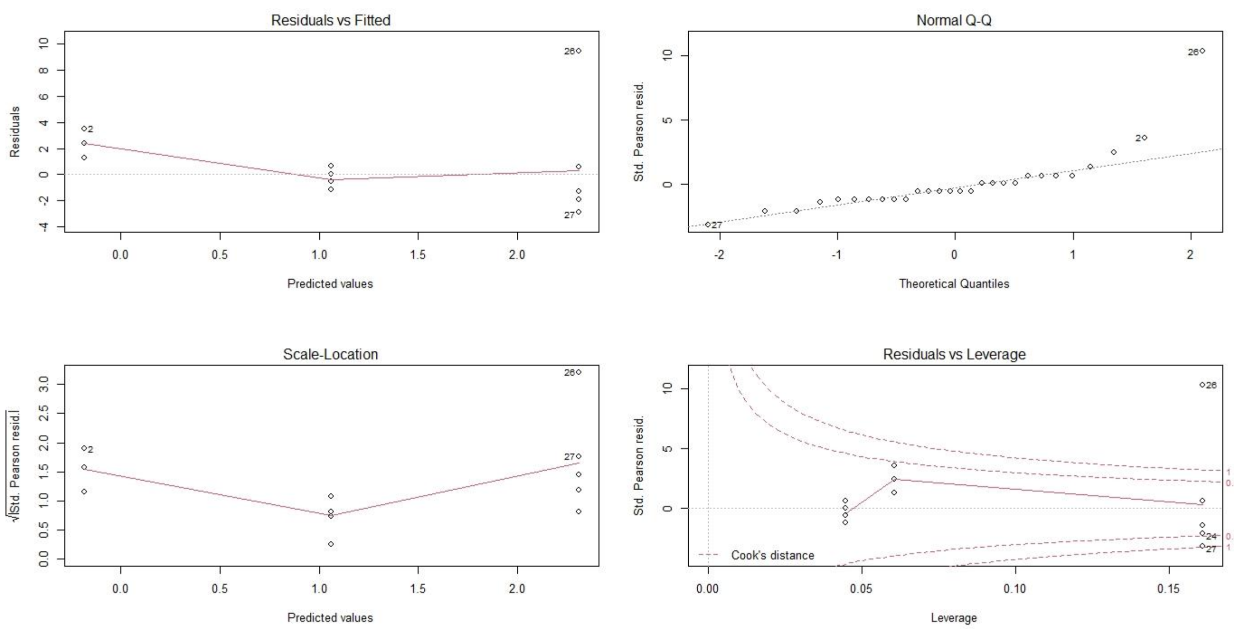
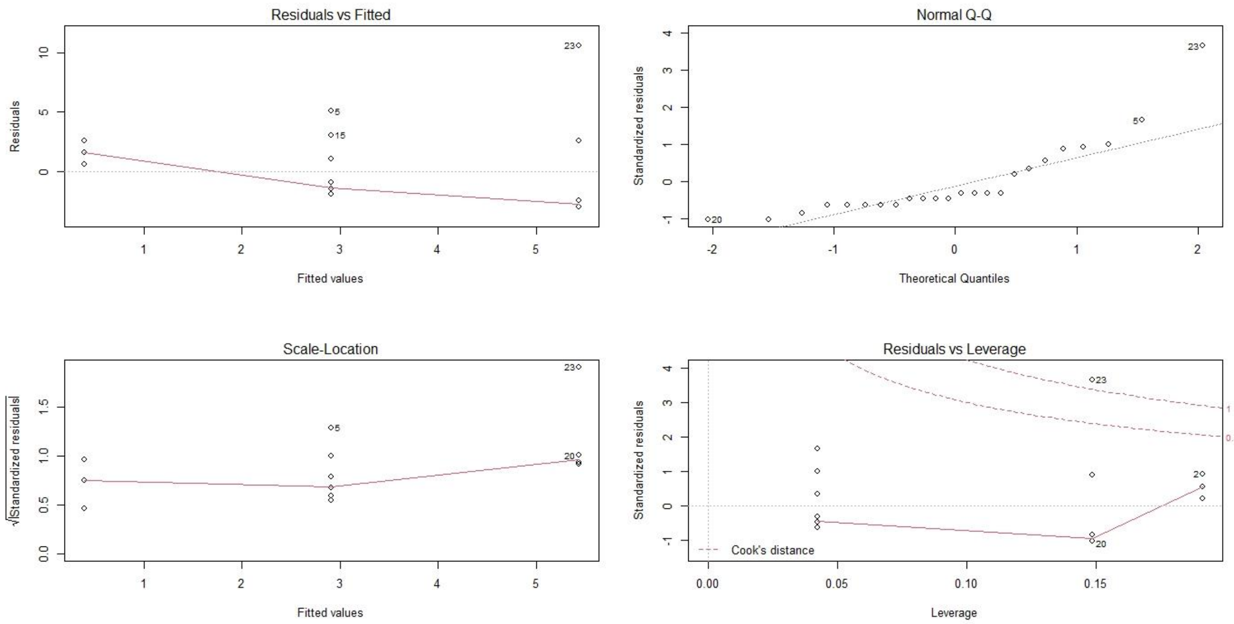


Figure AI. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Andamabe.



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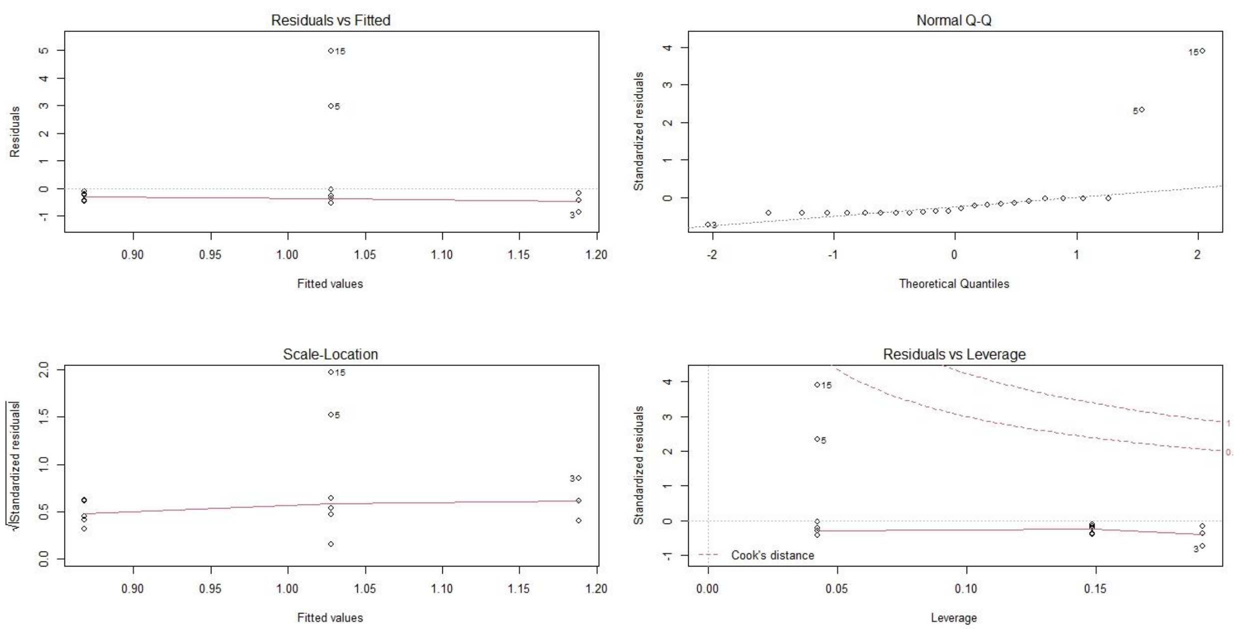


Figure AK. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Andamabe.

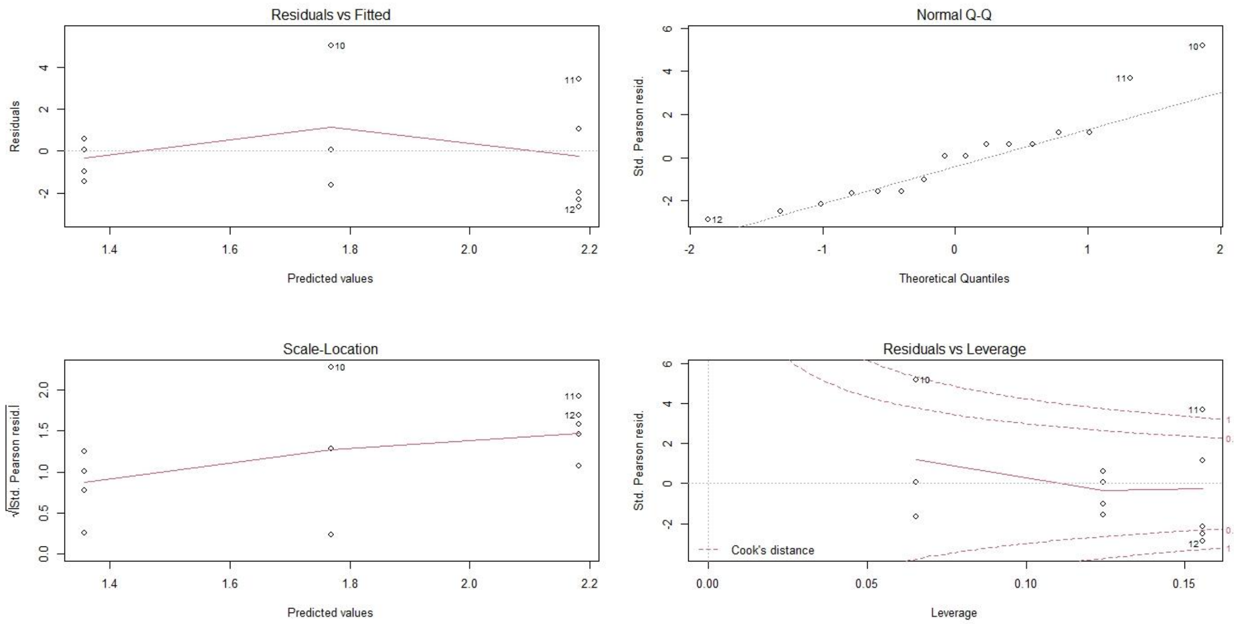


Figure AL. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anjokozoko.

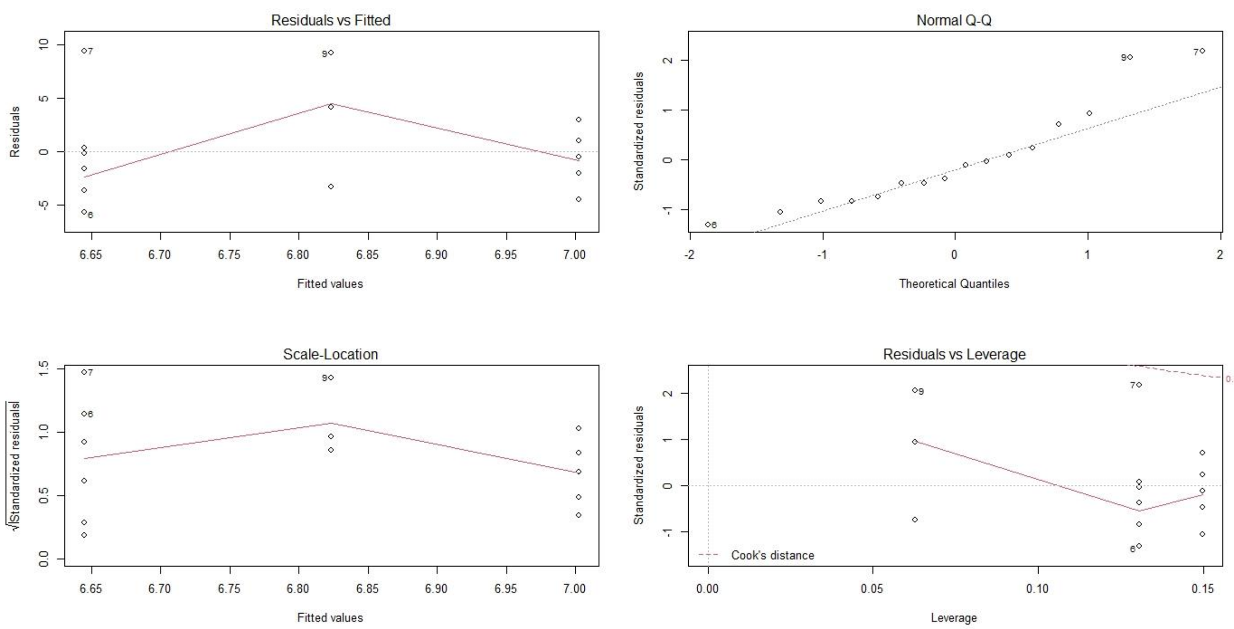


Figure AM. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anjokozoko.

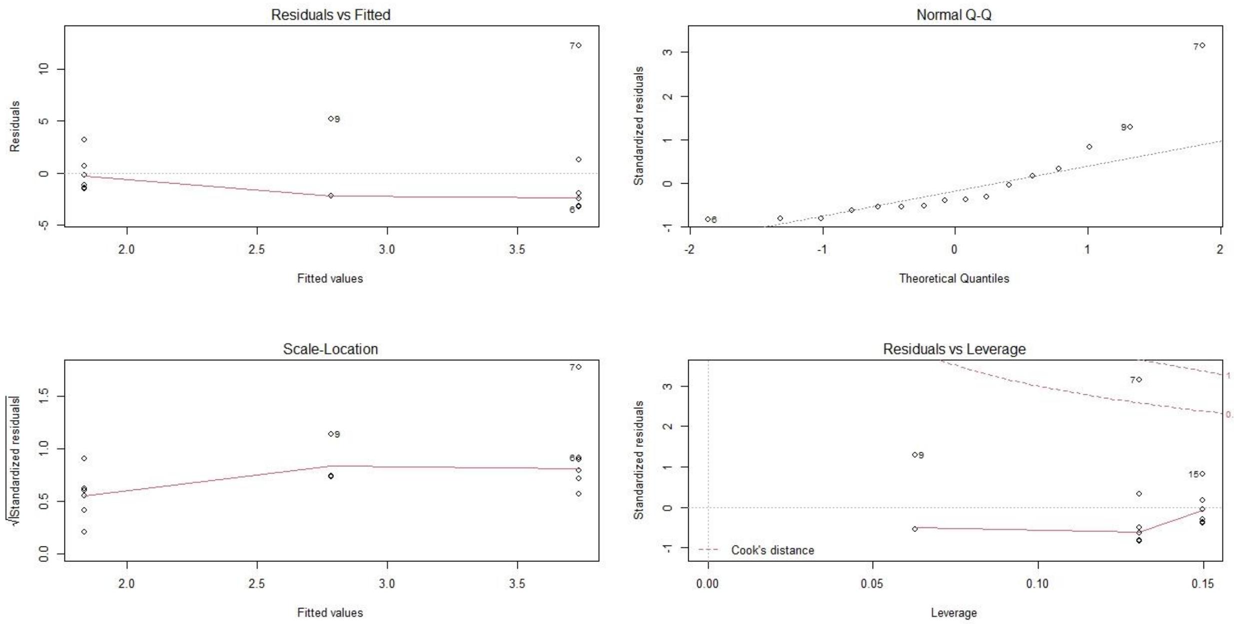


Figure AN. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anjokozoko.

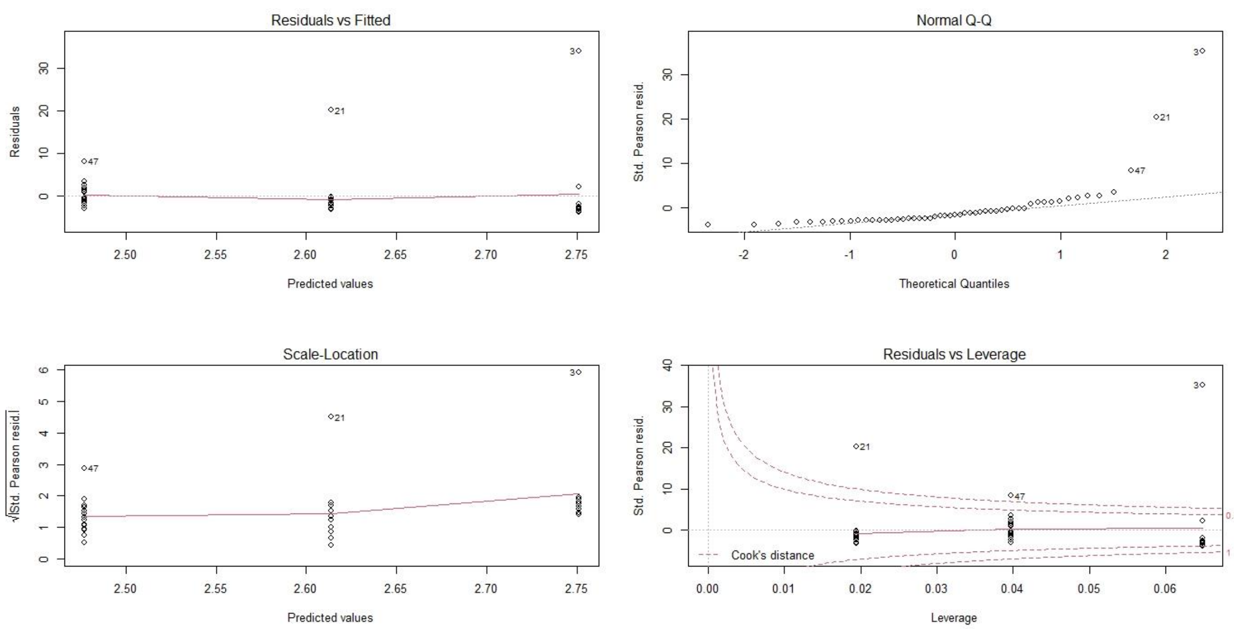


Figure AO. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Belamera.

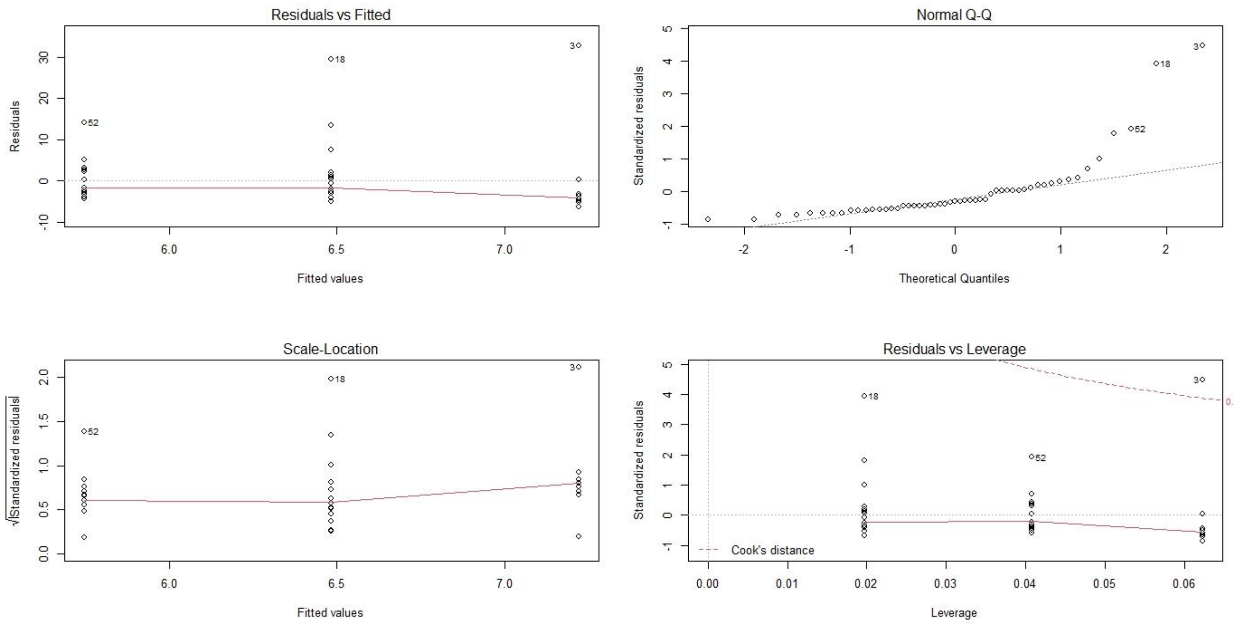
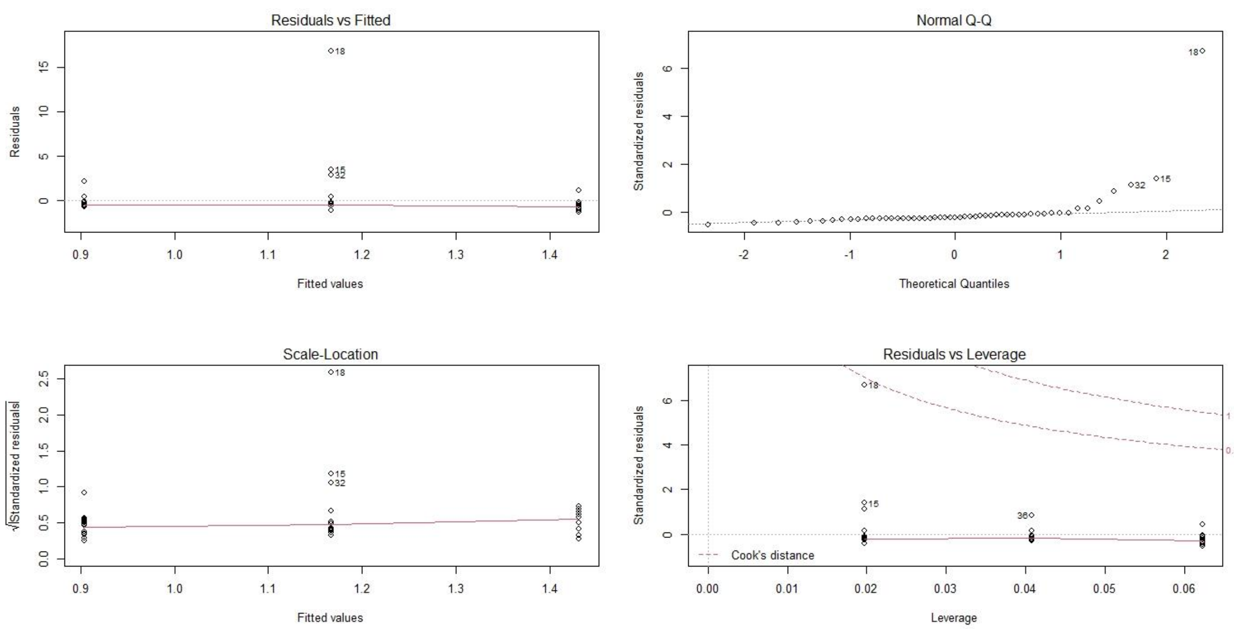


Figure AP. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Belamera.



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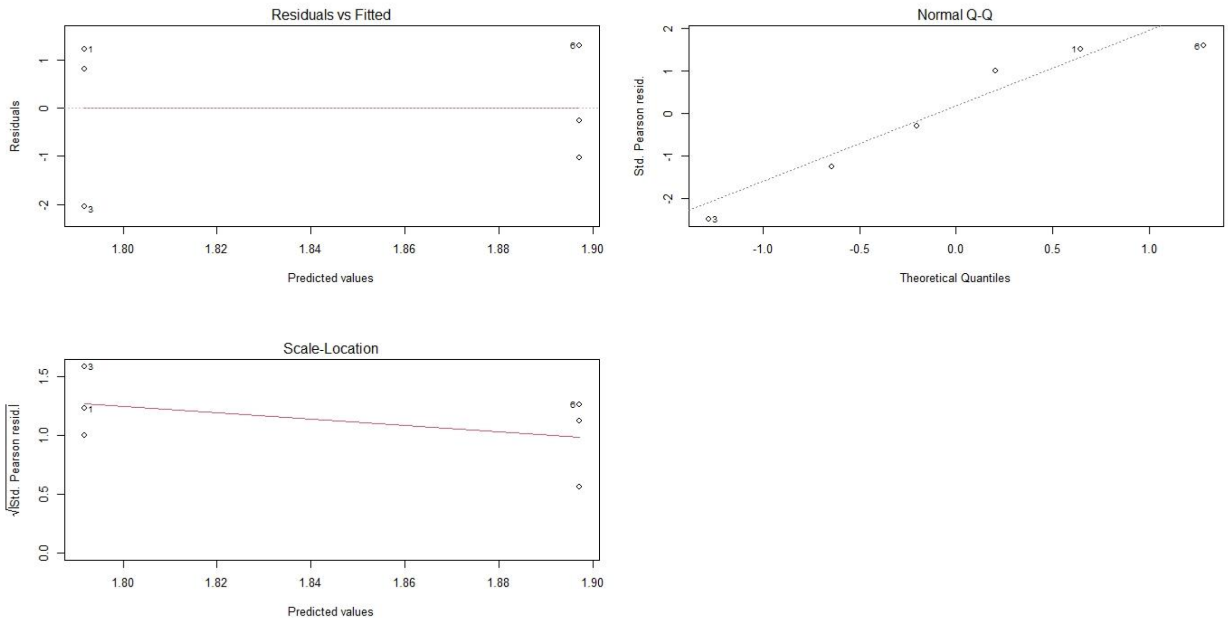
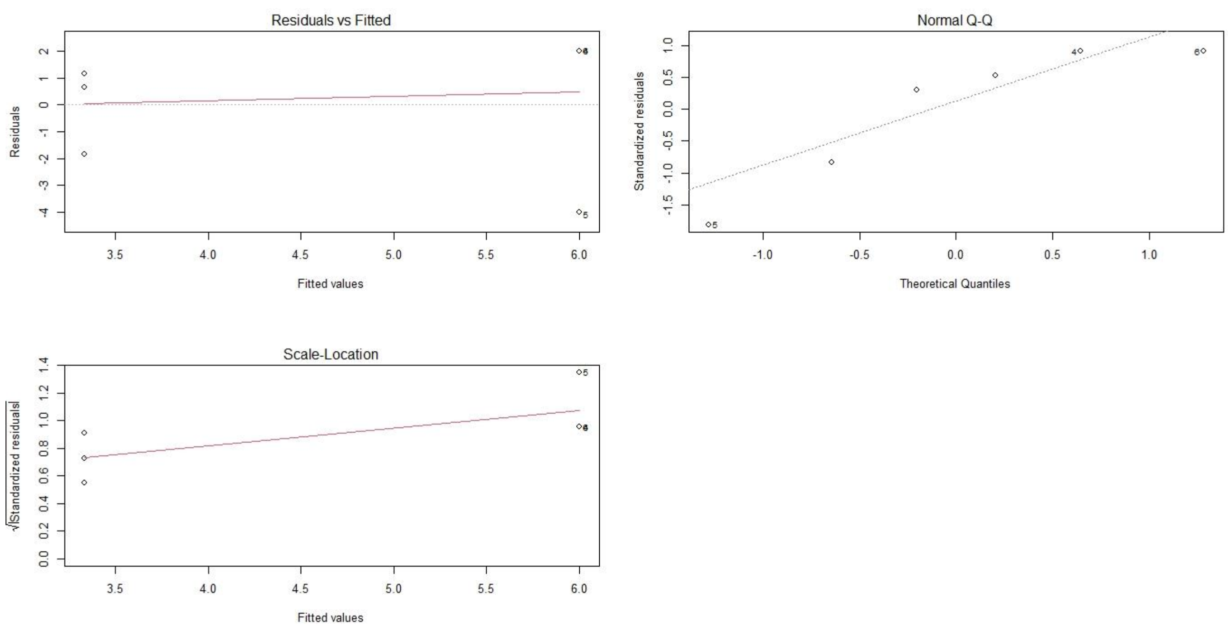


Figure AR. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Nandoa.



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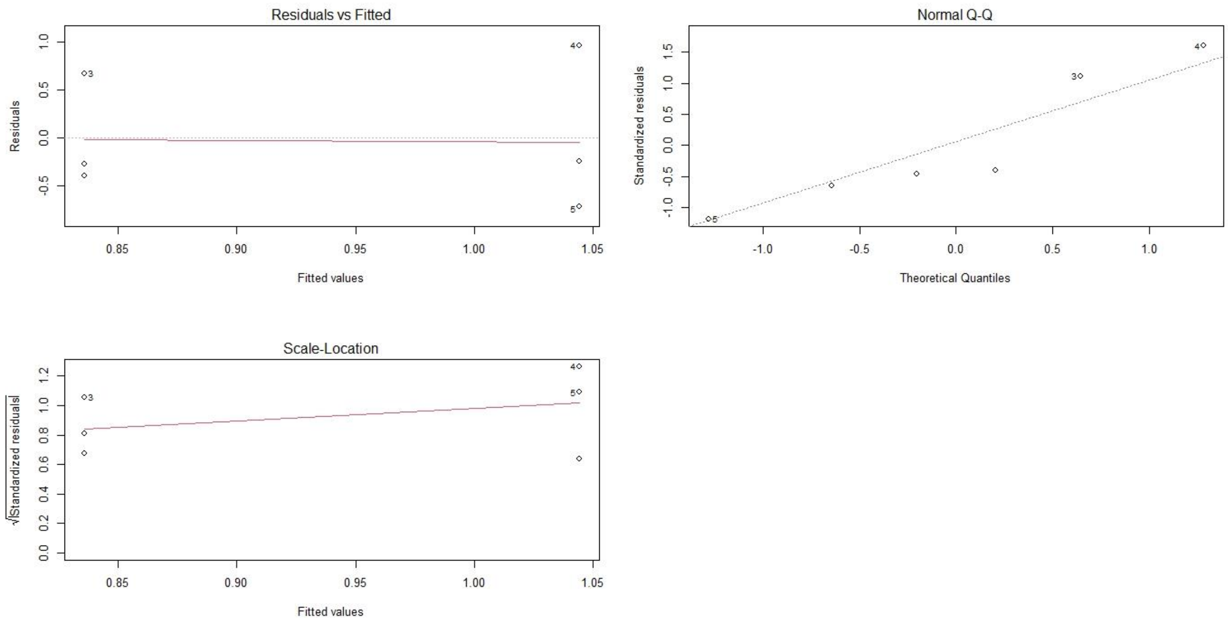
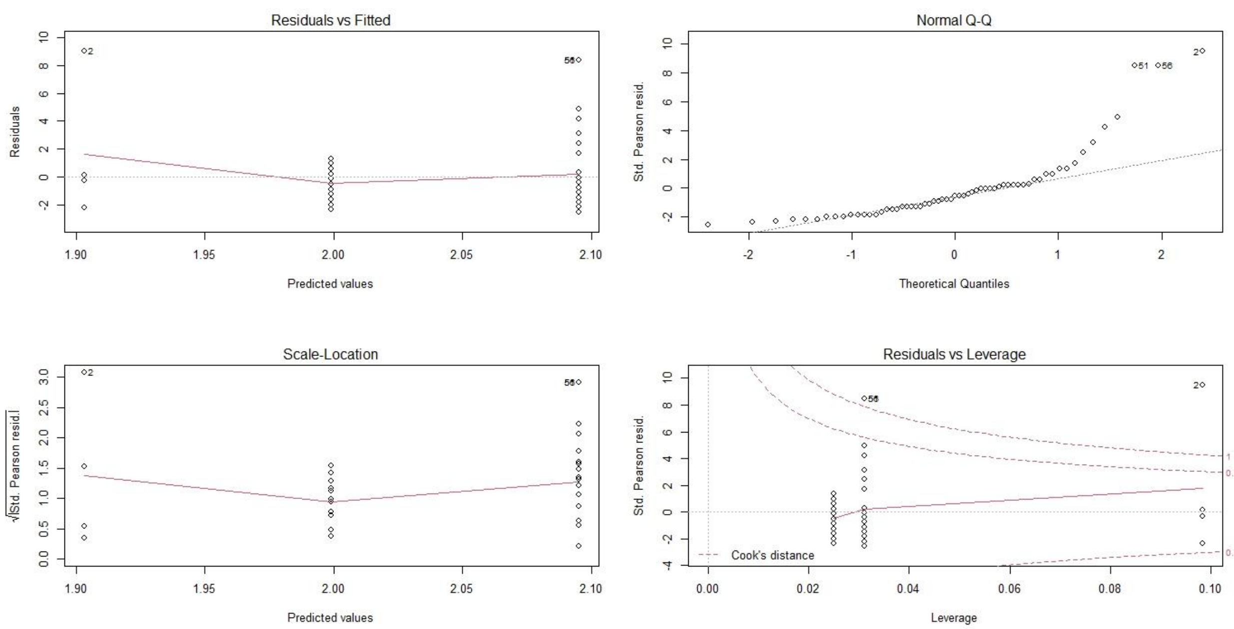


Figure AT. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Nandoa.



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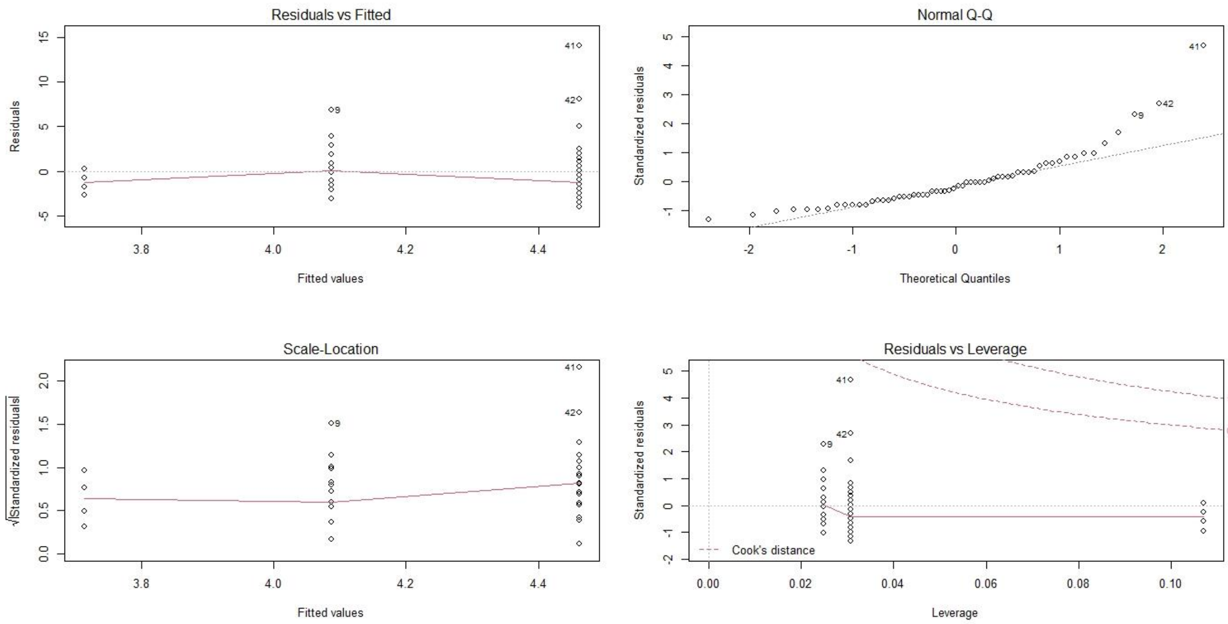

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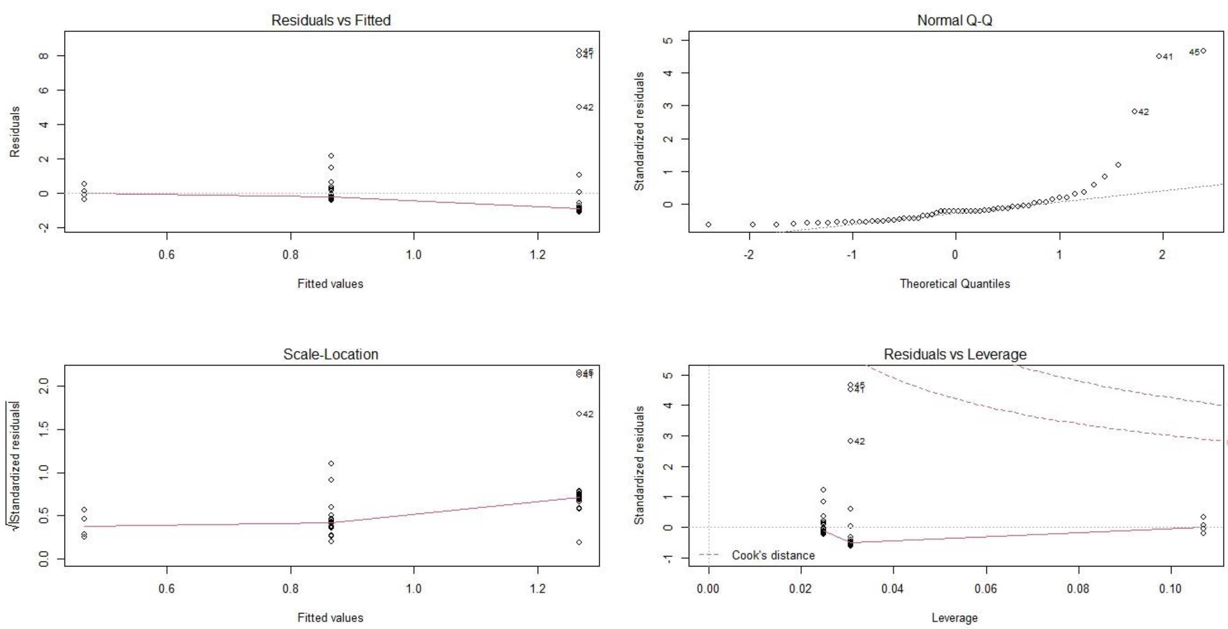
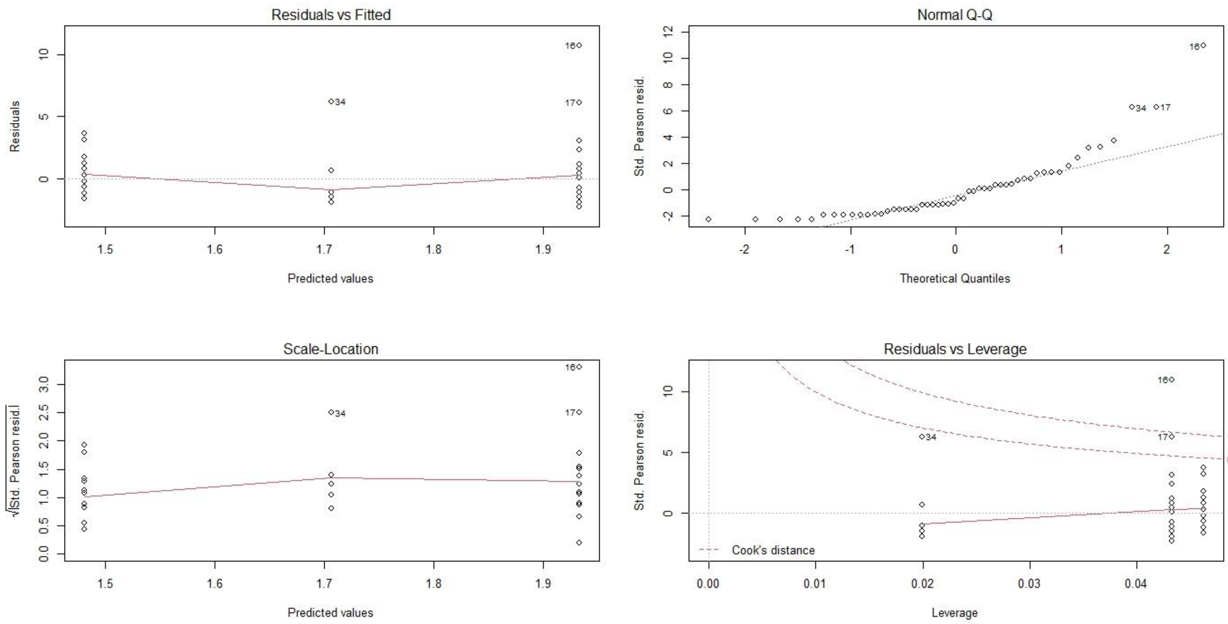


Figure AW. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Fish landed per trip in November and December 2011, 2015, and 2019 at the fishing site Nanohofa.



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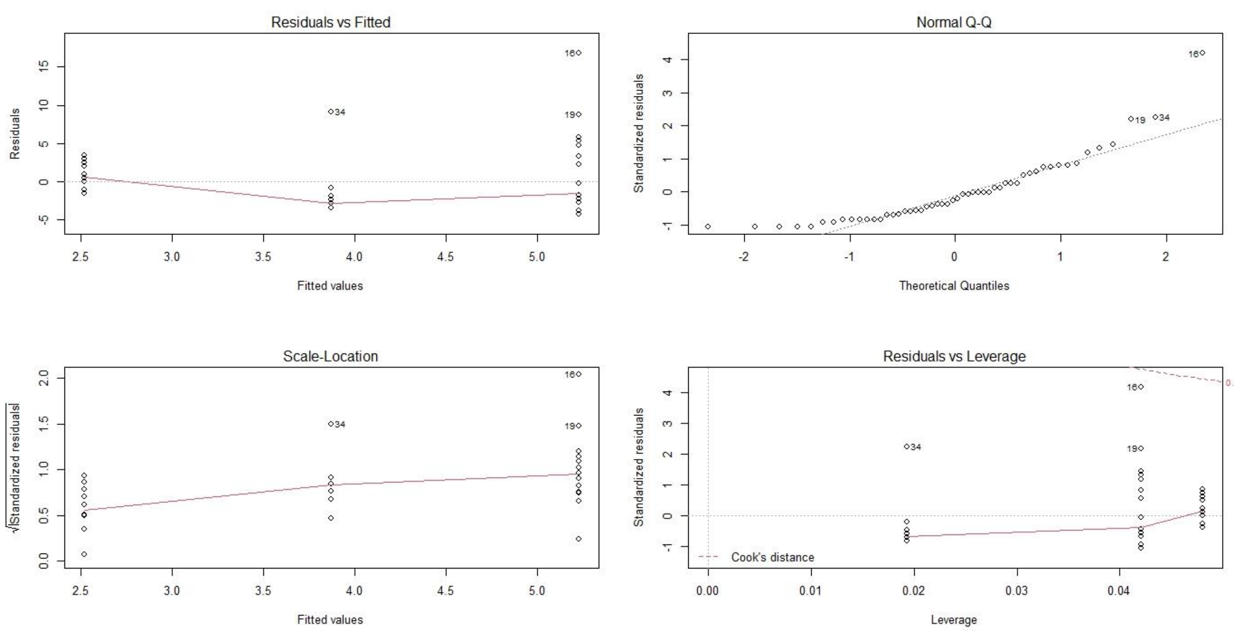


Figure AY. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Anananose.

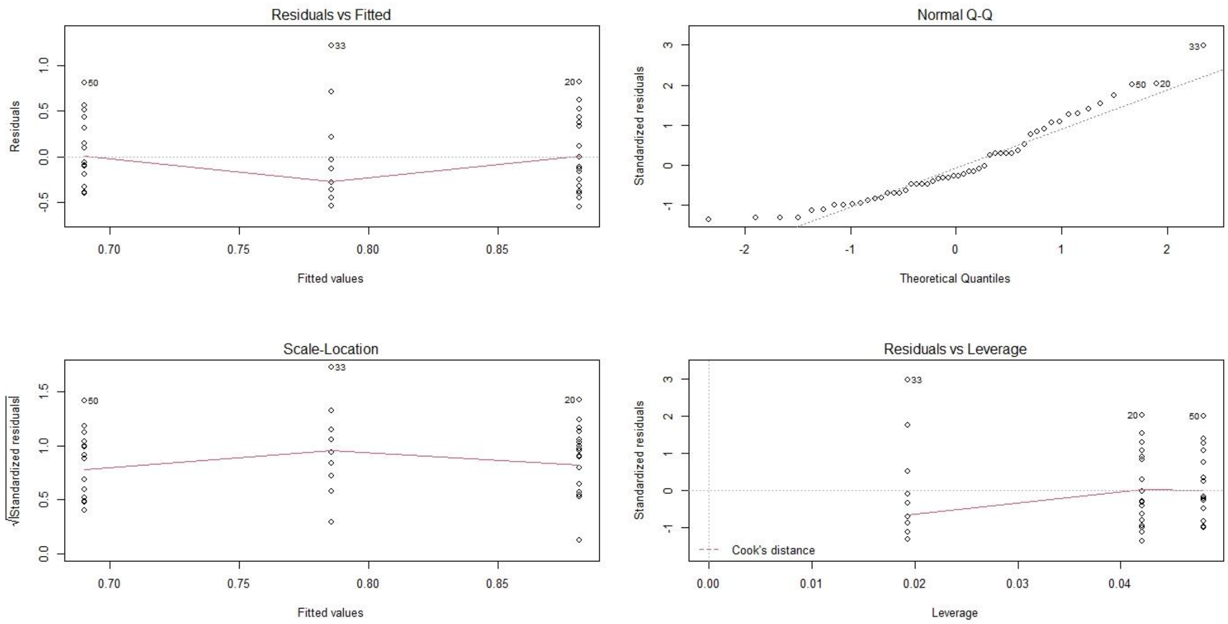


Figure AZ. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Ananansose.

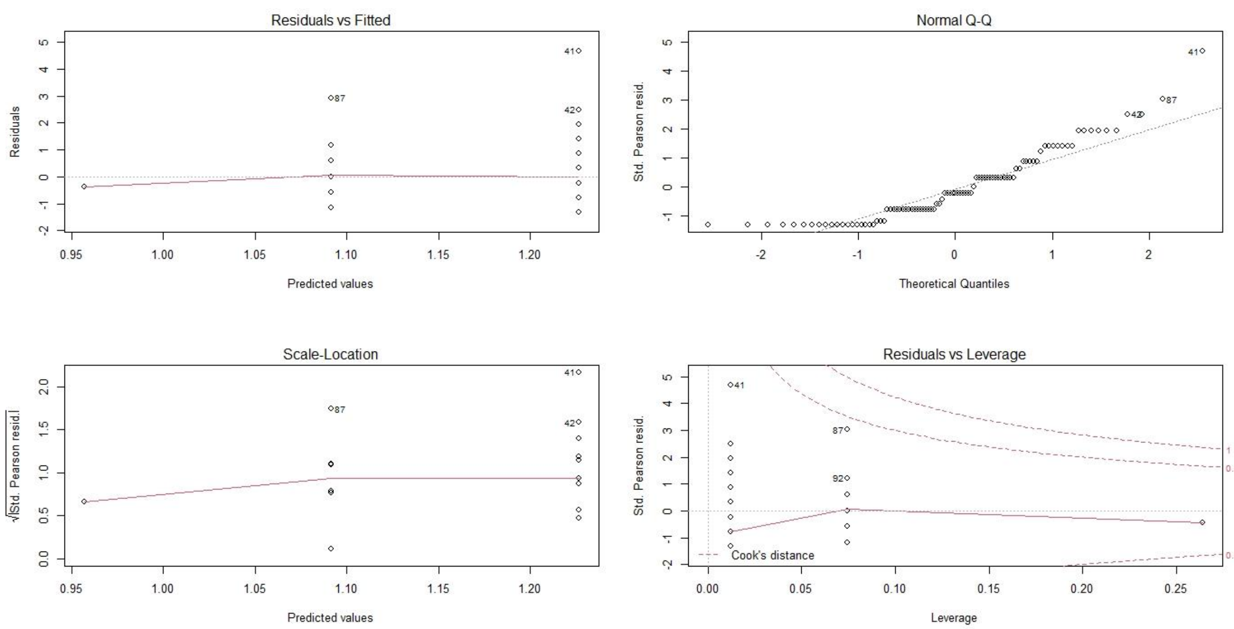


Figure BA. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Andamabe.

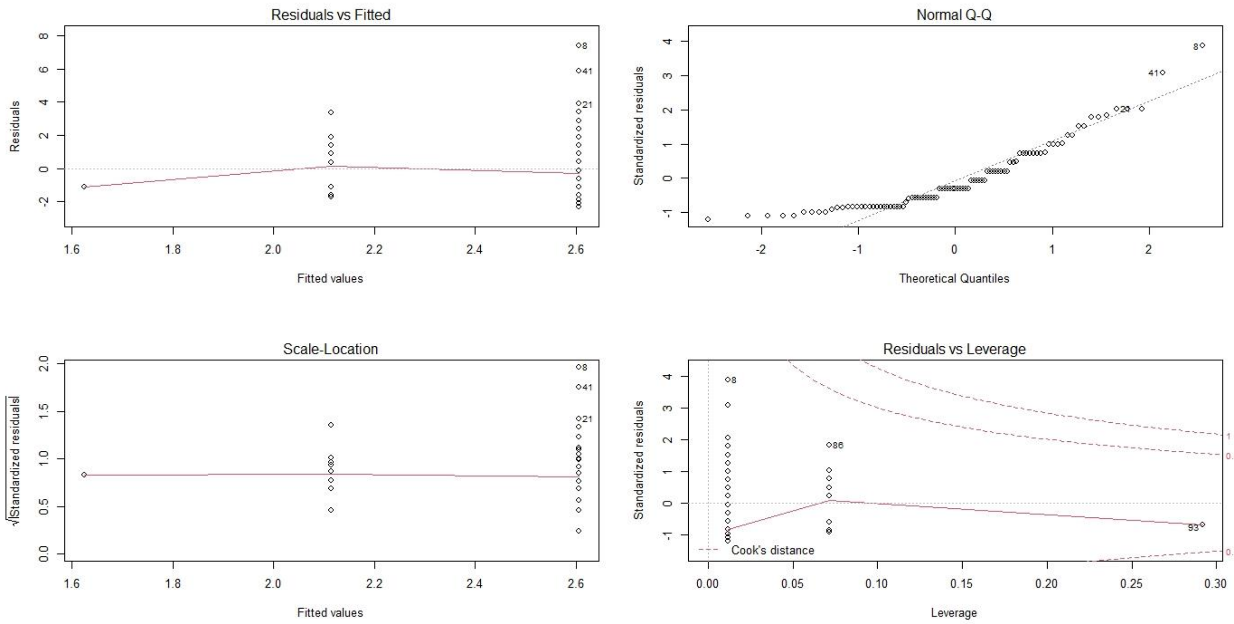


Figure BB. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Andamabe.

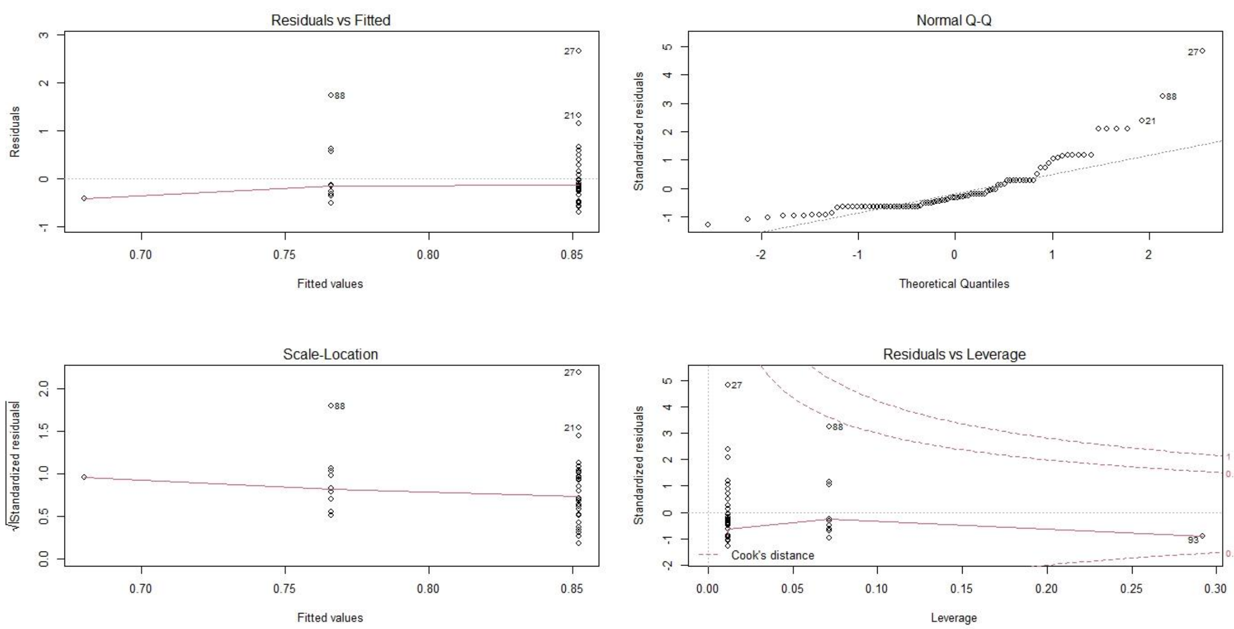


Figure BC. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Andamabe.

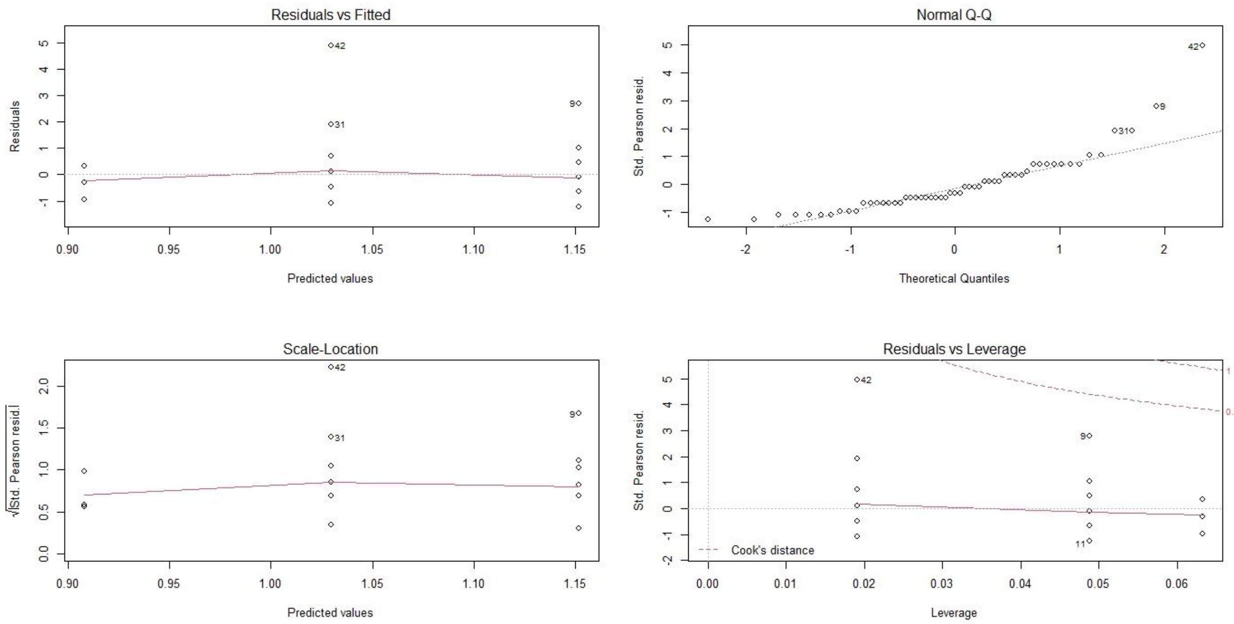
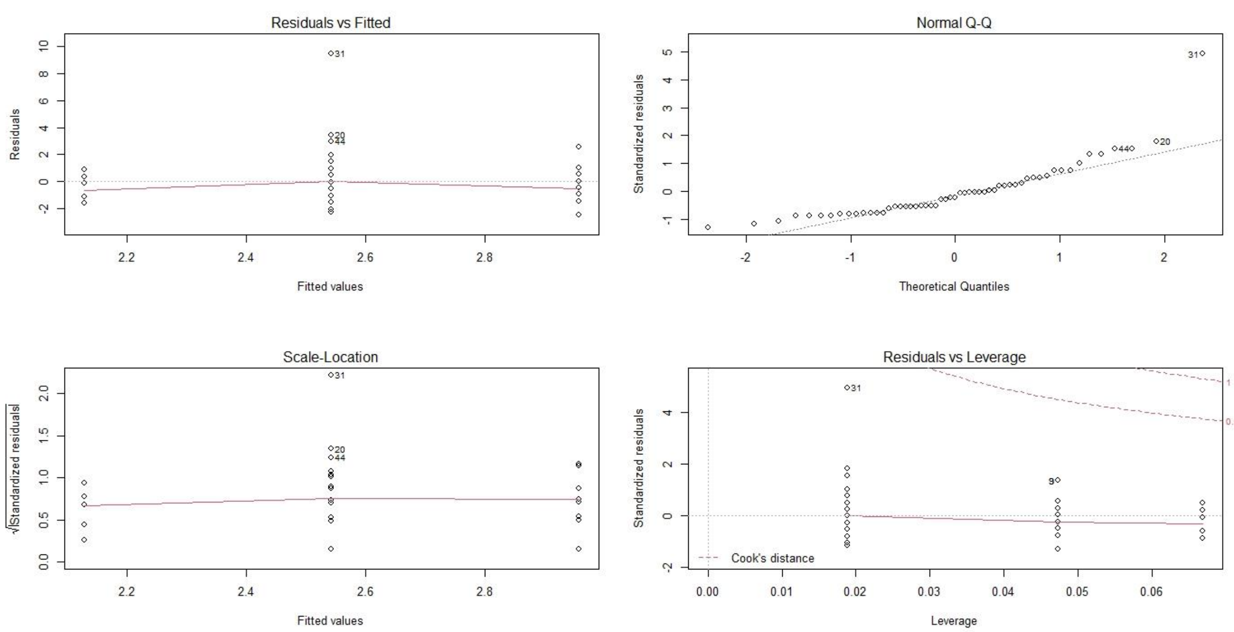


Figure BD. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Anjokozoko.



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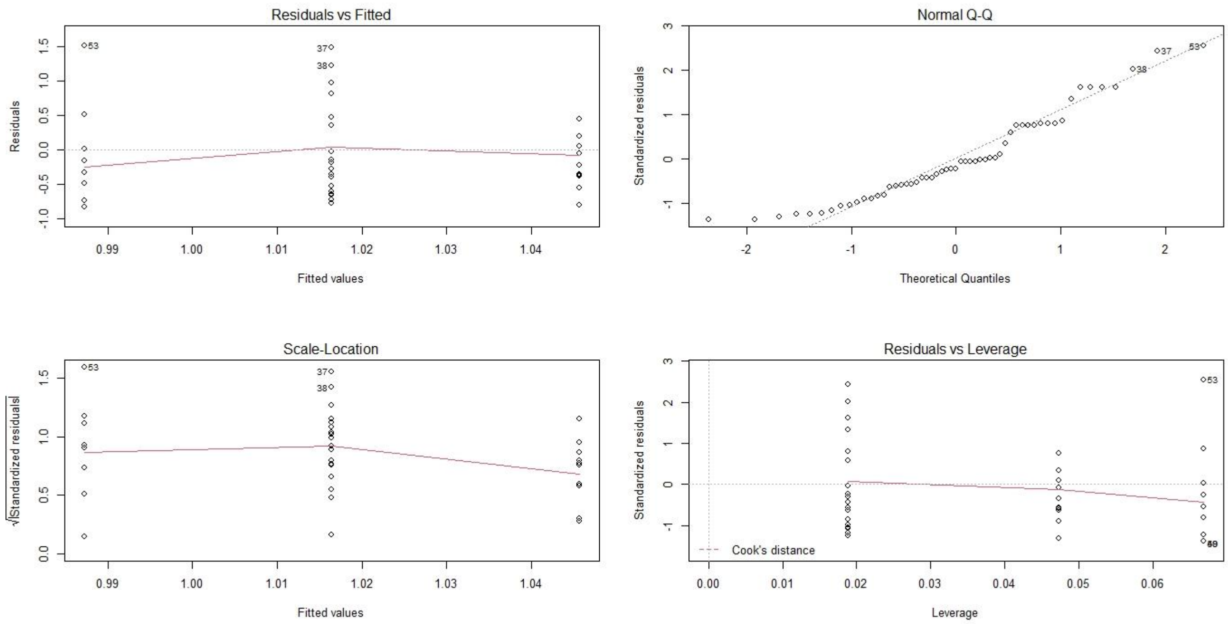

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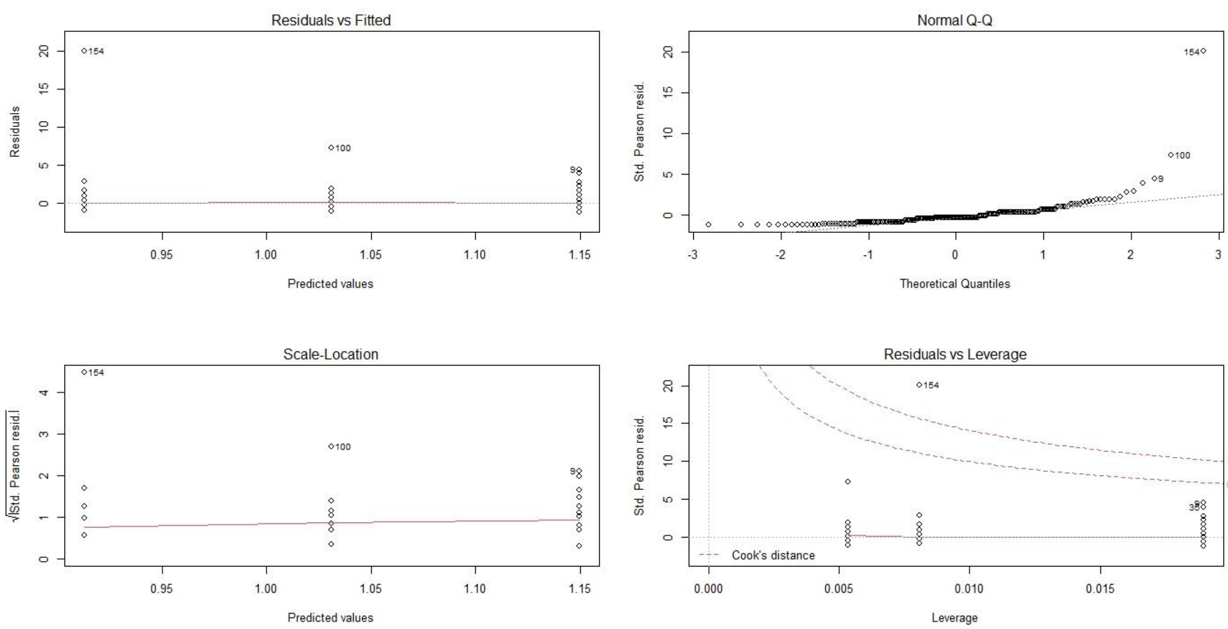


Figure BG. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Belamera.

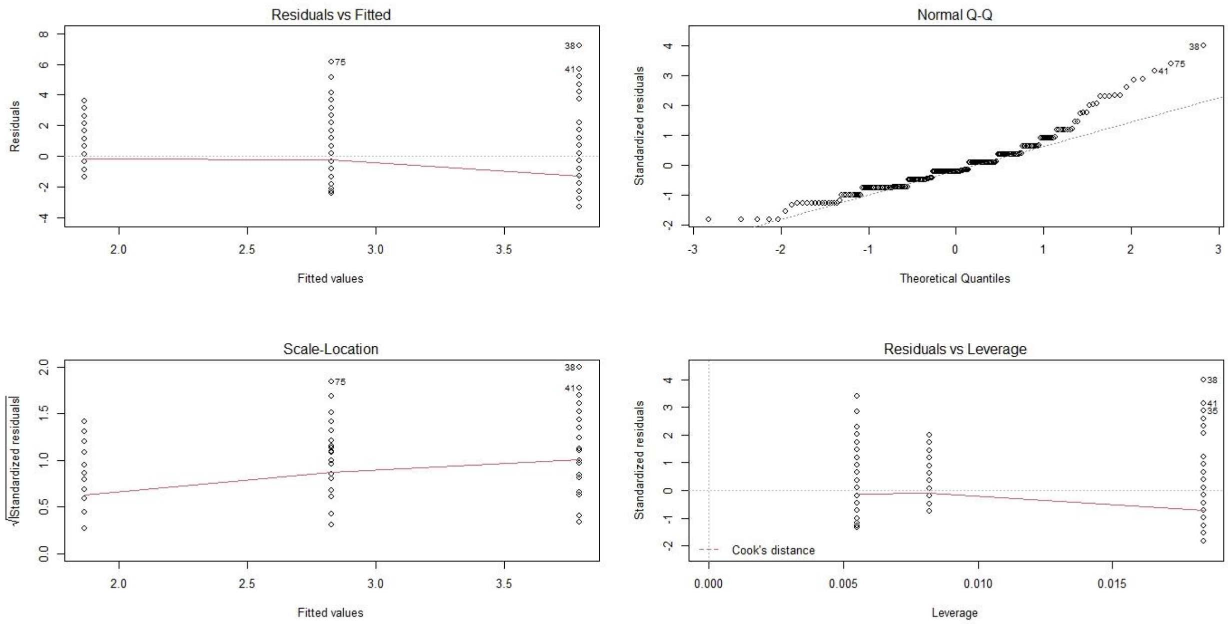


Figure BH. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Belamera.

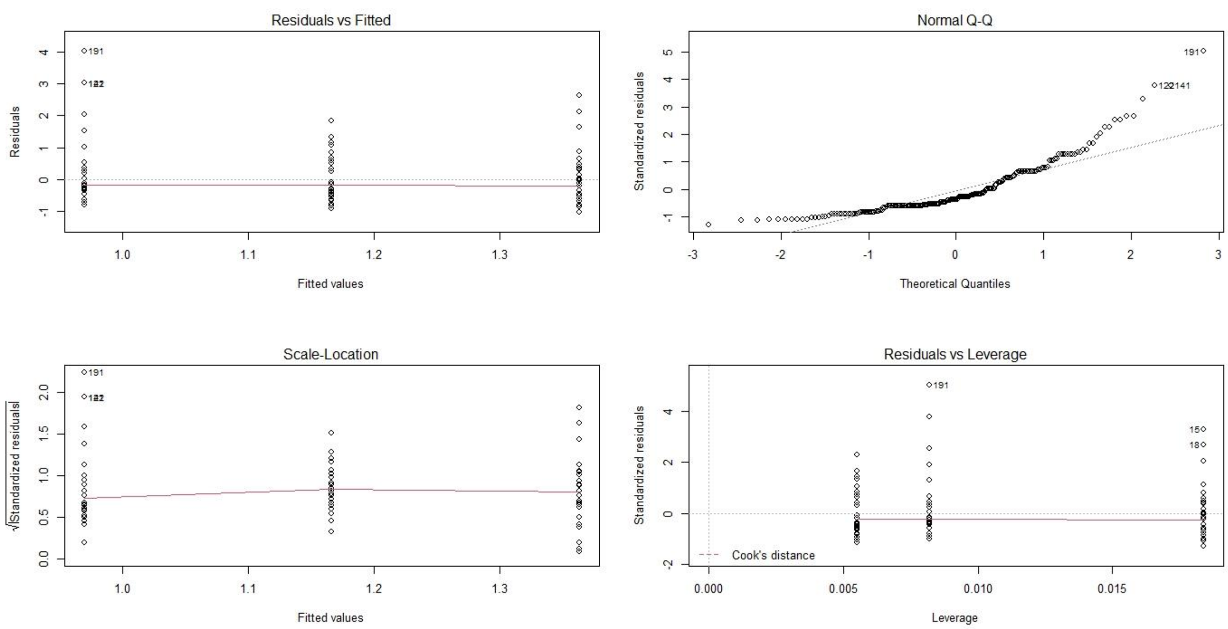


Figure BI. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Belamera.

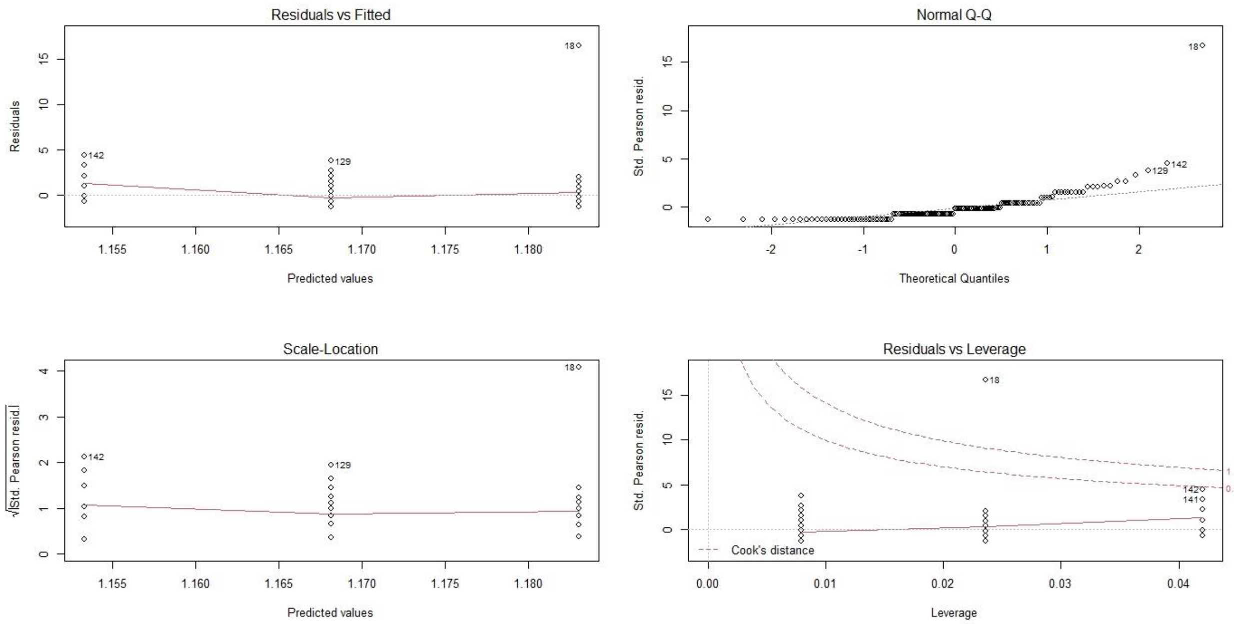


Figure BJ. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nandoa.

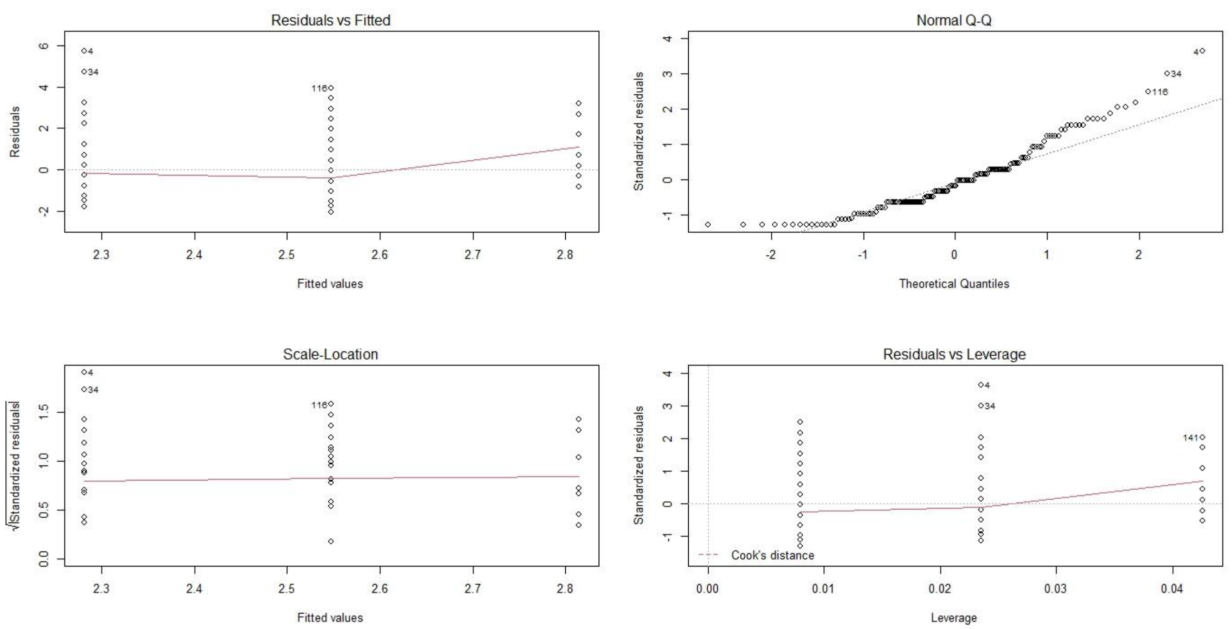


Figure BK. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nandoa.

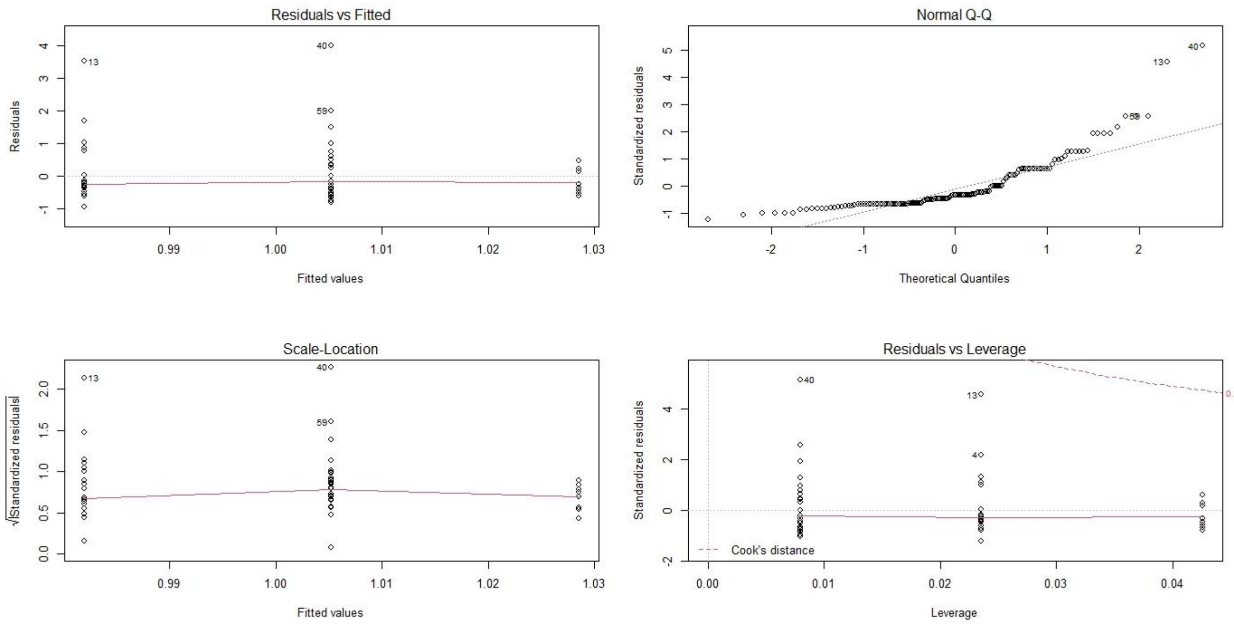
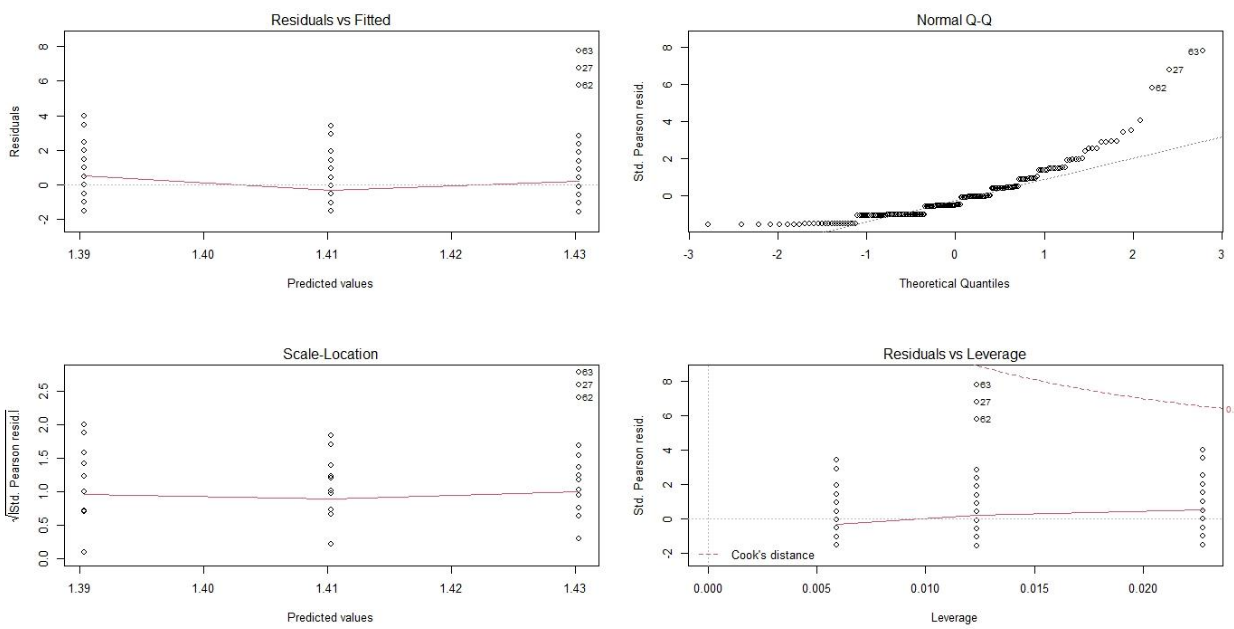


Figure BL. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nandoa.



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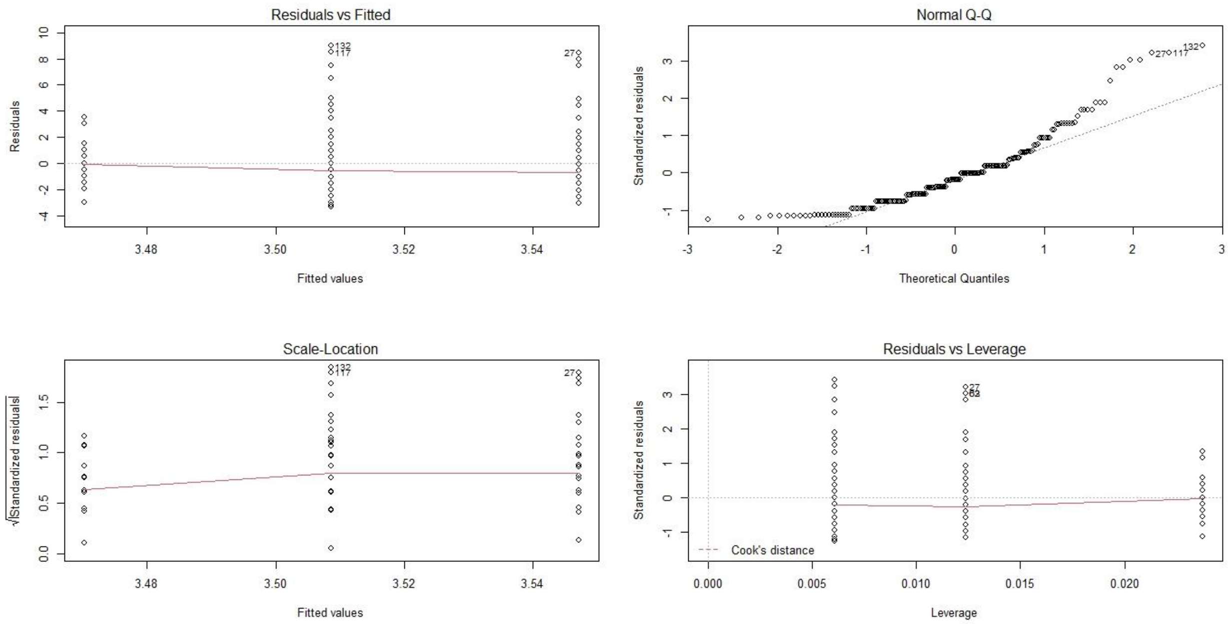


Figure BN. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nanohofa.

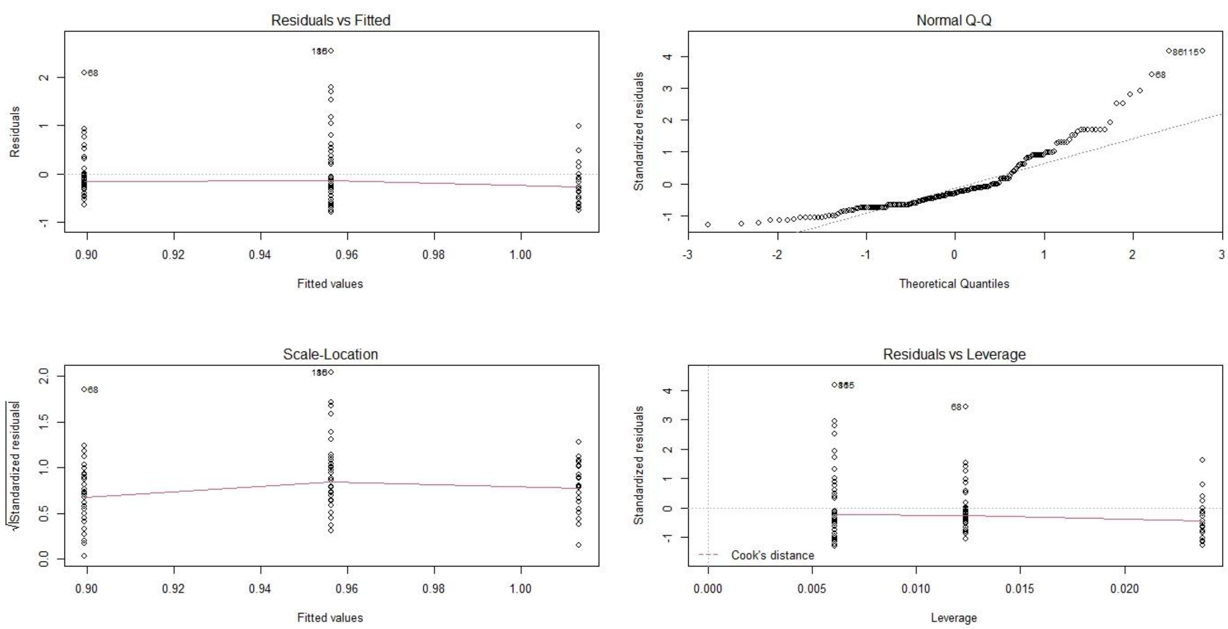
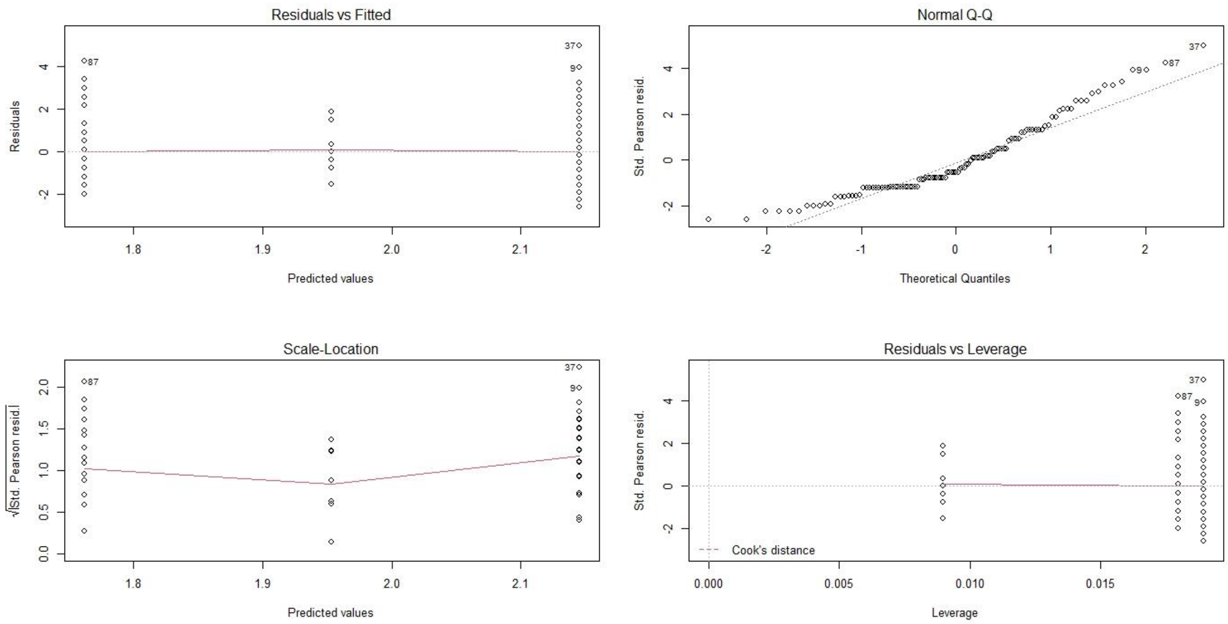


Figure BO. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in July, August, September 2010, 2015, and 2020 at the fishing site Nanohofa.



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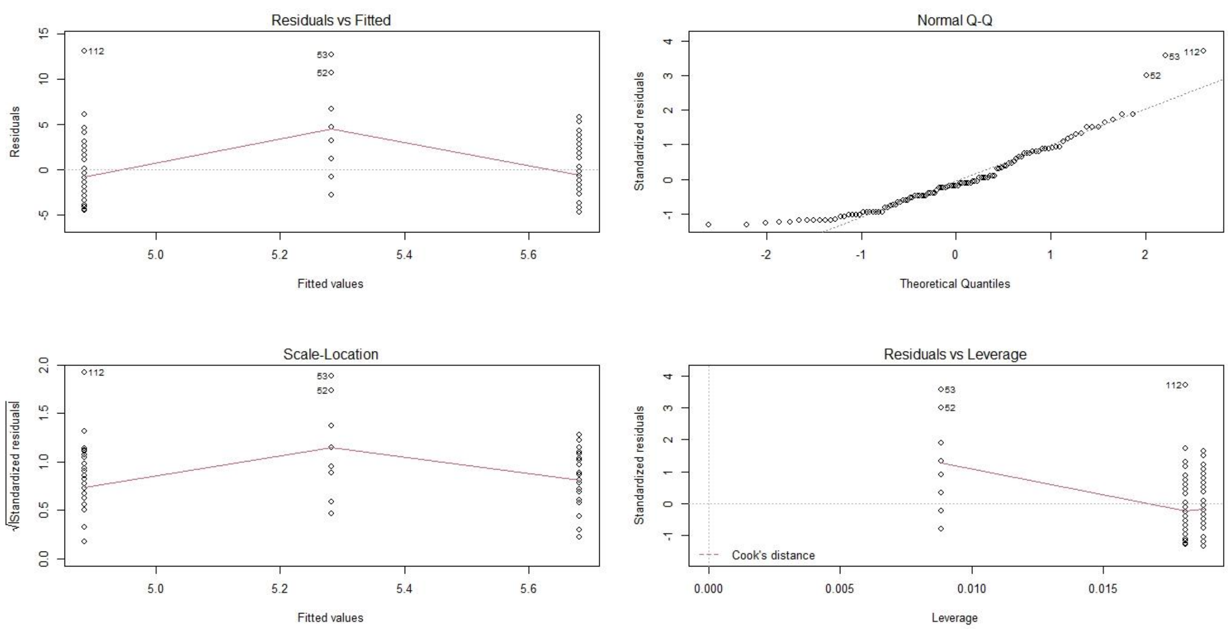

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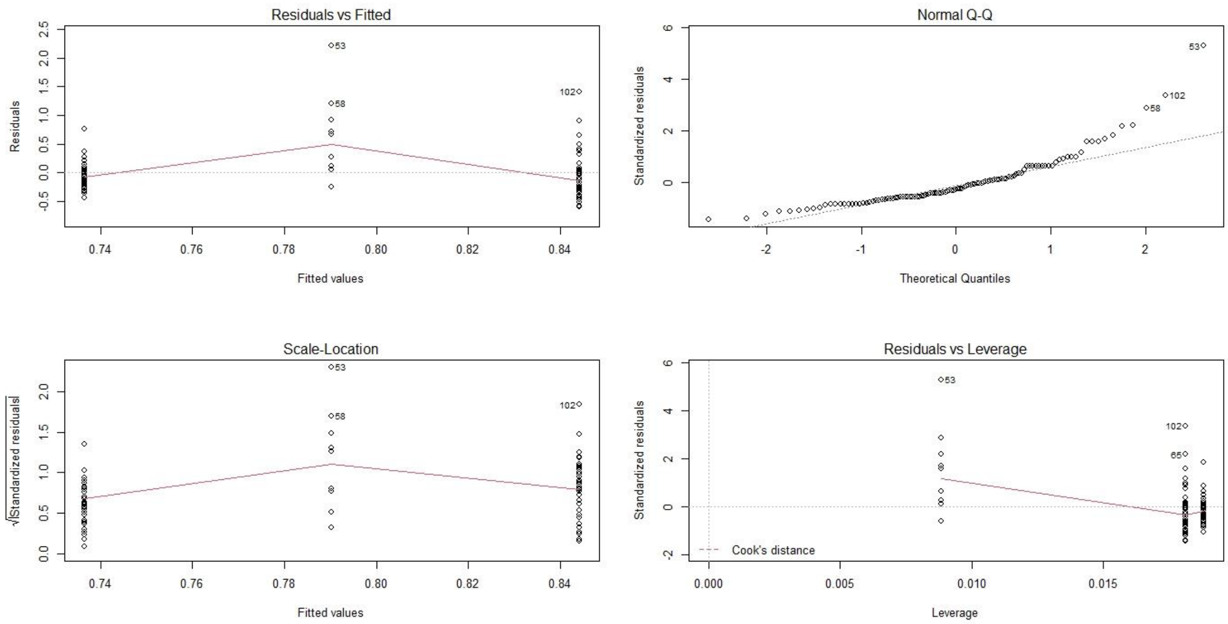


Figure BR. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Ananamose.

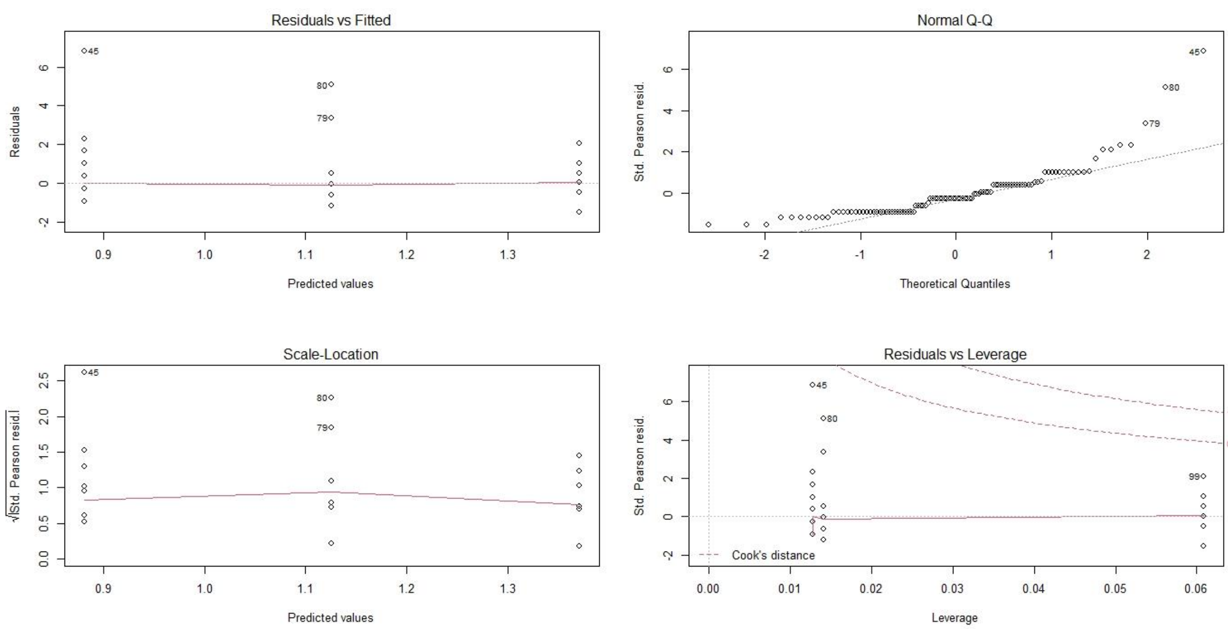
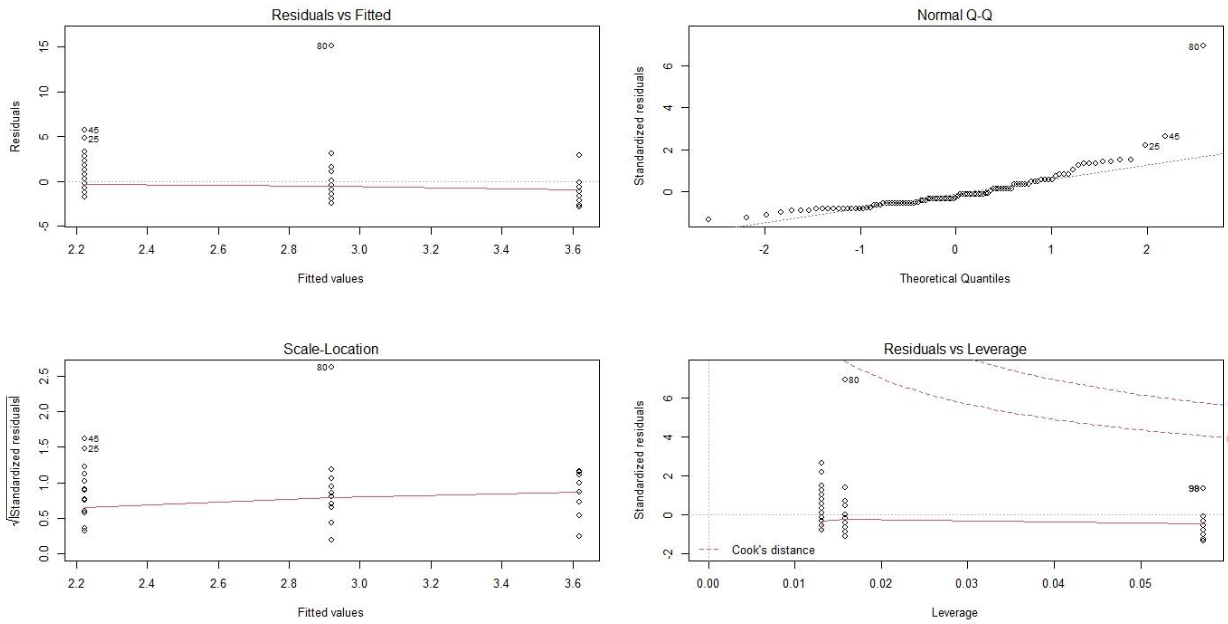


Figure BS. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Andamabe.



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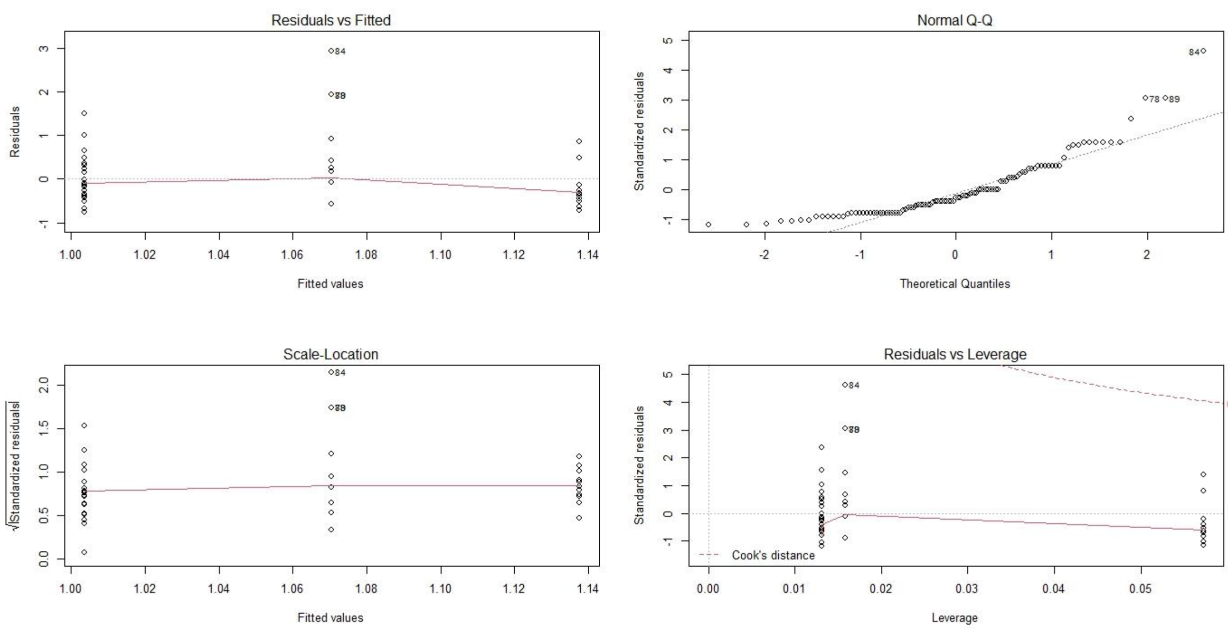


Figure BU. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Andamabe.

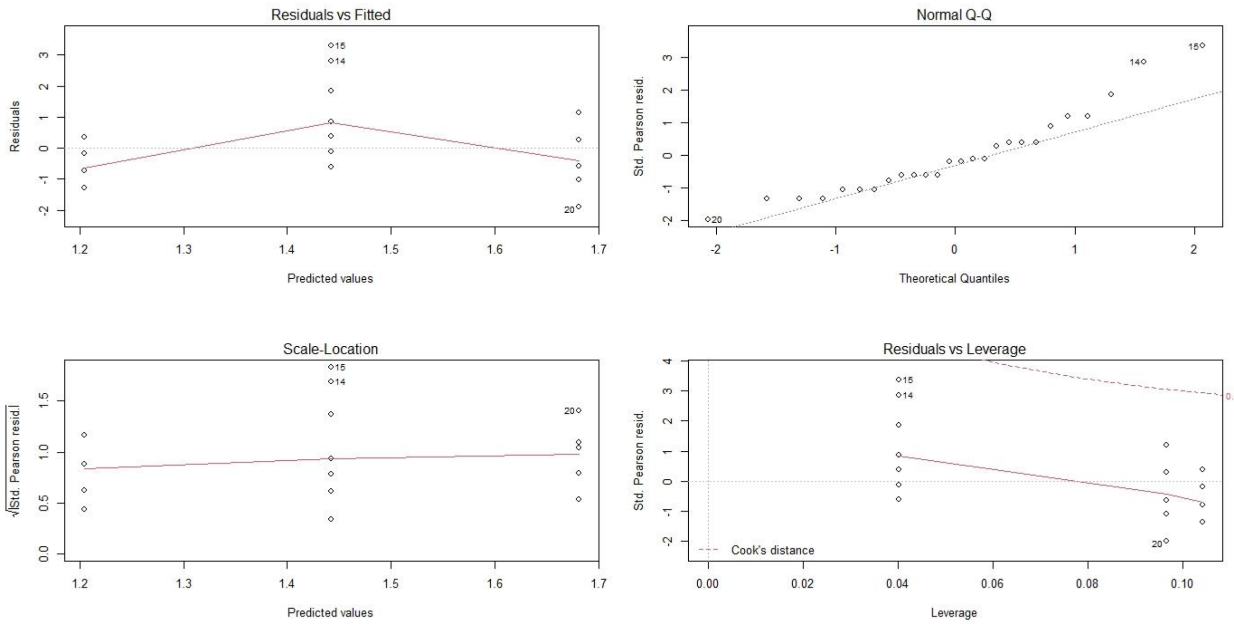


Figure BV. Residual plots for generalized linear model (with a Poisson error distribution) of the number of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anjokozoko.

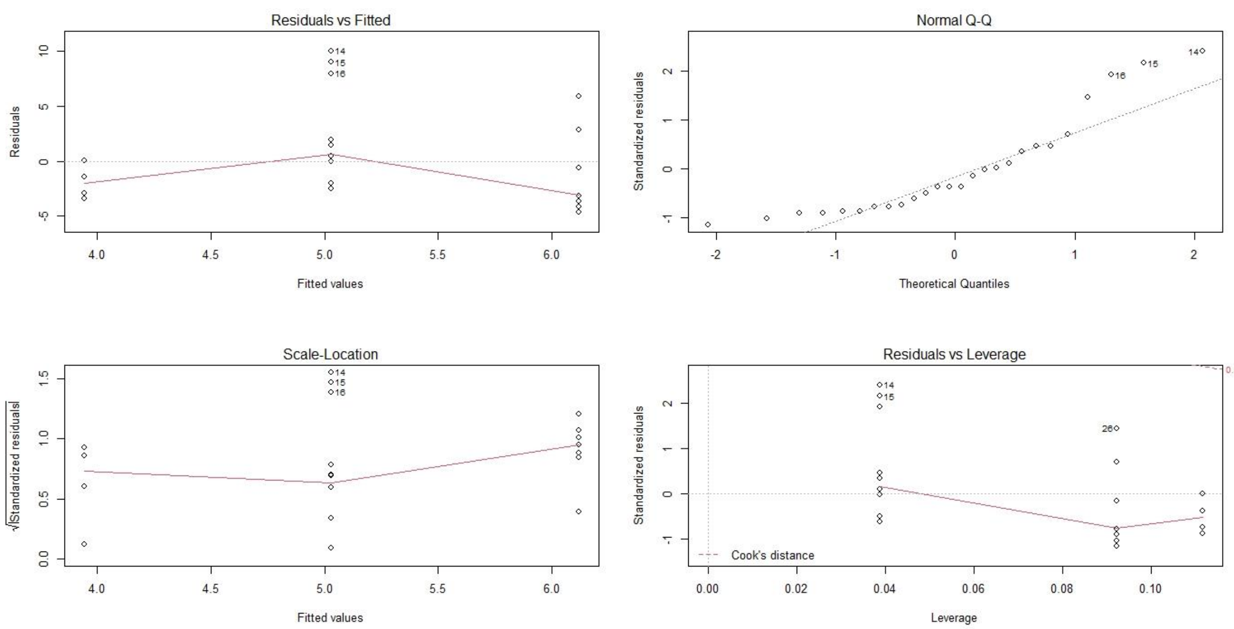
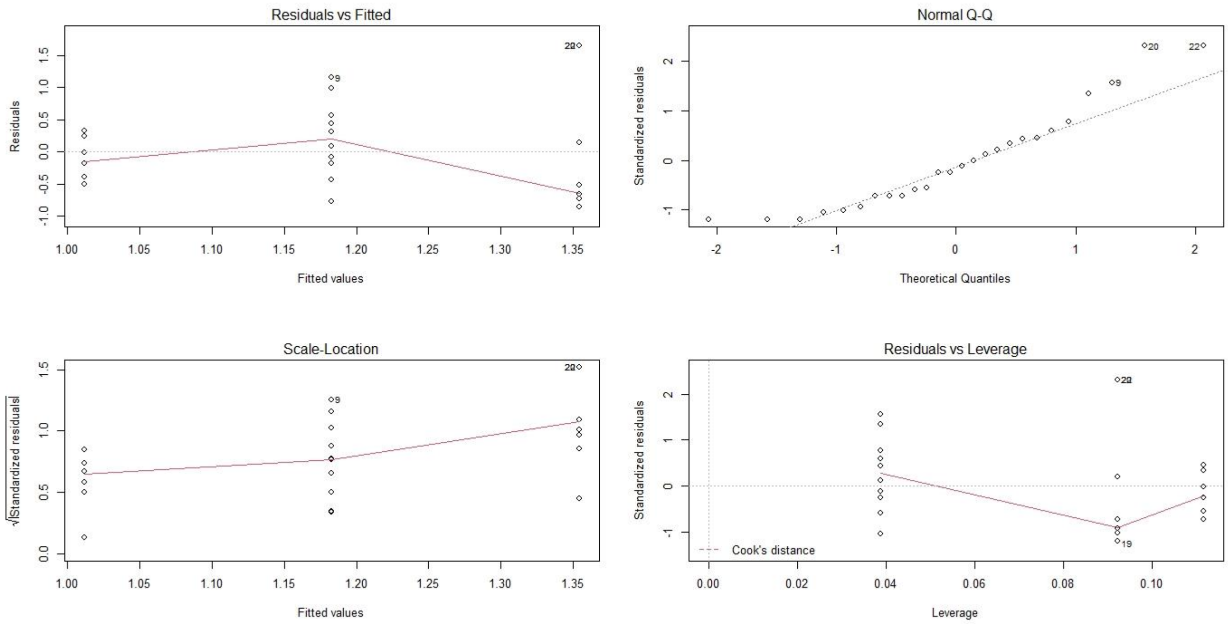


Figure BW. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Anjokozoko.



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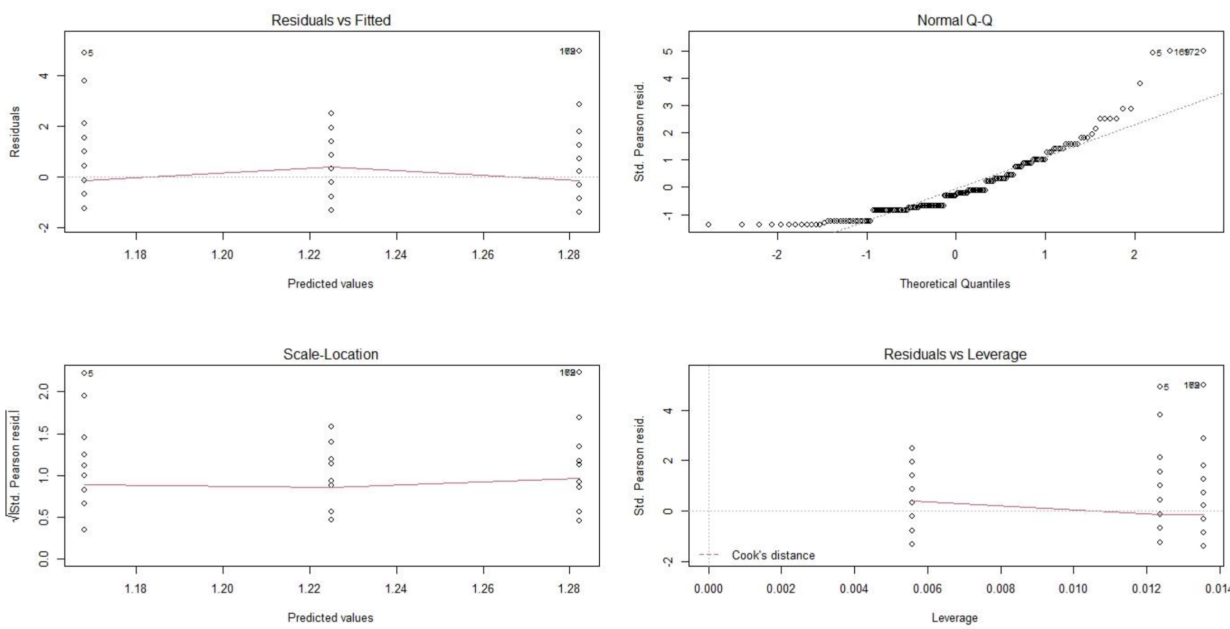

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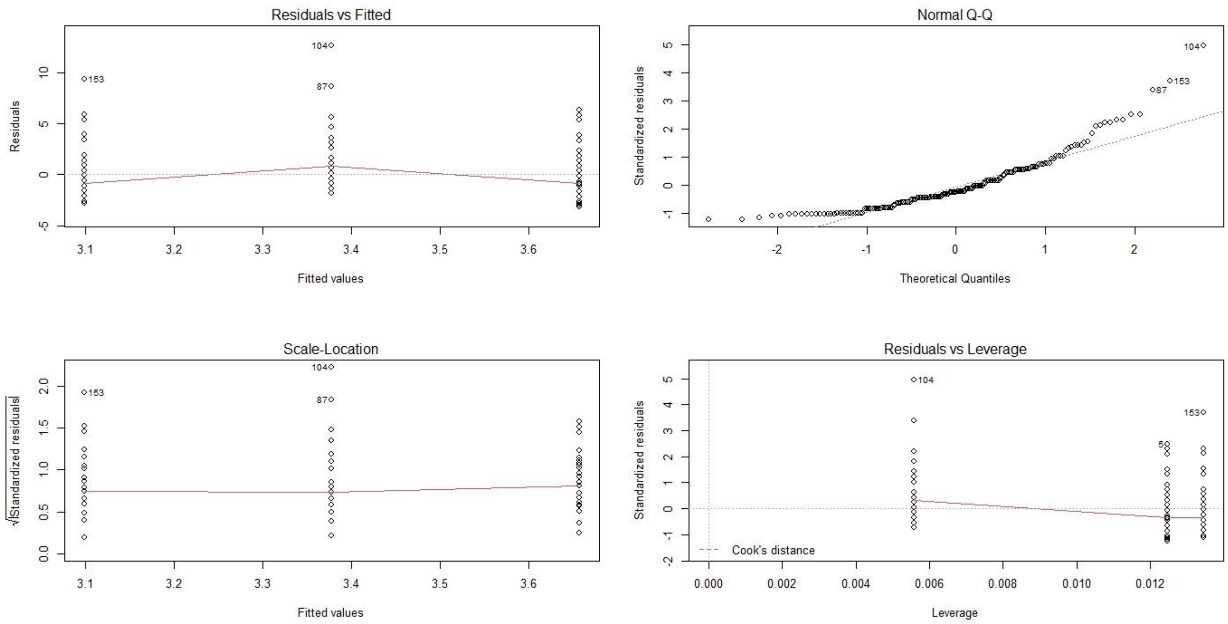
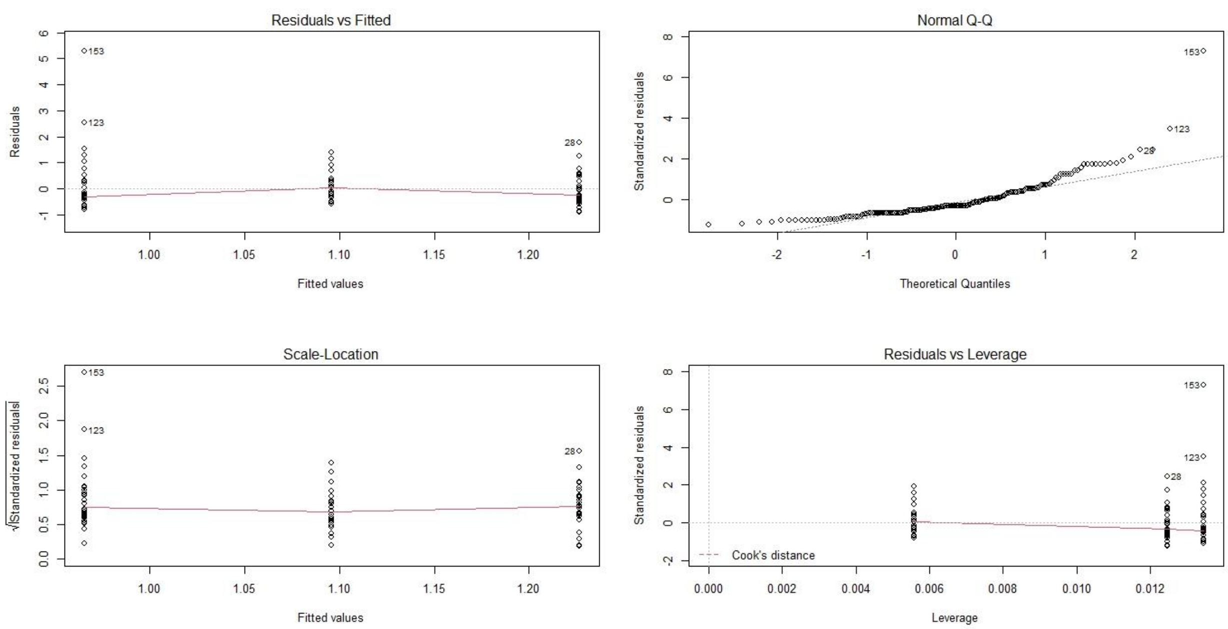


Figure BZ. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Belamera.



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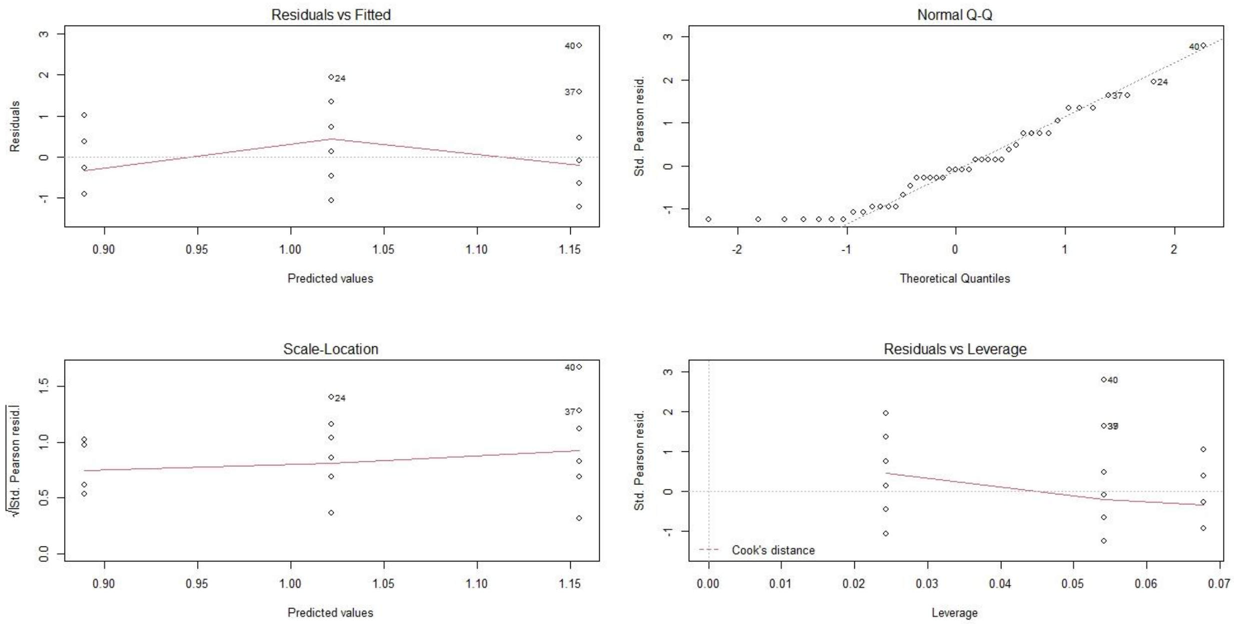

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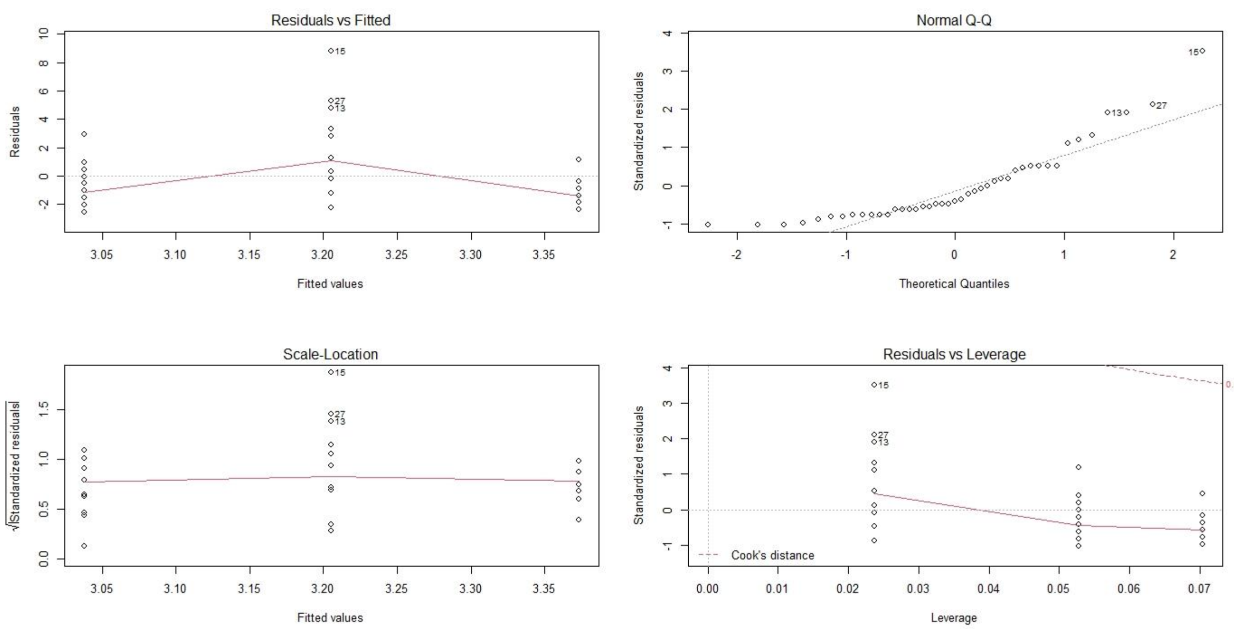


Figure CC. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Nandoa.

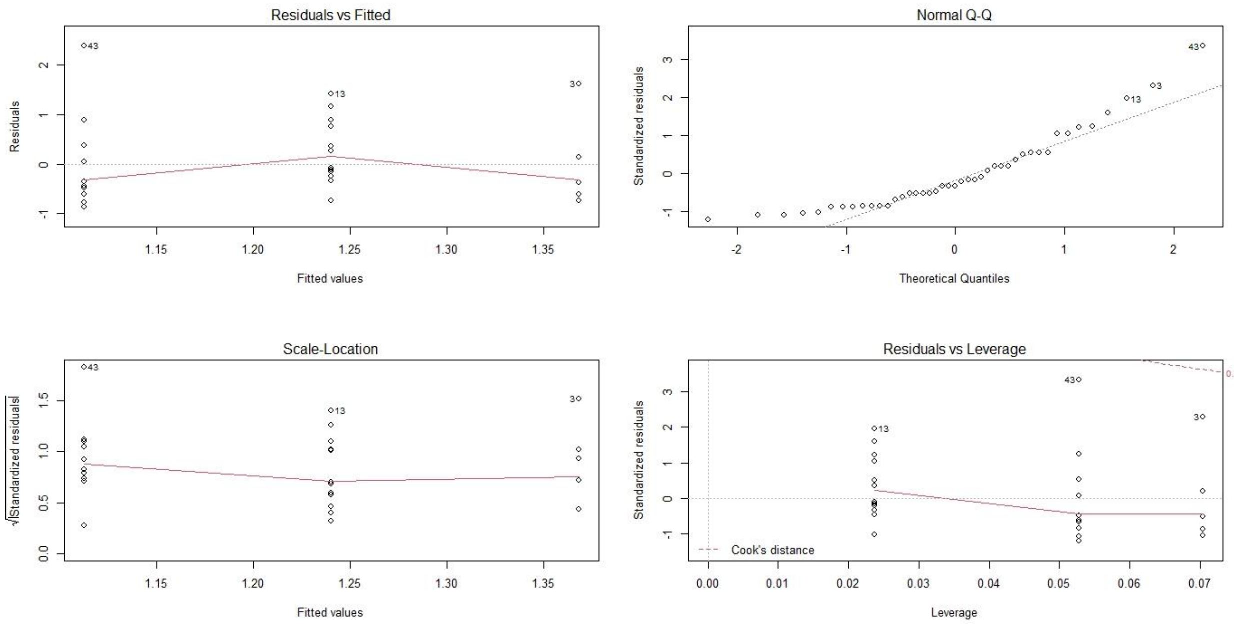
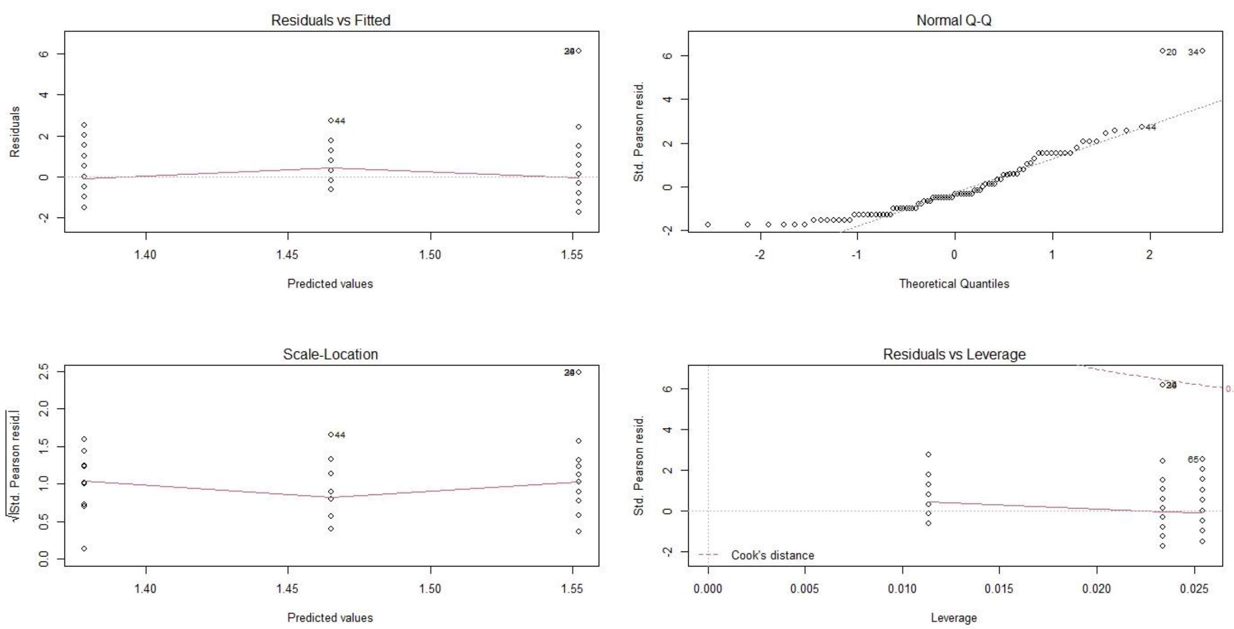


Figure CD. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Nandoa.



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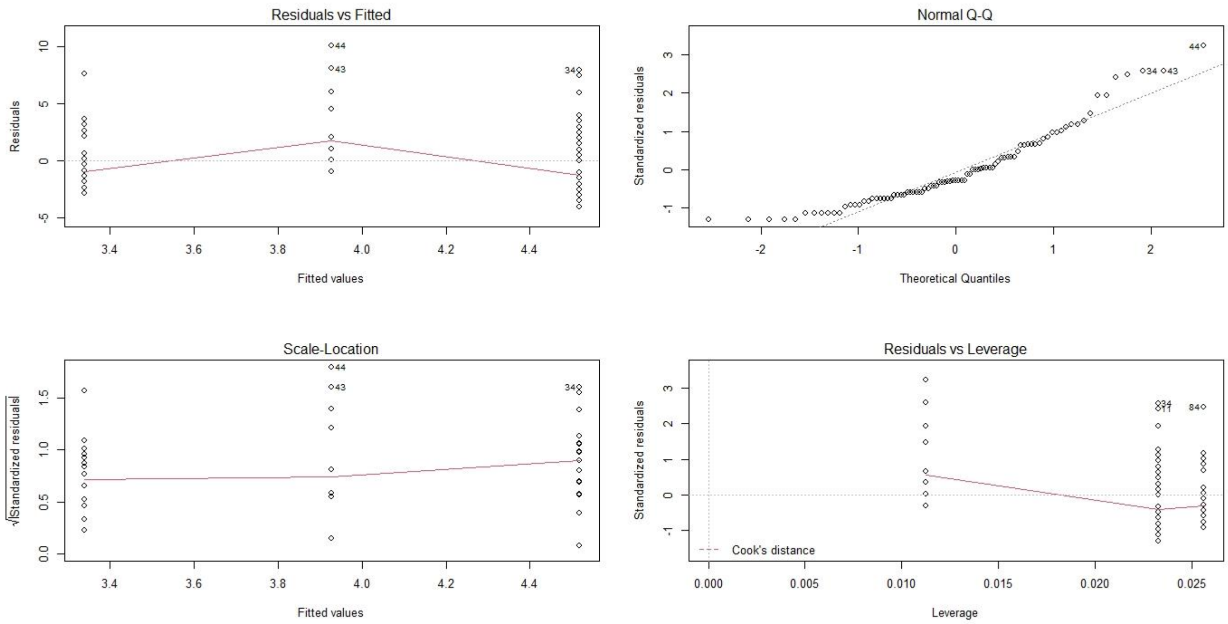

Figure CF. Residual plots for generalized linear model (with a Gaussian error distribution) of the total weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Nanohofa.

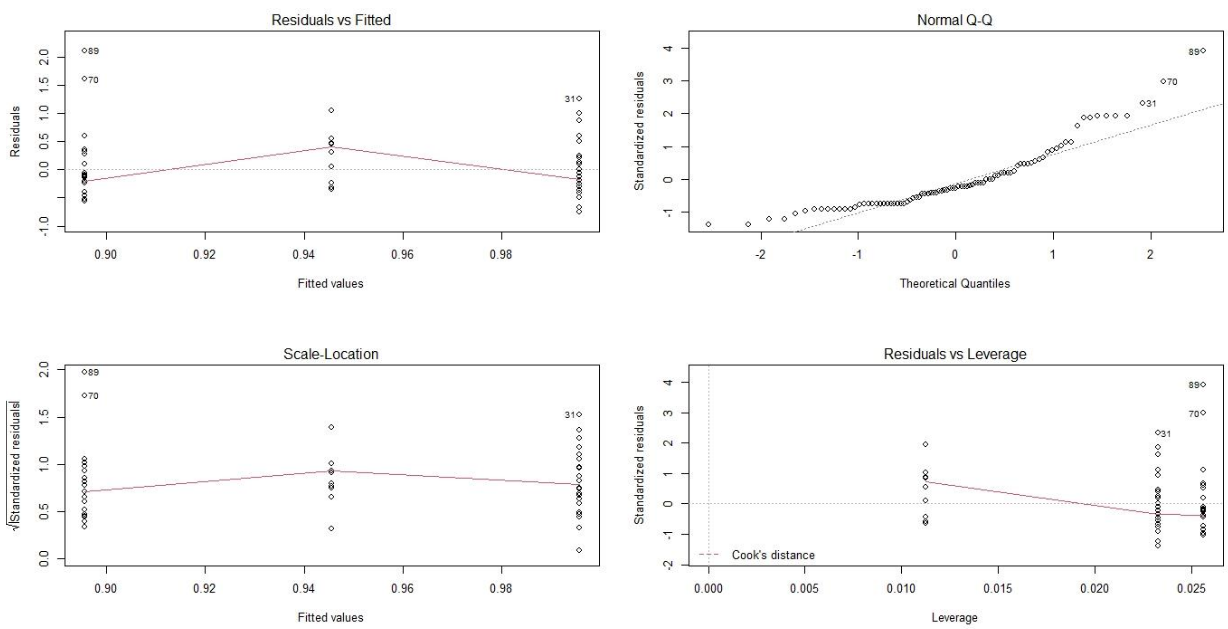

Figure CG. Residual plots for generalized linear model (with a Gaussian error distribution) of the average individual weight of Octopus landed per trip in November and December 2011, 2015, and 2019 at the fishing site Nanohofa.

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