Using GIS to identify potential dynamic marine protected areas: A case study using shortfin mako shark tagging data in New Zealand

by

Marie Anne Taylor

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To my parents, for supporting me in every adventure I undertake

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List of Abbreviations

CHUAs	Core Habitat Use Areas
DMPAs	Dynamic Marine Protected Areas
EEZs	Exclusive Economic Zones
GIS	Geographic Information System
MPAs	Marine Protected Areas
NIWA	National Institute of Water and Atmospheric Research
NOAA	National Oceanic and Atmospheric Association
SPOT	Smart Position and Temperature (Transmitting Tags)
SSSM	Switching State Space Model
UTM	Universal Transverse Mercator

Abstract

Analyzing pelagic shark behavior is an ongoing challenge due to the highly migratory nature of these animals, as well as outside threats such as overfishing and climate change. Increased protection of vital habitats is essential in combating declining species numbers. Although some shark species, like the shortfin mako (*Isurus oxyrinchus)*, have made a steady comeback in the last decade, there is still significant room for improvement. Comprehending the connection between how sharks use their environment and move between protected territories can benefit our understanding of shark behavior and conservation as a whole. By analyzing shark movements over time and creating visual representations of core habitat use areas, an assessment can be made on the potential for implementation of seasonal dynamic marine protected areas (DMPAs) in New Zealand's waters to aid in pelagic conservation.

Starting with a large spatio-temporal dataset of tagging data collected for 13 mako sharks over five years, these data points were first cleaned and filtered in order to create individual shark track lines for visualization of the data as a whole. Next each shark's track was divided into seasonal chunks and these were buffered to a 32km wide zone, which, based on the data, accounts for an average day's movement of a mako shark. This collection of seasonally tagged polygons represent the areas used by each shark in each season. The next step was to intersect and count overlapping seasonal polygons to identify the "high use" areas. The result is a map showing areas where seasonal closures might benefit overall conservation, the areas to consider as the core for future DMPAs.

Chapter 1 Introduction: Why Sharks?

Sharks have been a subject of discussion spanning a multitude of disciplines from folklore to scientific research. Rising ocean temperatures and overfishing cause detrimental effects on the ocean's ecosystem (Chin et al. 2009). Marine biologists around the globe are working to develop new methods of tracking and monitoring pelagic sharks, like the shortfin mako shark (*Isurus oxyrinchus*, henceforth referred to as 'mako sharks'), so that we can better understand their food web and how they utilize their environments. Understanding this delicate ecosystem will aid in increased local and global conservation efforts as well as improving upon conservation efforts already in place. This project spatially analyzed the core habitat use areas (CHUAs) for the mako sharks in New Zealand's territorial waters and created a methodology that can be used to delineate seasonal dynamic marine protected areas (DMPAs) for any species.

1.1. Location: New Zealand

Using data obtained from Dr. Malcolm Francis of the National Institute of Water and Atmospheric Research (NIWA), this study is focused on the waters around the northern island of New Zealand as this is where his thirteen tagged mako sharks spent the majority of their time. The exclusive economic zones (EEZs) and marine protected areas (MPAs) already in place protect mainly static species surrounding islands, shorelines, and inlets. By analyzing the mako shark's habitat use in regard to these specific protected areas, this project may help to expand conservation efforts by illuminating areas for improved protection for pelagic species.

Choosing to focus this research on the mako sharks tagged off of New Zealand coastline was a result of accessible data as well as an interest in helping to improve the current marine regulations in place. There are 14,882 marine protected areas or reserves globally, which only covers 7.59% of the ocean (UNEP-WCMC and IUCN 2019). New Zealand hosts 107 MPAs, with over 30 of those areas designated as no-take reserves. This totals over 12,000 sq. km, comprised of the Auckland Islands Marine Reserve near the southern island and the Kermadec Islands Marine Reserve to the north. Despite the large number of reserves, there are still significant challenges that New Zealand faces while aiming for a 10% marine protected environment goal (MCI 2019). Figure 1 gives reference to the north and south islands comprising New Zealand and its location in relation to Australia.

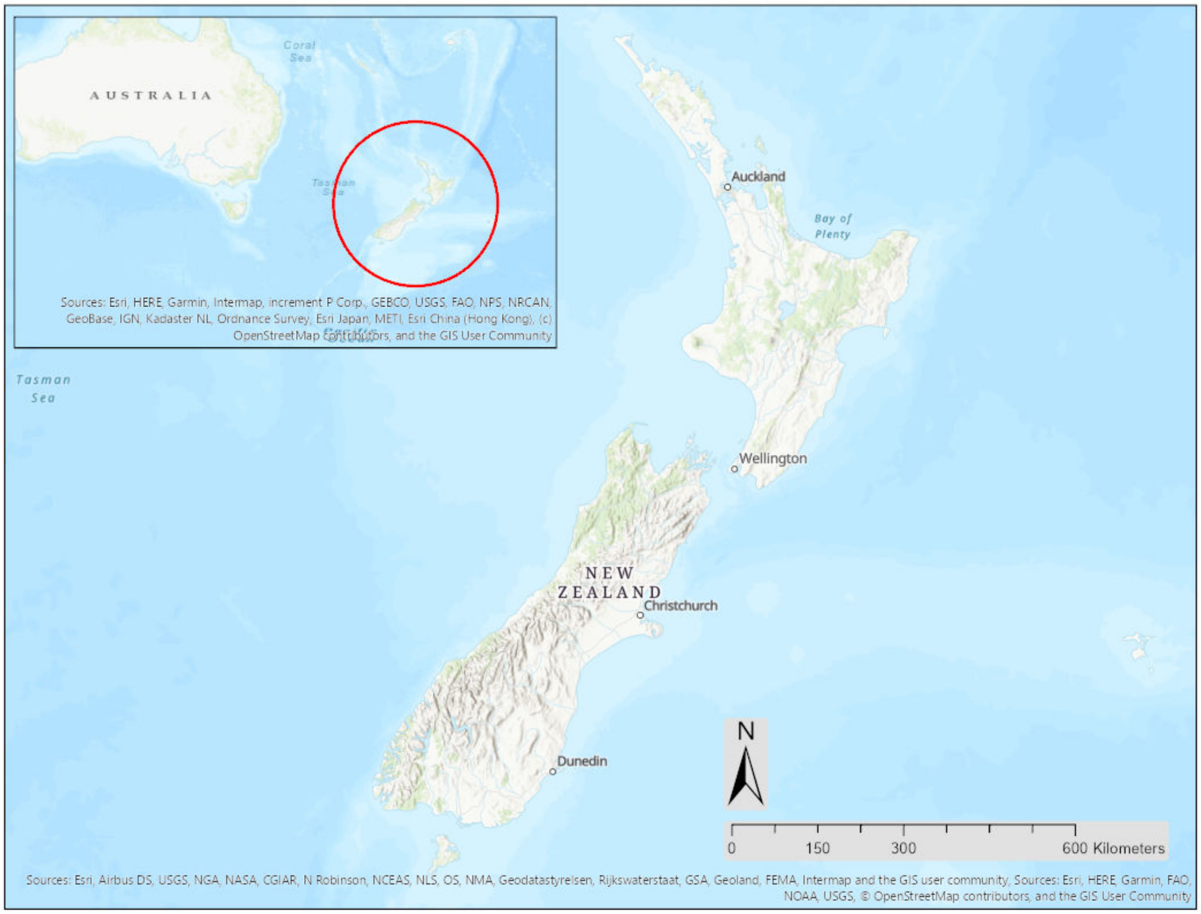


Figure 1. New Zealand Reference

Figure 2 shows the EEZs outlined as well as the current marine reserves surrounding the islands. Most of the marine reserves are relatively small and are within inlets, close to the shoreline, though there are significant reserves off the mainland.

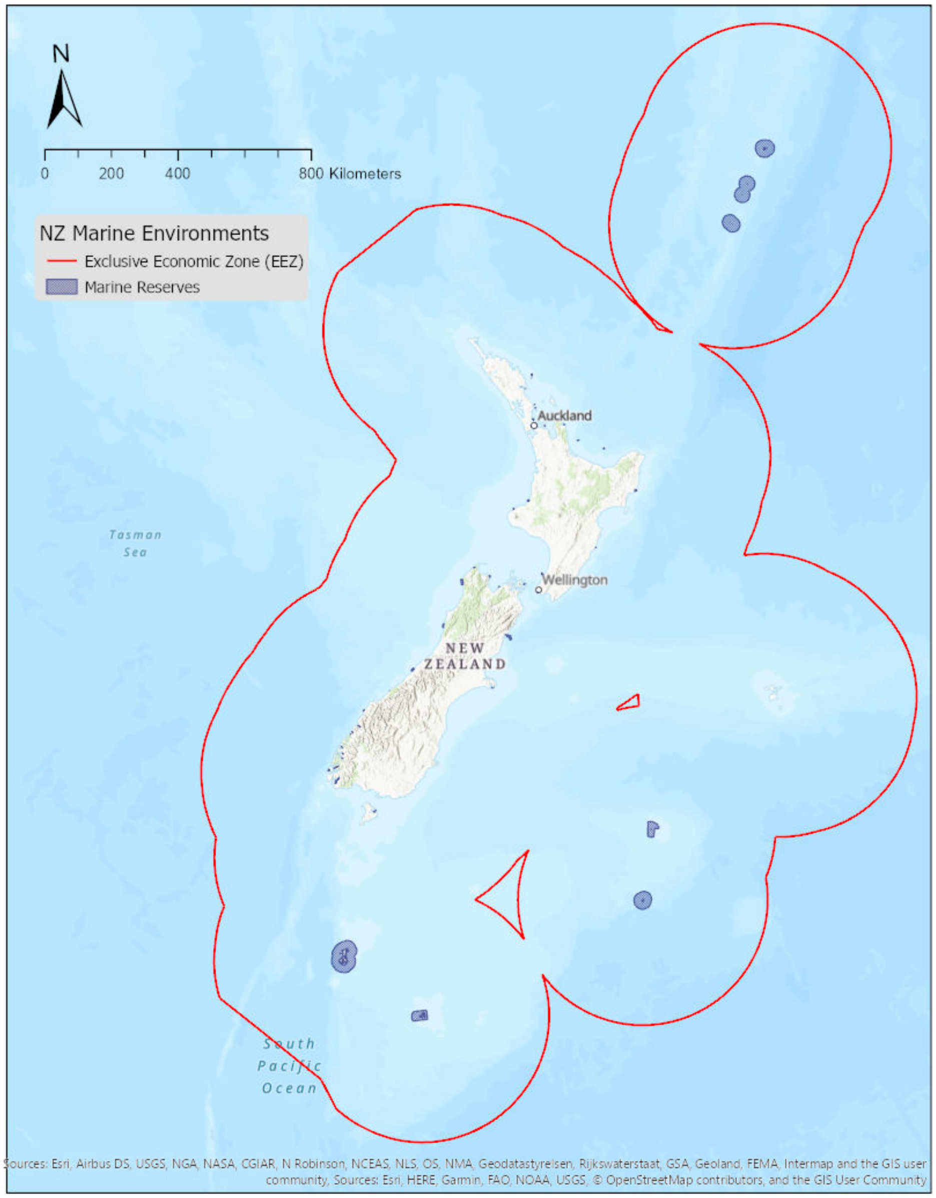
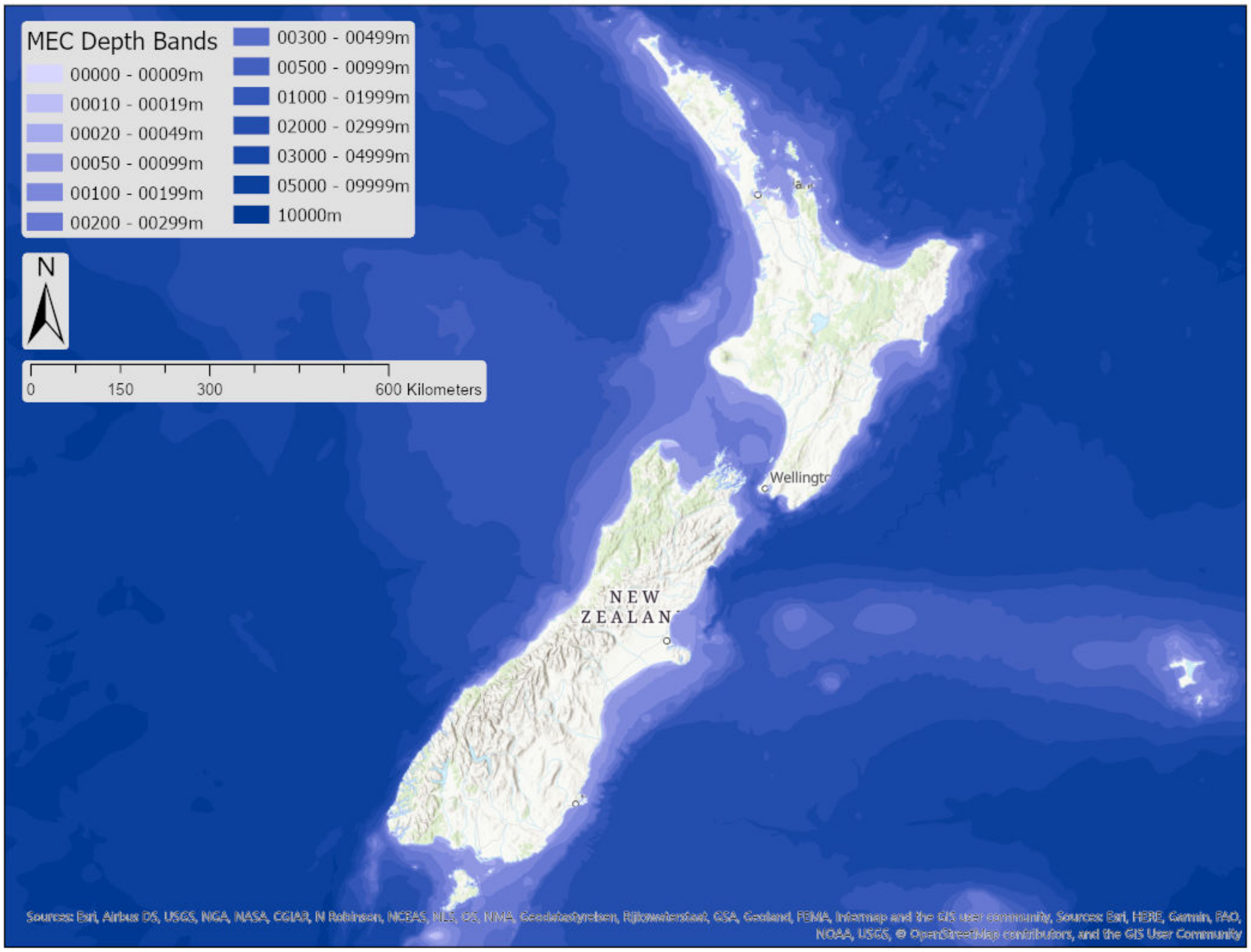


Figure 2. New Zealand Marine Environments

The islands and the neighboring areas provide a unique hunting ground for the apex predators that reside in the waters off the coast of New Zealand, specifically mako sharks. The surrounding plateaus give increased protection from deeper waters for all the local wildlife, and the varying depth changes provide exclusive hunting and migratory opportunities for the ocean's larger predators. Figure 3 shows the varying depth ranges off the coastline and surrounding waters of New Zealand.



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

Figure 3. Ocean Depth Ranges in New Zealand

The significant variations in seabed topography supports a wide array of wildlife for this area. This combination of flat plateaus and shelves, with large trenches and deep waters, makes this location particularly interesting to larger pelagic shark species like the mako. Understanding that the various depth ranges that surround New Zealand are favored by sharks when they hunt helps to comprehensively understand how these marine animals move in and use their environment. Observing connections between seafloor topography and favored core habitat areas where these mako sharks reside can aid in understanding the gaps in marine protection regulations and where improvements could be made.

1.2. Motivation

There is no greater need for marine conservation as there is right now. Every piece of understanding helps in the overall goal of conservation. This project uses the tagging data from mako sharks in New Zealand to help create a generalized methodology that can be used to delineate areas suitable for seasonal closures to be used in an effective DMPA. The shark tagging data includes a latitude and longitude location, year, time, tag number, sex of the shark, a nickname given to each individual, along with other pertinent information. This project used GIS techniques to delineate the zones in New Zealand's waters that might be identified as dynamic protected areas for these mako sharks. This is all in an attempt to benefit biological and environmental conservation not only for the New Zealand government, but that can be applied to other areas around the world.

By acknowledging areas as CHUAs, stronger restrictions and management decisions can be made to ensure species and environmental survival. Seasonal closures or catch restrictions in areas of high usage may help bolster species numbers throughout the year, combating some population decline caused by climate changes. The relationship between climate change and animal behavior adaptation is becoming more prevalent and understanding how species use these habitats that are under siege from climate change, overfishing, or resource overuse could prove useful in numerous ways (Rosa 2014).

There are a number of studies that show site-fidelity among larger pelagic sharks, hinting that they can also remain within known areas for extended periods of time (Francis et al. 2018). This could mean that the previous regulations covering the existing marine protected areas (MPAs) may not be effective in protecting mako sharks. Without adjusting the definition of marine protected areas to include mobile pelagic sharks, moving both inshore and offshore, we are creating a vulnerability that could be exploited by commercial and recreational fishing. Creating dynamic marine protected areas that can change over seasons could help cover a larger area and provide greater protection for pelagic species.

Being one of the most threatened groups of marine animals globally has planted sharks at the forefront of conservation concerns. Overfishing along with habitat loss has caused several species to change and adapt. However, at the rate of current degradation it is impossible for sharks to adapt as rapidly as necessary (Rosa et al. 2014). The issue is global, not local, but the more we can understand at a local level, the better we can be at implementing real global change. At a local level, Rosa et al. were able to make a direct link between temperature and pH changes and the behavior of juvenile sharks in tropical waters. Their work emphasized experimental-based risk assessments connecting sharks to climate change, and the necessity of this exploration to aid policy-makers in protecting endangered species.

The effectiveness of MPAs as a tool to conserve large pelagic sharks is currently being examined based on the migratory nature of large apex predators. In one study, scientists attempted to understand the relationship that tiger sharks (*Galeocerdo cuvier*) have with their food source, in this case green sea turtles (*Chelonia mydas*), and uncovered a direct spatial pattern that can be observed between the two species (Acuña-Marrero et al. 2017). By using spatial analysis, there is an advantage to discovering spatial relationships and how specific species interact, which can benefit ecologists and biologists alike.

1.3. Protecting Shortfin Mako Sharks in New Zealand

Shortfin mako sharks are among several shark species that reside primarily in open ocean ecosystems. They are known to travel great distances, reach up to at least 545 kg (1200 lbs.), and can reach cruising speeds of 74 kilometers per hour and even 100km/hour for short bursts, which can help catch their favored fast prey, tuna (Oceana 2019). These predators reside in tropical and temperate locations worldwide which means they are targeted commercially for fishing as well as included in accidental bycatch.

New Zealand's waters play host to a variety of large marine predators due to the moderate temperatures. Great whites (*Carcharodon carcharias*) and tiger sharks (*Galeocerdo cuvier*) are known to frequent the territorial waters around New Zealand and Australia. Mako sharks have been categorized as largely pelagic creatures that, along with great whites, make long-distance movements. Considered as both coastal and oceanic, their habitat spans waters from 0-600m in depth and 16ºC or warmer, though it is known this species has made dives to deeper waters as cold as 10ºC. There is data to show that mako sharks tagged in New Zealand have traveled as far as Fiji, Tonga, and New Caledonia. One shark travelled over 13,000km in only 6 months, moving back and forth between New Zealand and Fiji (Ebert, Fowler, and Compagno 2013).

Because these sharks can travel such vast distances in their lifetime means they are susceptible to oceanic fishing tactics. Mako shark numbers have historically dwindled due to longline fishing tactics that target marlin, swordfish, and tuna, which inevitably attract pelagic sharks to be caught either on purpose or accidentally. Makos are valued highly for their fins and meat, which are of high quality because, like tuna, they share a countercurrent exchanger blood vessel structure. Other species that have this adaptation, like tuna and great white sharks, have the ability to maintain their body temperature despite the surrounding waters. Adaptations paired with specific evolutionary changes makes mako sharks both ideal pelagic hunters and viable product for meat markets worldwide.

1.3.1. New Zealand Culture Significance

Island cultures worldwide have a strong tie to the ocean as not only part of their food source, but in mythology and tradition as well. The Māori of New Zealand are no different and they have relied heavily on fishing for their survival. However, as true with many other island cultures, Māori people believe strongly in the concept of conservation and they have a legitimate concern in regard to outsiders encroaching on their land and cultural beliefs (Roberts et al. 1995). This is of the utmost importance when discussing how to implement new conservation methods. Community involvement is the only way to successfully and sustainably maintain a network of marine protected areas.

1.3.2. Community Involvement and Enforcement

One topic that cannot be overlooked for a successful protected area is a clear and achievable management plan. Pelagic ocean management is difficult, so having feasible goals makes it easier for local and state governments to be involved and to track progress. Making this plan not only cover management goals but community participation means that the project will engage people rather than exclude. Again, this involvement is essential for any long-term goals to be achieved. Creating a conversation about local customs and cultural sensitivities means that policy makers will not be overlooking a group of people that rely heavily on fishing.

Specifically, pelagic species can cover a vast amount of space in a lifetime. This means that enforcement is nearly impossible for all life stages of a particular shark. We can focus on areas where consistency is known, like breeding or birthing areas, but once the shark leaves these zones they are in open water. Using the local fisherman communities is a way to help enforce the restrictions without using an exhaustible amount of law enforcement. Creating incentives for fishermen to be held accountable for their catch means that they are far more likely to engage in reporting true catch numbers as well as conservation efforts. Using GIS techniques to outline areas that are viable for fishing and areas that it could be detrimental to the ecosystem, and having this information available to the public, is instrumental for success.

1.4. Research Goals

The main goal of this project is simple: to create a workflow that can be applied to any marine species tracking data in any location. Specific objectives were to use the mako shark tracking data to determine migratory patterns that can yield overlapping areas of use. From there, these overlapping areas could be used to create CHUAs which indicate the need for increased protection in these particular areas. Seasonal breaks can thus be created to ensure that commercial or economic resources are not eliminated. This can provide clear and malleable areas that could be opened and closed per seasonal fluctuation based on species use.

Using the tagging data from the mako sharks, a generalized workflow was created, and high use areas were identified. This workflow resulted in the identification of overlapping areas where the tagged mako sharks congregated during various seasons. While this project was not intended to suggest specific management actions, it did demonstrate how dynamic protection areas can be identified using available data and various GIS techniques. These results can be used directly by the local government when they consider seasonal closures and catch limits.

1.5. Contents of This Document

Following this introduction there are four additional chapters. Related research is discussed in the next chapter. From this, the reader will gain an understanding of the tactics used in satellite tagging, the existing work being done with MPAs and conservation as a whole, and the issues that come along with global climate change. Chapter Three covers the data compiled and the preparation of that data used throughout the project. In addition to the data discussion, this chapter discusses the requirements and constraints of developing a DMPA, including the necessity for community involvement and cultural respect, as well as the methodology developed to identify seasonal high use areas and outlines the steps to achieve the same result using different data.

Chapter Four discusses the results from the methodology outlined in Chapter Three. Using programs like ArcGIS Pro and ModelBuilder, a clear workflow was created that can be explained and applied to any other project if needed. Chapter Five includes a summary of the results as well as an analysis of steps taken, process failures encountered, successes and provides an assessment of the results and future applications for this project.

Chapter 2 Related Research

By studying different species, specifically marine animals, we may be able to understand how to properly implement and maintain protected areas to ensure the preservation of rapidly declining ecosystems. Reviewing previous research that focused on pelagic shark behavior, marine resource management, and specific marine ecologies aided in understanding the overarching topics addressed in this thesis.

2.1. Different Species, Same Goal: The Use of Satellite Tags

Satellite tagging has been a crucial part of studying the behaviors of migratory animals, particularly helpful with marine animals. By using electronic tags, rather than traditional number marked tags, scientists are provided with much more detail on pelagic shark behavior. These tags have improved scientists' knowledge concerning life history, migration, and general behavior of sharks (Ebert, Fowler, and Compagno 2013). According to Ebert et al., satellite tag development has continued over the years to include various types of tags for different situations, most popular being satellite and acoustic tags. Importantly, these methods can be applied to tracking almost any marine animal.

Using spatiotemporal techniques to understand the distribution of tagging locations of sea turtle nesting sites along the east coast of Florida, scientists can explore how human and climate changes can cause shifts in nesting locations. Ecological spatial pattern hypotheses are usually linked to the dispersal of resources or other critical features (Weishampel et al. 2003). By understanding the change in nesting locations and the decrease in the accuracy of individuals finding their way back to the same beaches, scientists can understand how humans and the environment affect change in animal behaviors.

Studying sea turtles is significantly easier than a pelagic species of shark because sea turtles have shown extreme site fidelity, by coming back to the same beach where they were born to give birth, as well as having the necessity to leave the water to lay their eggs. This gives conservationists time and opportunities to implant tracking devices and monitor nests and hatchlings easily. Luring sharks into a location where a team can use tracking equipment is strenuous and can be incredibly dangerous; however, the amount of data received could potentially be worth the risk.

Spatial data is necessary to understand movement in such a vast area as the ocean. Satellite tags are invaluable to teams attempting to create a full picture of the life cycle of a pelagic shark. Creating areas of conservation, either protected areas or reserves, requires in-depth knowledge of how an animal moves through and uses their environment. Some sharks can travel several miles a day, or move seasonally over great distances, while other species are in-shore most of their life. The ability to combine all of these data points with habitat and protection requirements to come up with areas that could be used in conservation is essential.

One study used tracking devices affixed to the shells of sea turtles to understand how better to protect one of the most endangered species, the Olive Ridley sea turtle, in Central Africa (Maxwell et al. 2011). By using satellite data and telemetry, a collection process for data collected in remote or inaccessible locations, these researchers were able to observe animal biology and movement and how they relate to political boundaries. Inevitably, this can lend information on how to approach conservation jurisdiction and effectiveness. In this case, the concern was centered around the effectiveness of the MPAs surrounding Gabon and studying how the error that comes with satellite telemetry can cause ineffective boundaries. Ultimately, the goal of the project was to understand the distribution of a particular species of animal within an already established boundary, the MPA. The results found that there *is* a significance to the area when combined with other sea turtle tracking data from different species, thus proving the need for increased and maintained protection off the coast of Gabon.

Tracking sea turtles by satellite systems, in many cases the Argos satellite system, and then downloading the information automatically gives researchers an edge in understanding animal migration and behavior. In addition, this can provide information needed to move forward with addressing effective conservation methods. Smart Position and Temperature (SPOT) transmitting tags are used on the mako sharks within this project but are increasingly used throughout marine research. Unlike previous archival tags that stored information and had to be retrieved, SPOT tags are equipped with a strong radio transmitter that can relay information back to satellites as far as 1000km above the Earth (Ocean Tracks 2017). Figure 4 shows an example of a SPOT tag, though they can come in several shapes and sizes depending on the target species. Useful in marine mammals that breathe air, these tags have also had great success when affixed to the dorsal fins of shark species as they ascend to the surface to feed.

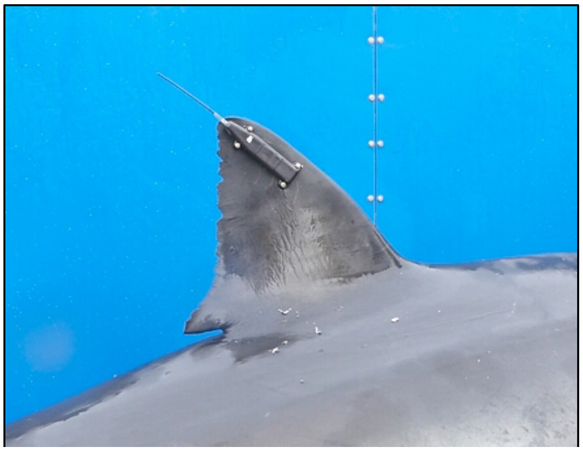


Figure 4. SPOT Tag Example. Source: MarineCSI 2010

A project using remote sensing and satellite tracking data monitored pelagic sharks as they moved through the North Atlantic Ocean and their relation to fishing fleets that patrolled the same areas. The team of scientists focused on this particular area because of it being one of the most heavily fished ocean ecosystems, both sharks and humans following the fish (Queiroz et al. 2016). By tagging and tracking over 100 sharks over approximately 8,000 days they were able to understand the spatial distribution between the shark migration patterns and the two fishing fleets. By identifying the locations where the animals and vessels overlapped, they were then able to focus on those areas for conservation.

2.2. Shark Behavior and Ecology

In general, sharks are highly migratory animals which presents a distinctive challenge for conservationists due to their ranges being so vast. These migratory sharks, along with tuna, sea turtles, and cetaceans, are often victims of pelagic or bottom longline fishing (Calich, Estevanez, and Hammerschlag 2018). Fishing in remote areas presents a difficult challenge when it comes to conservation as longline fishing specifically targets large pelagic species, including tuna, marlin, and sharks. Adding fuel to the fire, overfishing remains mostly unregulated due to unknown but suspected aggregation areas where shark populations overlap with fishing fleets.

Still, much is not known about the migratory behaviors of pelagic sharks. In Mexico, the quantity of research about adult great white shark biology has been increasing rapidly, but nearly nothing is known about juvenile great whites (Hoyos-Padilla et al. 2016). There is a significant gap in knowledge surrounding pelagic shark behavior due to the difficulties of the subject. Overall there is a general knowledge of migratory behavior and how sharks interact with their prey, but still there are gaps when looking at the full lifecycle of certain species.

Sharks are an integral part of the marine ecosystem, so understanding how protected areas benefit, and fail, them would be exceedingly important in analyzing how we can improve conservation efforts. The tools associated with conservation change are also important, one being the Integrated Risk Assessment for Climate Change, or IRACC. This assessment was used to study the vulnerability of sharks and rays in Australia's waters off the Great Barrier Reef. The IRACC used the framework for vulnerability caused by climate change in place and applied it to fishery ecological assessment (Chin et al. 2009). Similar tools and techniques are needed to improve our assessment of ecological health and subsequently our protection of various species.

To understand the full picture of an animal's life cycle it is imperative to analyze how that animal hunts for its prey. Inevitably, due to mere survival tactics, a predator will adjust its hunting techniques as its prey adjusts its movements. In Australia, a team of researchers focusing on tiger sharks found that studying the predator-prey relationship between tiger sharks and green sea turtles unearthed a greater understanding of foraging habits of this apex shark species (Fitzpatrick et al. 2012). New Zealand boasts a large amount of large prey items for mako sharks, specifically varied types of tuna. Genetically designed similarly, mako sharks and tuna are well matched for a perfect predator-prey relationship. In addition to tuna, large gamefish such as marlin and other sharks are often on the menu for the average mako shark.

Tuna play a huge role in a mako shark's diet due to the unique structure of the caudal fin. Both tuna and mako sharks share a distinctly similar caudal fin, which allows the mako shark to reach the same speeds as the fast-natured tuna (Ebert, Fowler, and Compagno 2013). Figure 5 shows the physical outline of the mako shark and highlights the streamlined features shared by most sharks, but with the caudal (rear) fin much more equilateral than most other shark species. For example, the bottom part of the caudal fin in great whites is much shorter than the top. In the case of the mako shark, they are much more even which gives the mako a much stronger fin to allow for faster bursts of speed. Figure 6 shows the tuna outline with its similar evenly-lengthened caudal fin that allows for speed.

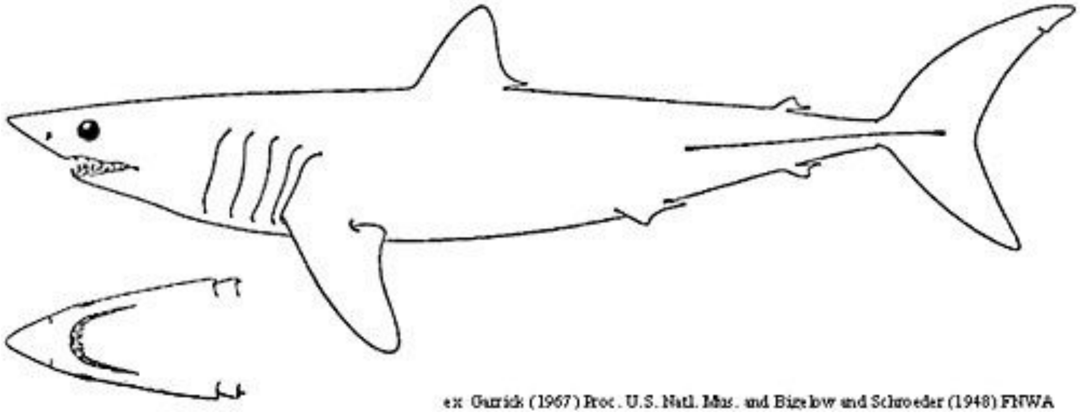


Figure 5. Mako Shark Anatomy. Source: Bigelow and Schroeder 1948

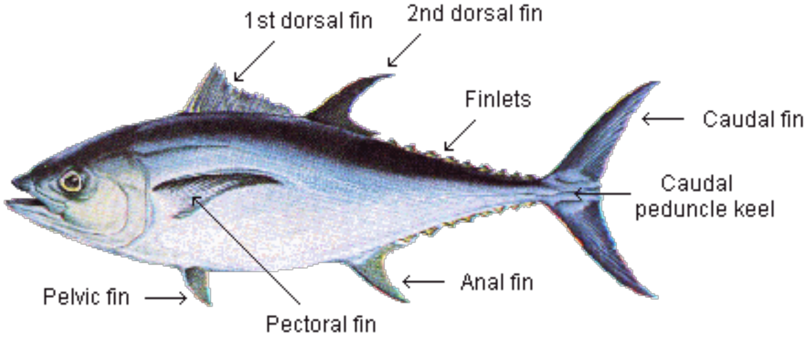


Figure 6. Tuna Anatomy. Source: Bigelow and Schroeder 1948

The abundance of prey paired with the genetically favorable design of the caudal fin creates a perfect match for tuna and mako sharks. In addition to the varied species of tuna, marlins are a popular prey animal for mako sharks due to the speed that mako sharks can reach. These two main species could affect how the mako sharks hunt and move throughout their habitats. Understanding prey relationships is important in defining areas of use.

2.3. New Zealand's Current MPA Policies

The Marine Reserves Act 1971 has been in place since its initiation but potentially could be replaced by the Marine Protected Areas Act. This new act aims to create a balance between protecting the marine environment without declining the commercial, recreational, or cultural opportunities that New Zealand provides. In addition, it would establish four types of marine protected areas and Table 1 shows these four distinct types and a general idea of what would be protected (MfE 2016).

Table 1. Proposed New Zealand New MPA Designations

Marine reserves	Strictly protected with the purpose of conserving biodiversity in its natural state. (The same as under the current Marine Reserves Act 1971.)
Species-specific sanctuaries	Similar to current marine mammal sanctuaries but available to other marine life such as albatross or great white sharks, with rules focused on the specific protection of that species.
Seabed reserves	Protect areas of the seafloor and include prohibitions on seabed mining, bottom trawl fishing and dredging.
Recreational fishing parks	Recognize that there are areas where the recreational fishing experience could be improved by providing a preference for non-commercial fishing for some species. Customary fishing and marine farming will continue.

As a country, New Zealand has been at the forefront of environmental protection globally. It has over 15,000km of coastline and has the largest exclusive economic zone (EEZ) in the world. As a culture, New Zealanders value their marine environment not only as an economic resource, but socially, spiritually, and culturally as well. The government believes that by investing in the health of their marine environments they are investing in a healthy economy (MfE 2016). This could create the perfect environment for a potential DMPA to be enacted, both giving seasonal closures to protect wildlife while still understanding the need for recreational and economic importance.

2.4. Understanding Our Role in Protection

Sharks are a vital part of the food chain, and as we have seen with the growing number of extinctions, the food chain is incredibly delicate. Disrupting this ecosystem by destroying one of the top predators will have devastating effects on the rest of the world. Rising sea temperatures along with other climate change factors have forced larger sharks inland to feed (Ebert, Fowler, and Compagno 2013). Although many animals we see today have adapted to the changes in the environment over time, sharks specifically have a limited ability to adapt to the direct effect humans have had on environmental changes (Rosa 2014). This provides another reason why protecting areas that are used by sharks, like the mako, is so important.

The film *Jaws* (Spielberg 1975) rooted the notion that sharks could seek out a particular person, and that they even have a taste for human flesh. This is categorically incorrect, and the fact remains that it is still incredibly unlikely to be bitten by a shark, without provocation (Chapman 2017). Chapman does admit that, yes, bites do happen, but it is much more likely to be killed by a lightning strike or a vending machine. In general, our understanding about shark behavior is still so limited it allows false notions and fears to mount when in reality we need to be focused on increasing protected areas. This is not to say that fatal interactions do not happen, but we still have a limited knowledge of how or why they happen.

Tiger sharks (*Galeocerdo cuvier*) around Hawaii's islands have caused a significant amount of shark bite incidents over the past few years. A study compared the spatial behavior of tiger sharks surrounding four of Hawaii's islands in order to evaluate if there is a connection based on local movements and the rising number of shark bites in Maui compared to Oahu (Meyer et al. 2018). Oahu is larger than Maui by a factor of six, based on population size, which begs the question if there is an environmental difference causing the increase in shark bites. The data used in Meyer et al.'s study revealed that there were more tiger shark detections around Maui over Oahu, but they noted that the insular shelf surrounding Maui was home to a resident population who used this particular habitat to hunt.

2.4.1. Existing Work in MPAs

The benefits of spatial management zones, like MPAs, is still under examination; however, there are studies that aim to close that knowledge gap (Graham et al. 2016). By studying core habitat use areas (CHUAs) in relation to the surrounding MPAs and EEZs for three species of sharks in the North Atlantic, the team was able to spatially analyze how the sharks use these protected zones. They found that expanding protected areas to include territorial waters would protect all of the habitat use areas that are essential to these three particular species.

In the past few years advances in concepts concerning MPAs have been made and previous criticisms of the effectiveness they provide has been addressed. The concept of MPA networks has been introduced to help manage the spatial scale and life-history of pelagic species, which includes the use of information about overlapping critical habitats (Hooker et al. 2011). The purpose of these networks is to provide levels of protection that single reserves are unable to achieve. However, MPA networks require international cooperation and prioritization, which can be difficult when working with several different cultures.

2.4.2. MPAs vs Dynamic MPAs

To integrate cultural importance with conservation efforts, a plan that has malleable restrictions could benefit both the ecosystem as well as island cultural traditions. The marine protected areas that are currently in place only provide significant coverage for benthic and coral species. The draw of a dynamic marine protected area, or DMPA, is that it would be able to provide a malleable area that can seasonally shift based on the data. This means, there are areas that can be fished in a particular season and areas that are either no-catch, or limited catch zones in the same season. This gives freedom to the fishing culture that relies heavily on seafood, while still providing adequate protection for various species being hunted commercially.

Marine ecosystems are fragile, and any significant shift could be catastrophic including overfishing of any kind. This project does not aim to minimalize or erase the existing MPAs, but it does aim to provide a way to better protect pelagic species that move throughout the territorial waters around New Zealand. Providing a generalized methodology for using tracking data to identify temporally varying high use areas that can then be used to create seasonal closures creates an opportunity for local governments to have an integral role in the conservation conversation.

Areas similar to New Zealand, where conservation practices are combined with cultural significance, are in need of policies that respect both aspects of island culture. The people that reside within the region of the Bering Strait, a much harsher climate than the temperate waters of the Pacific, still struggle with balancing cultural needs of the Aleut, Inupiat, and Yupik people, with the intensified need for environmental conservation for the Arctic (Siders, Stanley, and Lewis 2016). This could be a situation where a DMPA would be invaluable, with the ability to change due to the varying extremes of weather and climate change the Arctic currently endures. MPAs have been suggested in these areas but, according to Siders et al., they are much more successful in stable environments, whereas in the Arctic, a more malleable system might perform better.

2.5. GIS in Marine Conservation

As one could imagine, GIS is vital in the analysis of any spatial dataset. Platforms like ArcGIS allow users to visually place datasets within their geographic locations. GIS has been used for terrestrial wildlife when analyzing data from animals tracked by GPS collars embedded with satellite transmitters, like in the case of tracking snow leopards through its remote habitat (Johansson, Simms, and McCarthy 2016). The applications for GIS in marine conservation have developed quickly over the past decade and now satellite tags are being used more frequently in marine science.

Attaching satellite tags to the dorsal fin of a shark is no easy task, but the data output makes the process entirely worth the trouble. GIS provides the ability to study marine phenomena in a way that has previously been impossible, including the assessment of disease spreading in marine populations. With the combination of GIS evolution and remote sensing advancements, the tools for studying marine animals have grown exponentially. New tools, methods, and spatial analysis techniques have provided useful resources in the study of wildlife conservation as a whole (Norman 2008). Using similar terrestrial techniques, and benefiting from technological advancements, marine researchers have developed new ways to study how marine animals utilize their environment. These powerful new research tools have become less expensive and are more readily available, lending to scientific discoveries being made more frequently (Ebert, Fowler, and Compagno 2013).

2.6. Summary

There are still significant challenges related to marine exploration regarding climate change, ecosystem development, and resource management that the marine science community will need to face in the coming decades (Wright 2011). Developing technologies mean that methods will change as better tactics and tools arise. Wright notes that GIS is a powerful technology in marine animal conservation, and it is slowly becoming a vital part of understanding how we can improve efforts overall. Spatial analysis of tracking data points provides a clearer understanding of necessary needs and gaps in current conservation efforts.

By combining technologies and techniques currently used in general wildlife conservation and using them in marine science, a better understanding of the marine environments could introduce better tools for conservation. GIS has moved from being a tool used solely to display data and is now being used to visualize, model, and provide support for decision making in all aspects of scientific research (Wright 2011). This project aims to add to this existing collaboration and provide a methodology that can help researchers integrate DMPAs into the conservation conversation.

Chapter 3 Data and Methods

Collecting or having the right kind of data in hand is key to a successful research project. For this study, several datasets were collected and explored to determine what kind of data is useful in understanding shark behavior, migration, and current MPA and EEZ locations. Once the datasets to use were chosen, the next step was to determine how to use them to create a methodology for identifying viable DMPAs. This chapter discusses the data used and describes the methodology developed.

3.1. Mako Shark Data

The main collection of data used in this study is from electronic tags deployed on mako sharks within the New Zealand waters. The original dataset is comprised of the locations in latitude and longitude of 14 mako sharks. Thirteen of these sharks were tagged on an irregular schedule between 2012 and 2017, the fourteenth shark was tagged in 2013 off the coast of Australia as part of another study. This project focused on the 13 within New Zealand's waters. This dataset includes individuals of both sexes and various sizes and is predominantly juveniles (Francis et al. 2018).

3.1.1. Data Source

This shark tagging data was provided by Dr. Malcolm Francis and his team at NIWA, the National Institute of Water and Atmospheric Research in Wellington, who have been instrumental in studying shark movements both locally and globally. Dr. Francis and his team deployed electronic tags on these sharks to study their movements, both temporally and spatially, and to understand how they use their habitats. They focused on how they moved and classified each shark's behavior as either Resident or Travel, considering whether they were within New

Zealand's coastal or oceanic waters. Their results showed that many traversed between the resident and travel classifications, but that several stayed within the EEZ surrounding New Zealand. This allowed them to conclude that these sharks were not as nomadic as previously thought, and that managing the fishing mortality should be on a local scale as well as a regional one (Francis et al. 2018).

To catch the sharks for tagging, angling was done from a small motorboat while chumming the waters. Chum is generally comprised of animal, mainly fish, heads, blood, and intestines which creates a slick across the top of the water. Sharks have a heightened sense of smell and can locate blood within one part per million (Ebert, Fowler, and Compagno 2013). Once on the line, the shark was brought alongside the boat and restrained while the boat was in motion, creating the necessary flow of water over its gills to keep it alive. After collecting various measuring markers and biological data, tags were attached to the dorsal fin of each shark by drilling small holes and using stainless steel bolts and washers in compliance with research standards (Francis et al. 2018).

The 13 sharks were tagged using SPOT5 or Splash tags from Wildlife Computers, a company based in Washington. All of these tags use satellite communication to relay information back to the Argos satellites whenever the shark's dorsal fin breaches the water. Although these tags did not have GPS functions, the location was determined based on the number of messages received from Argos satellites. This has varying degrees of accuracy and resulting locations are classified by an Argos system that is comprised of numbers and letters including: 3, 2, 1, 0, A, B and Z. According to experimental studies, the location classes 3, 2, 1 and A are considered to be accurate to approximately 2km. The locations with the quality classes 0 and B are considered accurate to approximately 5-10km, and class Z locations are considered invalid (Francis et al.

2018). Table 2 summarizes the specifics of each quality assessment along with estimated accuracies. Based on this table, the decision was made to include in this study only those data points that had a quality rating of 1, 2, or 3. This meant that the range in accuracy was 1000m to less than 150m. In the greater scape of the ocean, these points were determined to have sufficient accuracy.

Table 2. Tagging Data Quality Details. Source: Francis 2018

Service	**Satellite Location Class**	**Estimated Accuracy in Latitude and Longitude**
Standard Location:	3	< 150 m
Calculated from at least four messages received during the satellite pass	2	150 m <= accuracy < 350 m
	1	350 m <= accuracy < 1000 m
	0*	> 1000 m
Location Service Plus (named Auxiliary Location Processing in North America): • three messages received • two messages received	A	No estimate of location accuracy
	B	No estimate of location accuracy
• rejected locations	Z	(invalid locations)

Prior to delivering the data, Dr. Francis and his team analyzed all the tracks from the sharks and generated figures using the open-source programming language, *R*. In addition, the *argosfilter* R package was used to filter out Argos improbabilities for location accuracy. They used a hierarchical Switching State Space Model (SSSM) to filter the Argos locations to estimate daily locations. This helped the original project with determining the *resident* and *travel* classifications (Francis 2018). Although this DMPA project did not use those designations and did use individual data points rather than daily summaries, the initial filtering process meant that the data, once received, was ready for analysis and additional filters could be applied to suit this particular project on developing DMPA locations.

It is impossible to track every shark in the ocean, but this dataset provides a generalized example of how this particular species uses this specific environment. Dr. Francis and his team identified the areas in which resident and travel behaviors were focused by creating a kernel utilization distribution model. Figure 7 shows the results from that assessment. While not incorporated in to this study, these could be used later to verify the locations of high use areas identified in this DMPA project.

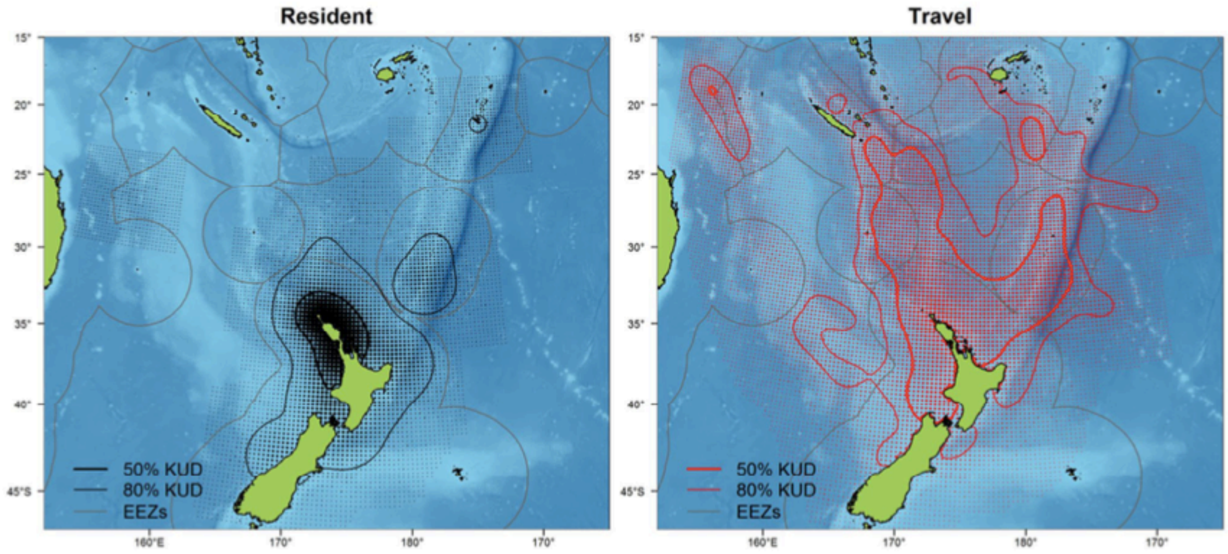
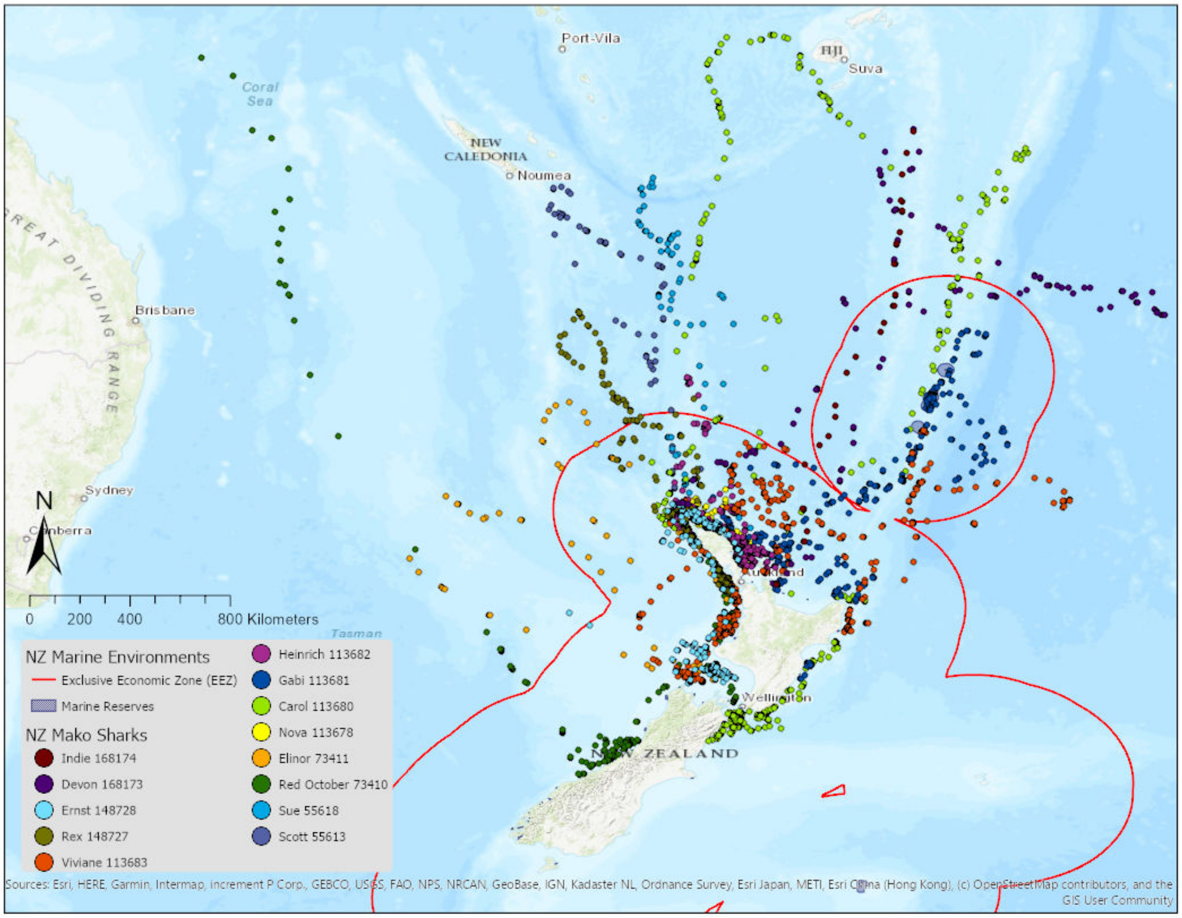


Figure 7. Kernel Utilization Distribution (KUD) Models. Source: Francis 2018

3.1.2. Tagging Data Exploration

Figure 8 shows the full extent of the data with each shark individually colored. Clearly there is significant travel among the individuals, with some showing stronger shore fidelity. According to Dr. Francis, the amount of time spent within the EEZ ranged from 42% to 100% (the latter in the case of “Nova” or tag number 113678). In addition, five out of the 14 sharks spent approximately 90% of their time within the EEZ, leading to the overall assessment that 47.3% of the sharks were classified as Resident (Francis 2018). This is contrary to the prior belief that mako sharks were predominantly nomadic. Showing this site-fidelity to inland waters increases the need for coastal and oceanic protection overall.

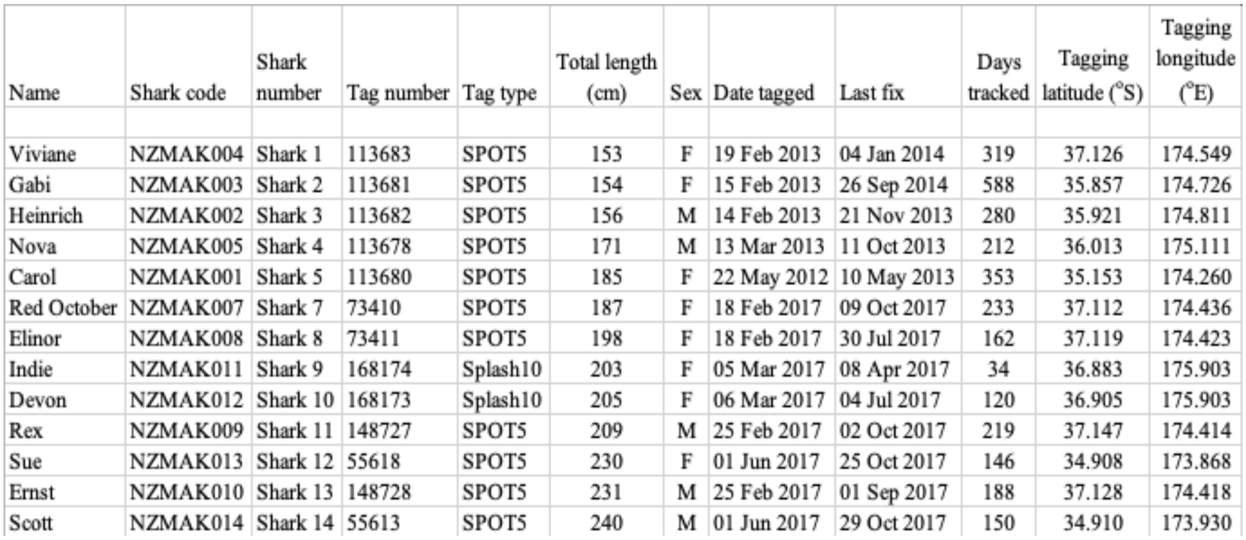


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 8. Mako Data - Full Extent

Table 3 shows the details of the mako sharks in the dataset, including descriptions of each individual shark in the project. In addition, this table includes the tag type, which are mostly SPOT5 tags.

Table 3. Tagged Shark Details



Name	Shark code	Shark number	Tag number	Tag type	Total length (cm)	Sex	Date tagged	Last fix	Days tracked	Tagging latitude (°S)	Tagging longitude (°E)
Viviane	NZMAK004	Shark 1	113683	SPOT5	153	F	19 Feb 2013	04 Jan 2014	319	37.126	174.549
Gabi	NZMAK003	Shark 2	113681	SPOT5	154	F	15 Feb 2013	26 Sep 2014	588	35.857	174.726
Heinrich	NZMAK002	Shark 3	113682	SPOT5	156	M	14 Feb 2013	21 Nov 2013	280	35.921	174.811
Nova	NZMAK005	Shark 4	113678	SPOT5	171	M	13 Mar 2013	11 Oct 2013	212	36.013	175.111
Carol	NZMAK001	Shark 5	113680	SPOT5	185	F	22 May 2012	10 May 2013	353	35.153	174.260
Red October	NZMAK007	Shark 7	73410	SPOT5	187	F	18 Feb 2017	09 Oct 2017	233	37.112	174.436
Elinor	NZMAK008	Shark 8	73411	SPOT5	198	F	18 Feb 2017	30 Jul 2017	162	37.119	174.423
Indie	NZMAK011	Shark 9	168174	Splash10	203	F	05 Mar 2017	08 Apr 2017	34	36.883	175.903
Devon	NZMAK012	Shark 10	168173	Splash10	205	F	06 Mar 2017	04 Jul 2017	120	36.905	175.903
Rex	NZMAK009	Shark 11	148727	SPOT5	209	M	25 Feb 2017	02 Oct 2017	219	37.147	174.414
Sue	NZMAK013	Shark 12	55618	SPOT5	230	F	01 Jun 2017	25 Oct 2017	146	34.908	173.868
Ernst	NZMAK010	Shark 13	148728	SPOT5	231	M	25 Feb 2017	01 Sep 2017	188	37.128	174.418
Scott	NZMAK014	Shark 14	55613	SPOT5	240	M	01 Jun 2017	29 Oct 2017	150	34.910	173.930

Table 4 shows an example of the tagging data with all relevant columns. Note that it includes specific temporal data along with the quality class assessment, calculated by the number of satellite signals received and by triangulation, given to each location. This particular table focuses on a small part of the data from tag number 113680, or Carol.

Table 4. Tagging Data Example

Object ID	Tag	Lat	Long	Quality	Date	Time	Datetime
1231	113680	-35.1529	174.2603	3	5/22/12	2:50:00 AM	5/22/12 2:50
1232	113680	-34.73493	174.23661	1	5/22/12	8:22:00 PM	5/22/12 20:22
1233	113680	-34.60964	174.25844	2	5/23/12	4:17:00 AM	5/23/12 4:17
1234	113680	-34.61453	174.25644	3	5/23/12	4:41:00 AM	5/23/12 4:41
1235	113680	-34.26348	174.44709	1	5/23/12	7:53:00 PM	5/23/12 19:53

The first step in understanding the shark tagging data was to identify each individual shark as it moved through space and time. One of the ways to achieve this was by using ArcMap’s tool “Tracking Analyst”. By using the temporal data provided for each individual data point, a timeline was created that could show from the first tagging date to the last known position, how all sharks moved through the area. Once individualized by tag number, the movement was animated, which gave a clear picture from one day to the next how each shark moved throughout space and time.

Visually understanding how the sharks moved helped in extracting seasonal information for each shark. Searching for seasonal changes in behavior by using the visualization of these track lines helped in understanding if there was a strong correlation between movement and time of year. Although the dataset was complete with hour, minute, and second times, only the month, day, and year was used. This choice was made based on the need for a DMPA to change seasonally, not day-to-day.

The seasons in the southern hemisphere are opposite to those in the northern hemisphere. Based on previous works, with some minor variations, the seasons for this project were defined as shown in Table 5. One variation can be found in the behavioral project from Dr. Francis that considers March as the late summer, but June as early winter (Francis 2018). For the purposes of this project, it was decided to keep the seasons equally balanced. As explained below in the methodology, this seasonal classification was used when manually separating the track lines into seasonal chunks.

Table 5. New Zealand Season Breakdown

Season	**Months Included**	**Month Number**
Spring	September, October, November	9,10,11
Summer	December, January, February	12,1,2
Fall	March, April May	3,4,5
Winter	June, July, August	6,7,8

To see the seasonal changes in space and time two methods were tried, but inevitably they were not included in the final analysis. There is a useful tool within ArcGIS Pro called the Data Clock that produces a data visualization showing the distribution of the data points over time (e.g. by month and year). Using this tool was helpful only in seeing that there was a significant temporal gap in the data. Although noting the gap in the data was useful, it was ultimately decided that the Data Clock was not the best visualization for the project as a whole. The data points were not evenly collected over time, the dates of collection were irregular and frequency varied depending on individual shark behavior and collection opportunities, not on any kind of structured sampling frequency. This meant that the Data Clock showed clusters whenever several data points were collected close in time but did not show the actual number of sharks at the time.

For the same reason, hot spot analysis could not be used since the data points did not indicate anything other than more frequent collection of data in one location. Again, the aim of this spatial analysis was to locate areas of high use from several sharks, not just one. It was determined that hot spot and kernel density analysis would not be useful in this particular project. Therefore, unfortunately, the Space-Time Cube analysis toolkit within ArcGIS Pro could not be used.

3.1.3. Seasonal Water Temperature Changes

Another data exploration surrounded the issue of climate shifts that could potentially affect shark migration and behavior. In the ocean, water temperatures can have a direct effect on how a fish moves through certain areas. Some sharks have the capability to adjust their body temperature; as discussed previously in this paper, the mako shark does have this trait and can make its body temperature higher than the surrounding waters. This allows the shark to move into colder or warmer waters easier than a shark without this ability.

The slightest change in temperature can create issues for smaller aquatic organisms like phytoplankton. This change can cause a ripple effect in the food chain, forcing smaller species of krill, fish, and microorganisms to move to different waters than usual. This inevitably creates a shift in prey behavior which can affect predator behaviors as well. Because of this connection, water temperature data was searched for that could track the temperature changes throughout the year. Seasonal changes can be either normal or abnormal based on the areas of study and temperature fluctuations help to indicate why a species makes adjustments in their normal migrations. There was one dataset that seemed viable to include in analysis, but it was eventually used in verification of the results rather than initial analyses. Further research in temperature changes could provide more insight into whether this plays a significant role in behavioral changes within sharks, but for the purpose of this thesis project there was no need.

3.2. Data Preparation

Once data are compiled, preparing them for analysis is the next step. This includes an overview of how the data can be integrated into the project and how it will best be displayed. Visualization is an important step of data exploration and choosing the correct projection is vital in correctly analyzing the data when it is displayed. The projection normally used in New Zealand is the Universal Transverse Mercator (UTM) 2000 and NZGD2000 is the official datum used for positions within New Zealand, so this is the datum that was used for this project. The original data was converted from the SSSM locations in latitude and longitude to UTM locations centered around zone 60, which is 174ºE -180º (Francis 2018).

The first step of the data preparation involved adding a field to the tagging data into which the season associated with each date could be inserted. Next, individual shark track lines were created using the “Point to Line” tool. After verifying the resulting lines contained the attribute data needed to identify them, the next step was to separate the lines based on seasonal breaks. To begin this process, a new layer was created for each shark to allow individual seasonal breaks to be more easily identified. Then, each shark’s track was displayed with sequential data points labeled according to season. By manually locating the two adjacent points on each side of a seasonal change, the track line was edited using the "Split" tool. This created separate season line segments that contained the same attributes as the original. In the end, this resulted in one to four sets of separate seasonal track segments for each shark, dependent on how long the shark was tagged.

From there, using the Buffer tool, a polygon was created around each seasonal line segment with a radius of 32m, which was the determined average distance a shark would travel in a day's time. Once all of the individual shark seasonal polygons were recombined into a single "Seasonal Polygons" dataset, the tagging data were now transformed into seasonal polygons that could be used to determine overlapping areas of importance.

3.3. Methodology to Identify Core Areas for DMPAs

The main goal of this project was to create a generalized workflow that can be applied in other locations for other species. Having a clear step-by-step explanation means that others will be able to use the same methodology and create results to help within their own communities. This section discusses the use of ModelBuilder and shows flowcharts with defined steps on how to create designated areas for protection. This project went through several variations of how to achieve designated areas of high use. The aim of the project, however, stayed the same—the need to identify areas that are used more frequently and could benefit from seasonal protection.

3.3.1. The "Spaghetti and Meatballs" Method

In order to determine the areas where the most use occurred, a Count Overlapping Polygons method was needed, named by its creator the "spaghetti and meatballs" method (Honeycutt 2012). Essentially this method uses the concept of cartographic "spaghetti" and creates centroid points, called "meatballs," to count the overlapping polygons. The process begins by intersecting (Union) all overlapping shark polygons (buffered track segments) for a single season, resulting in a collection of many tiny non-overlapping polygons, the “spaghetti” polygons. Creating the meatballs was achieved by using the “Feature to Point” tool on these spaghetti polygons and ensuring all centroids fall “inside” the polygons. From here, the next step is to perform a spatial join to count the number of original overlapping polygons at each meatball.

Using the ModelBuilder tool in ArcGIS Pro was vital in creating a user-friendly workflow that could be replicated by others. Figure 9 shows the final model workflow used in this project, utilizing the “spaghetti and meatballs” method. Several steps are dependent on input features being correct, which means that initially the dataset has to include specific ways to identify each track line and season, hence the importance of carrying over attributes.

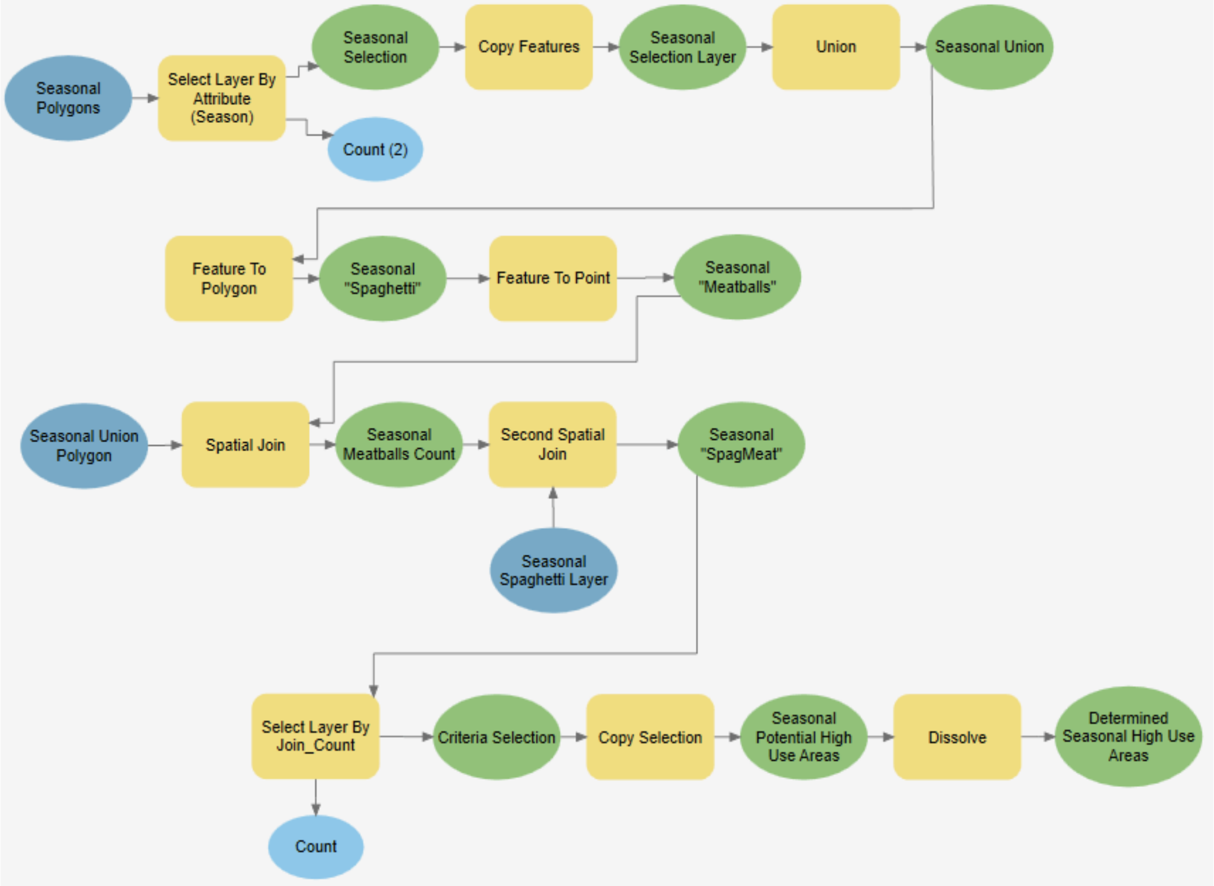


Figure 9. ModelBuilder Workflow

3.3.2. Identification of Core Areas for DMPAs

The next step was to display the high use areas visually. Each season has some polygons with high numbers, indicating locations more sharks frequent. This means these areas are used more than others which could indicate greater importance. Once these areas have been identified, an assessment can be made on the value of these areas as locations for seasonal closures. Using different colors and textures to identify the areas separately was an important factor. Being able to clearly see these locations means that the results are far more user-friendly and easier to understand.

By displaying the symbolized join count overlap, areas where there were concentrations of sharks are readily evident. These are the areas of high use. To make these clearly visible, the polygons with a join_count number higher than a specific number were selected and extracted. For the purposes of this demonstration, a join_count of 3 or higher was used, except in one case described below. This meant that these areas had seasonal polygon overlaps of at least three sharks, not one shark using that area three or more times a year. This number was chosen, somewhat arbitrarily, as it is the lowest possible number that still included enough data for analysis. For a dataset composed of tracks from only 13 sharks, one shark in an area could be a fluke, but 3 can indicate a pattern. The summer season, December to February, had the least number of data points and the join_count cut-off was dropped to include 2 or more for data visualization purposes. Future users of this method will need to choose their own cutoff point based on their data and knowledge of the species being studied.

Using the "Dissolve" tool on the join_count numbers, seamless weighted polygons were created. The areas with the critical overlap count were selected and became their own layer by using the "Copy Feature" tool.

This is the process that can be used and edited by others for their own projects. Using a program called Lucidchart, a workflow was created to show the generalized steps of the project, beginning with gathering data, and including steps to filter and digitize data accordingly. Figure 10 shows this workflow. The main goal of this workflow is to visually show the steps needed to get the end result, although this process is unique to this analysis of the mako shark tagging data.

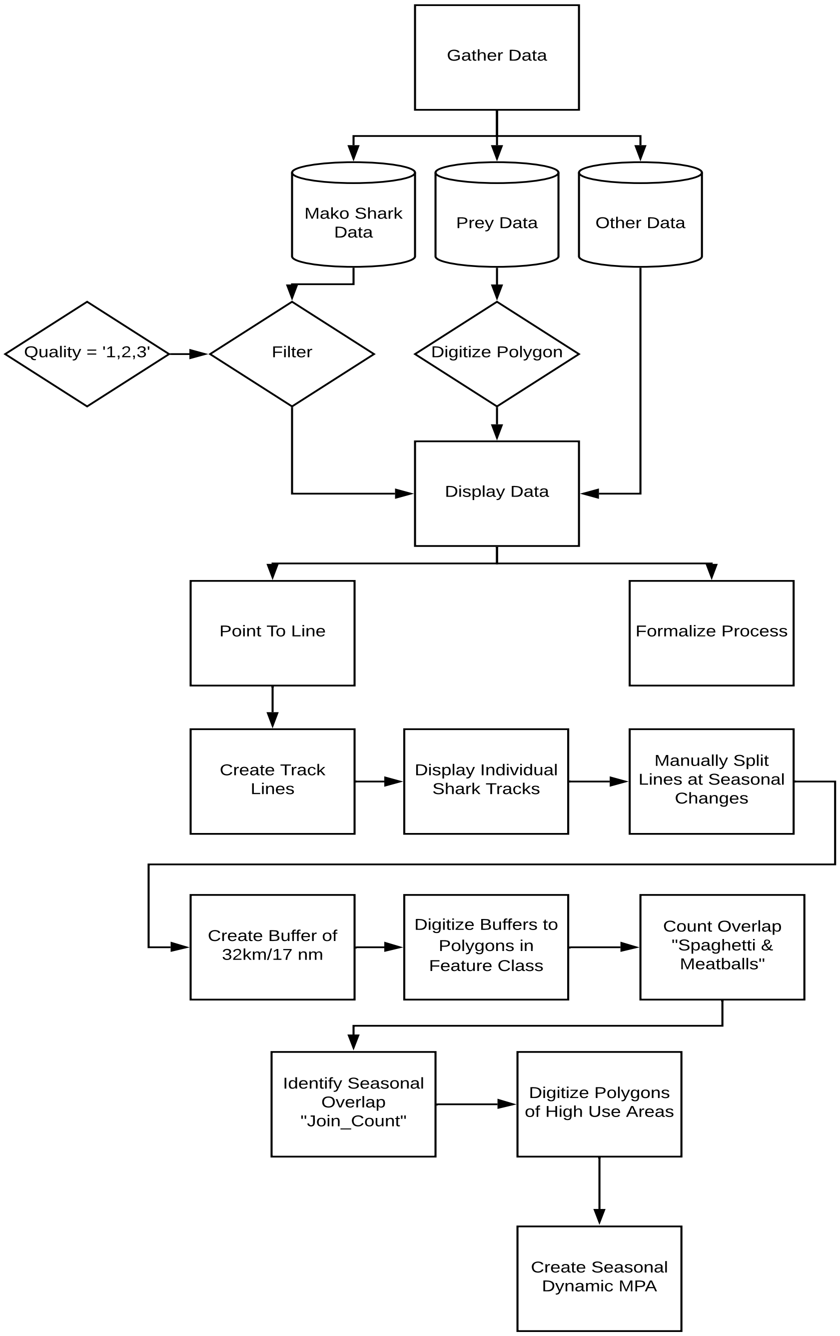


Figure 10. Project Workflow

Table 6 shows each of the steps outlined with details required for this particular project and DMPA.

Table 6. Detailed Workflow Outline

Step	General Method	Specific Requirements for mako DMPA
1	Gather data set	Minimum of 1000 data points over 3 years for tracking areas of heavy use
2	Extract useable data with best quality	Extract data with “quality” score of 1,2, or 3
3	Input data into GIS program	Add data to ArcGIS Pro
4	Create individualized tracks to best see data and area uses	Use expressions to “select layer by attribute” from the Mako Sharks dataset, use “tag” column data to identify individual sharks. Then use “XY Table to Point” to create separate tracks
5	Make use of temporal data	Convert in Excel to one column for date and time, use “Text to Columns” feature
6	Use the Tracking Analyst tool in ArcMap to study movements throughout time	Separate track lines for each individual tag number to ID isolated sharks
7	Create track lines in ArcGIS Pro	Use “Point to Line” tool to sequentially connect data points
8	Create Buffers around seasonally segmented lines	Use editing session to digitize, create a buffer of 32 km to account for day-to-day movement of sharks
9	Digitize Polygons for Visual Representation	Use “Spaghetti and Meatball” method to create polygons
10	Identify locations with significant overlap	Dissolve polygons based on join_count number
11	Display Polygons of closures for DMPAs	Use created polygons to show areas where seasonal trends occur and mark those as closures for the dynamic MPAs

3.4. Summary

Using these designated areas, a selection can be made where the count is above the number of overlaid seasonal polygons needed. In this case, greater than 3 is needed for the seasons fall, winter, and spring, and 2 needed for the summer season. With this selection, a new layer is created where polygons with only those counts exist, and these areas are the high use areas for each season. Showing all the polygons together suggests the areas that can be used to make up a DMPA in the area. Seasonal closures can include all, or parts, of the highlighted areas to ensure species numbers increase instead of decline.

Chapter 4 Results

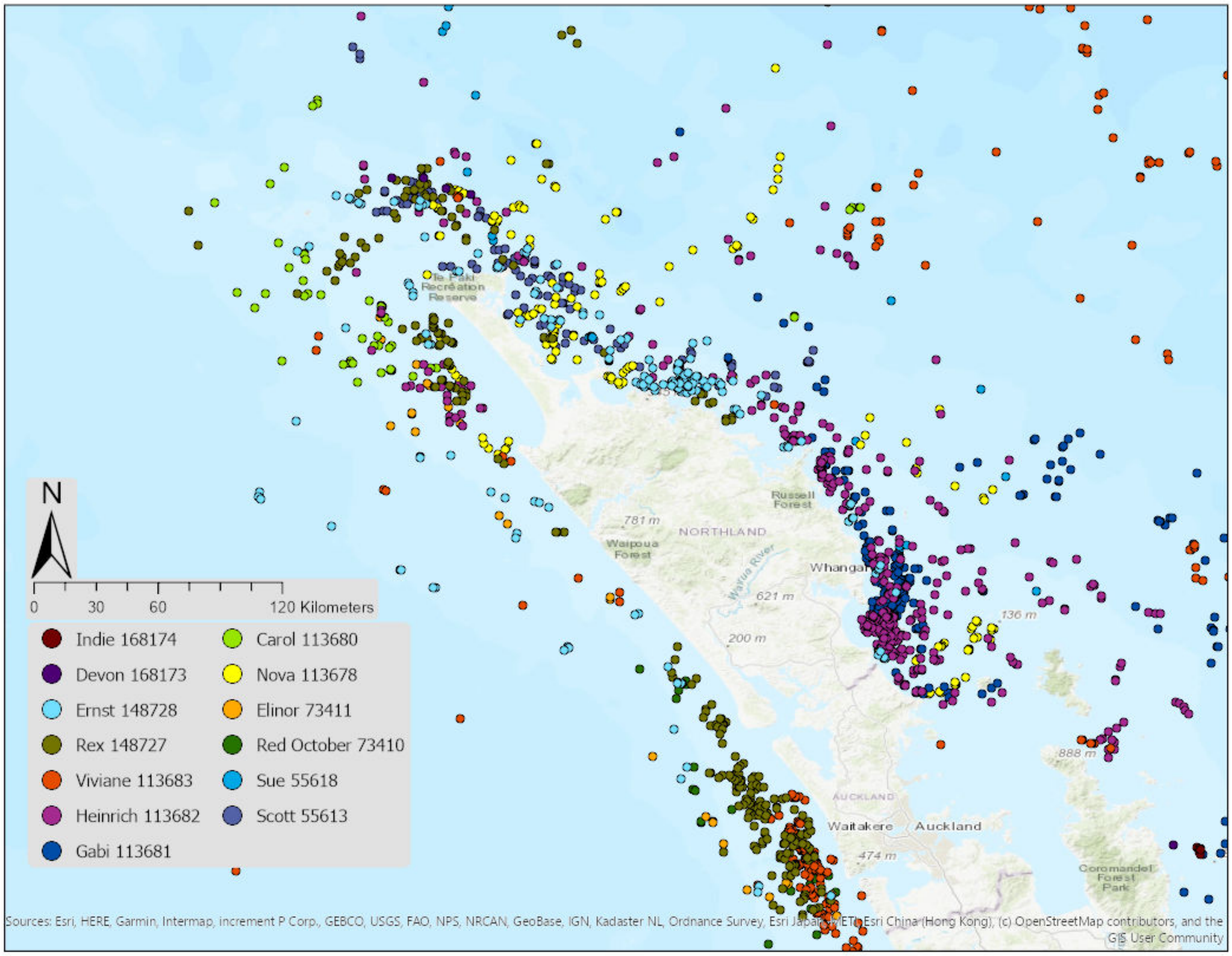
The workflow in this project was able to identify areas that might be considered as DMPAs for mako sharks in New Zealand. It is important to repeat, this project was not intended to provide details that would enable authorities to implement these policies, but merely is showing how appropriate data and GIS techniques can be used to delineate areas where DMPAs could provide increased protection for pelagic species. This chapter shows the results of each step of the workflow.

4.1. Workflow Results

The beginning steps included gathering viable data and filtering out any erroneous or unnecessary information. Looking at the original dataset, there were over 12,000 data points available. Filtering out by quality, based on the Argos legend provided by Dr. Francis, the final dataset ended up at just over 5,000 data points. From here, to achieve accurate results, only the data points with a quality rating of 1, 2, or 3 were used. Next, changing the symbology and displaying the data points by color-coding each shark was done to best see individual trends.

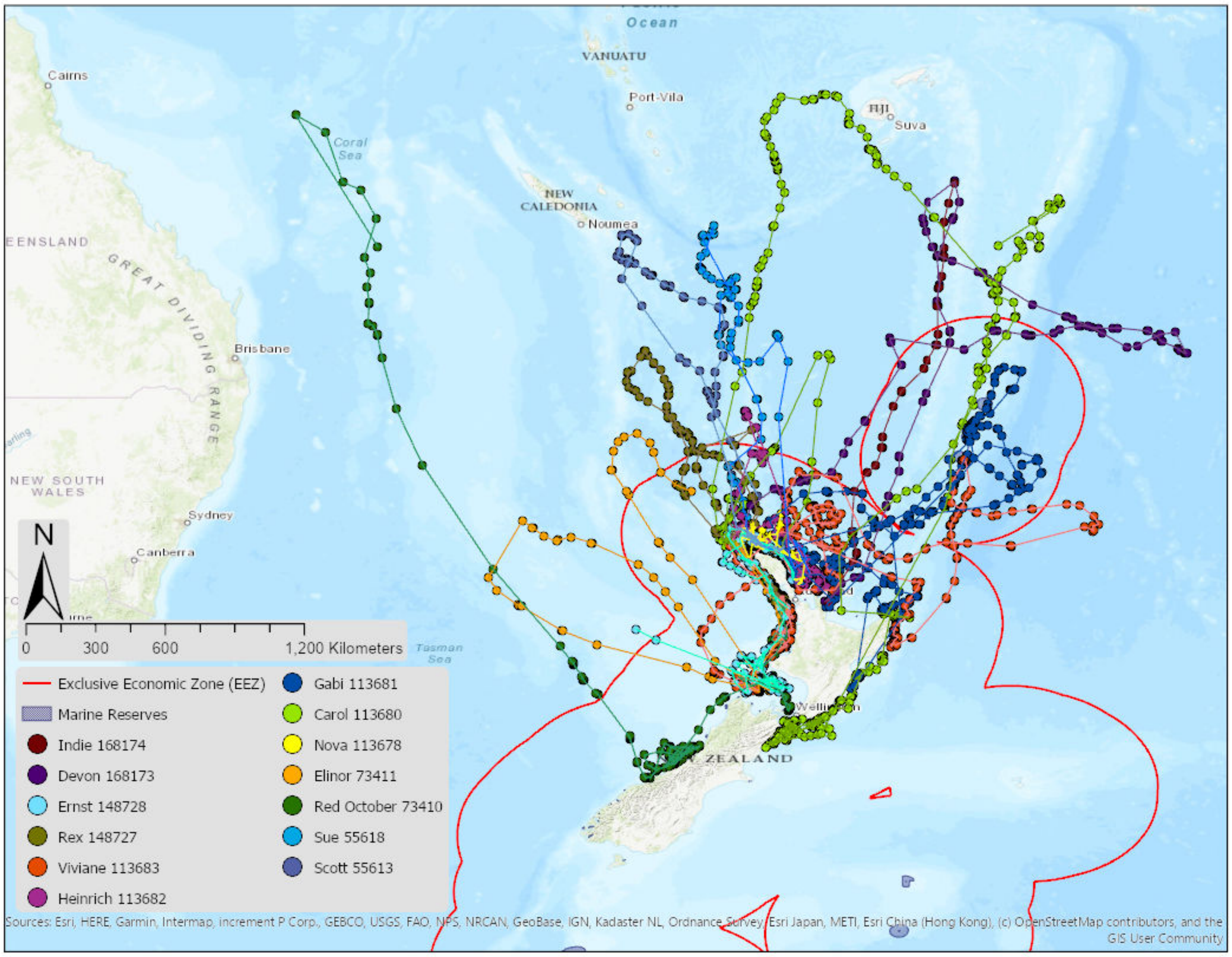
4.1.1. Creating Track Lines & Seasonal Splits

Once the data was gathered and displayed, creating track lines was the top priority. Figure 11 shows a closer look at the initial dataset, colorized and separated, to indicate each shark. Without track lines it is nearly impossible to follow each line, which is why using the "Point to Line" tool was so helpful. Figure 12 shows the datapoints with the track lines included; however, it is still difficult to see each track individually. Understanding how to properly display the data is essential in creating a valuable result. Initially, the idea of separating each polygon into seasonal colors was attempted, but the end result was still impractical. It was determined at this stage that using the buffers as polygons to determine overlap was the best course of action.



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

Figure 11. Individual Mako Sharks



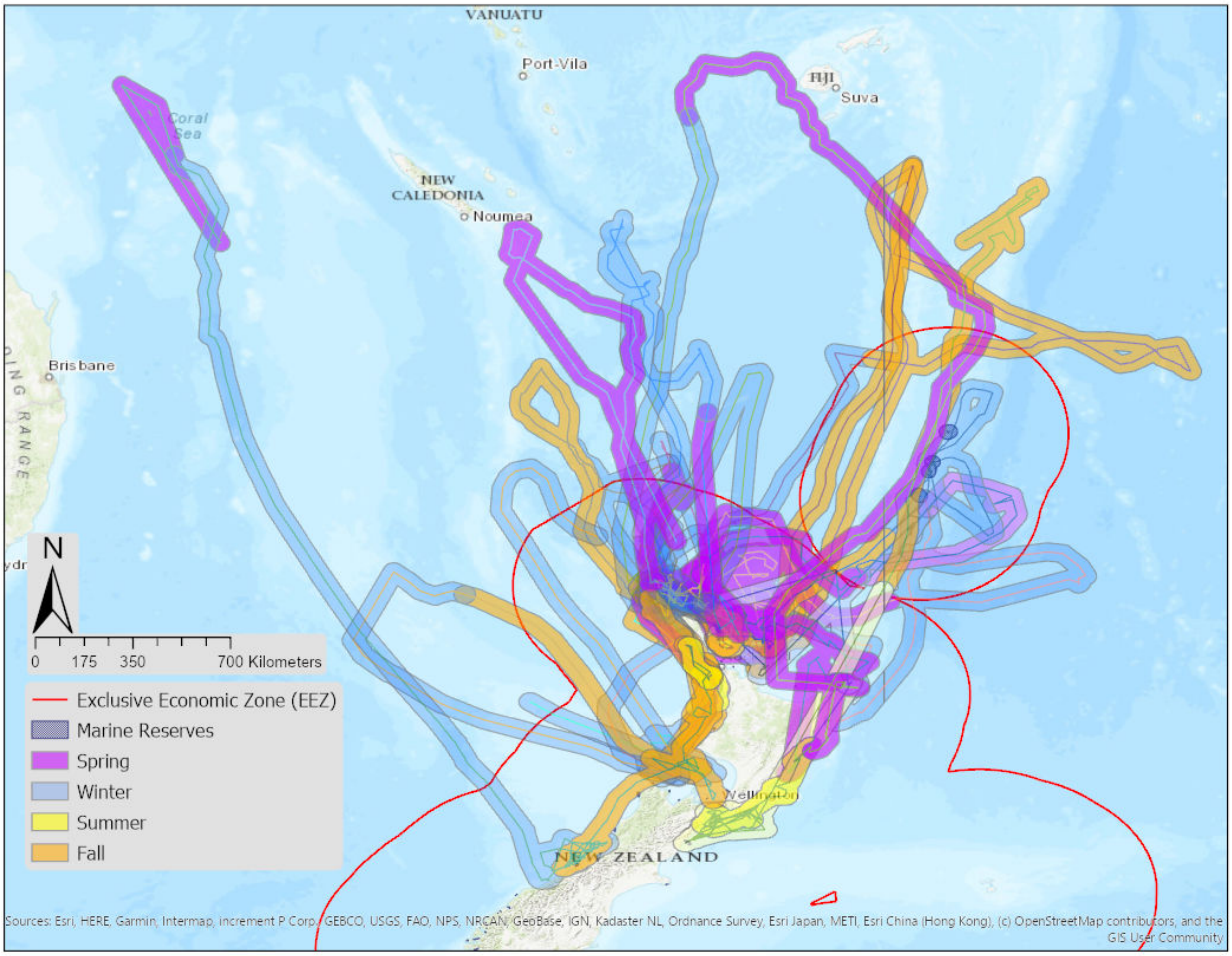
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 12. Data with Track Lines

The next step was to create seasonal breaks in each line, determining what areas were traveled in within each season. By using the “Edit” and “Modify” options in ArcGIS Pro, the “Split” tool was used to manually go through each track line and “break” the lines where the season changed. Then, by selecting each separate line segment, a new layer was created for each individual shark for each season.

4.1.2. Buffered Polygons and Spaghetti

The next step after splitting the lines seasonally was creating a buffer around each line segment. This indicated the approximated area a mako shark could travel based on randomly selected individual sharks and several data points. The determined buffer radius was 32km, which would provide enough of an area that could be seen and protected. Once each buffer was created, the final few steps could be identified. Figure 13 shows the buffered seasonal polygons used in analysis. This initial jumble shows all the areas that overlap, but this is illegible and needs to be altered further.



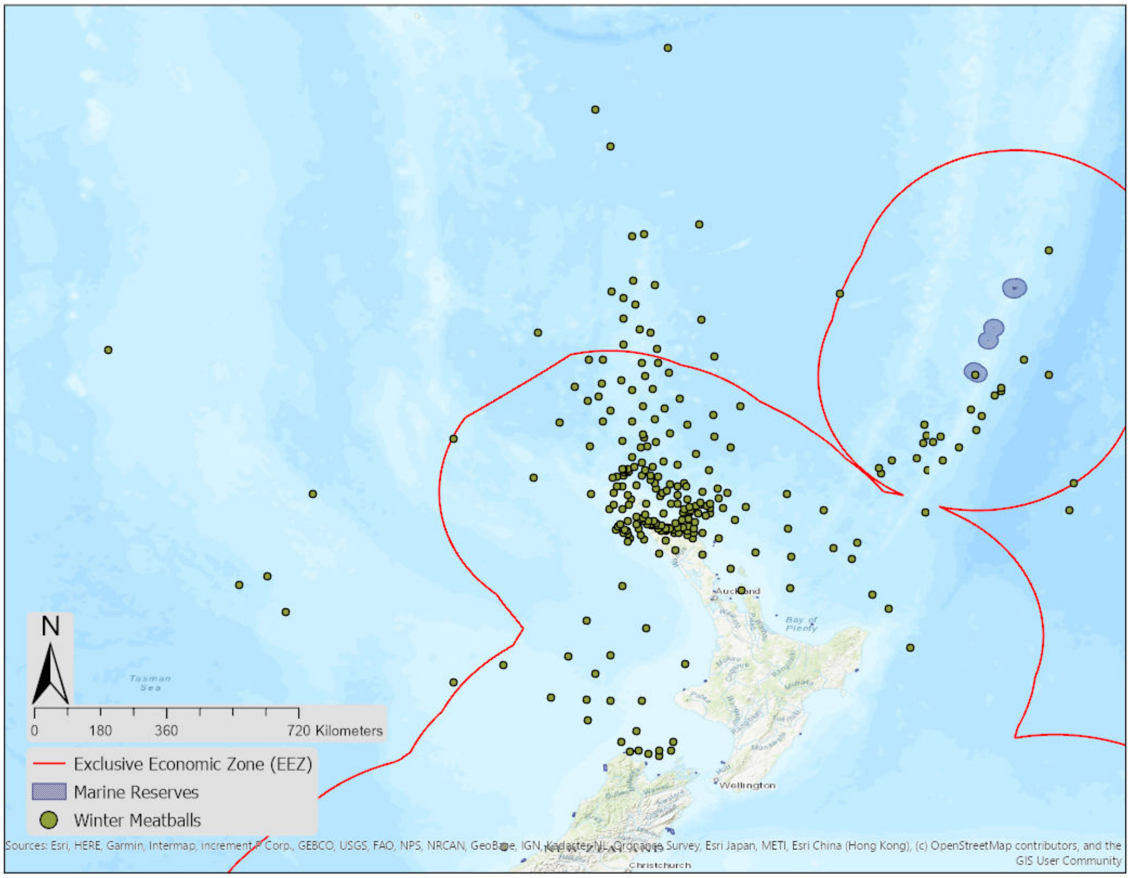
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 13. Buffered Seasonal Tracks

Creating the “spaghetti” layer included combining all the separate seasons, with corresponding attributes, into one layer with overlapping buffered zones. All the polygons in this layer were then intersected. Once this was done, each polygon overlap area could be identified and the next step of creating the “meatballs” could be implemented.

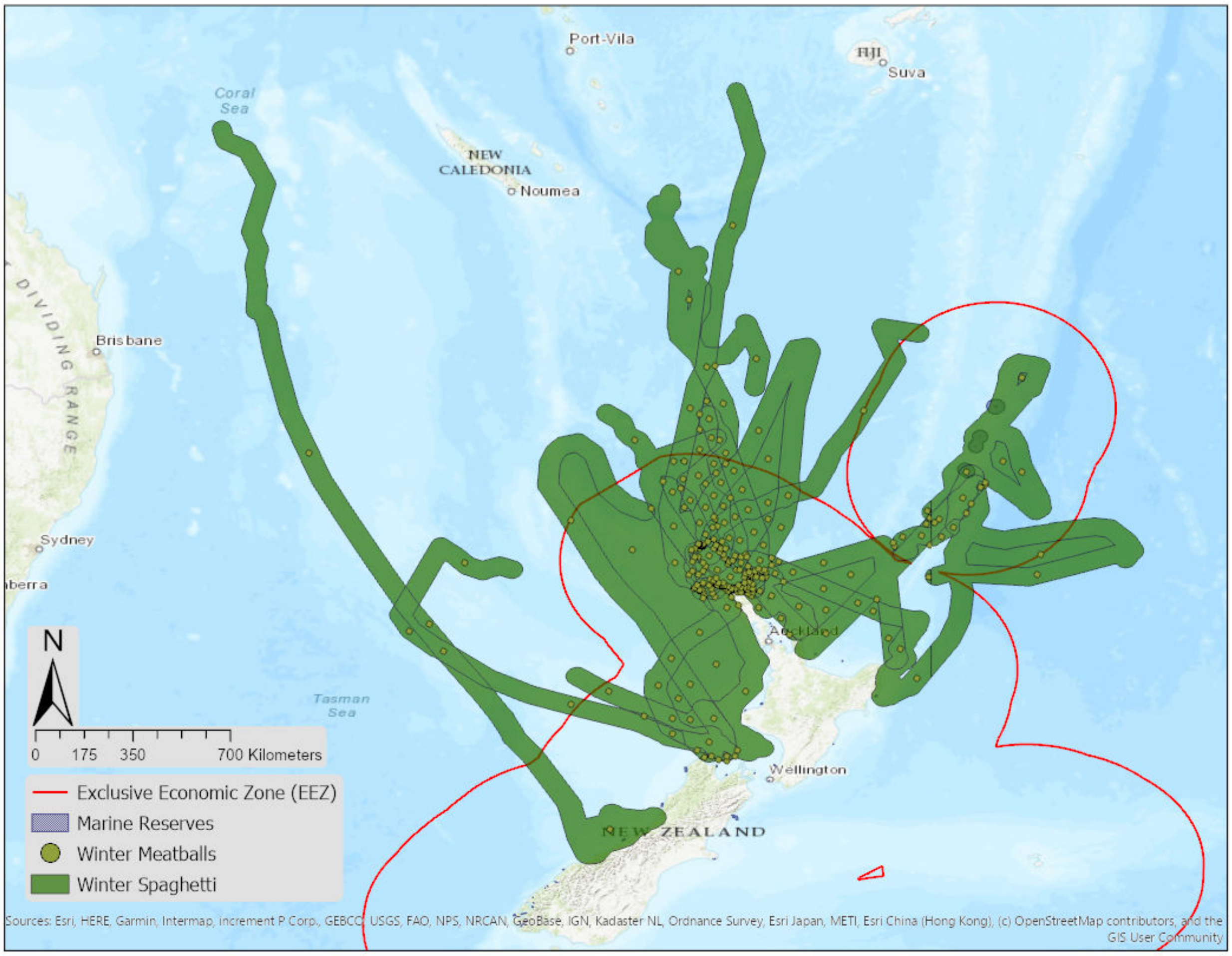
4.1.3. Meatball Spatial Join

Figure 14 shows the centroid points (meatballs) alone for the winter season, while Figure 15 shows those points within the respective polygons made by the “spaghetti”, creating the “SpagMeat” or spaghetti and meatball layer for winter.



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

Figure 14. "Meatball" Centroid Points



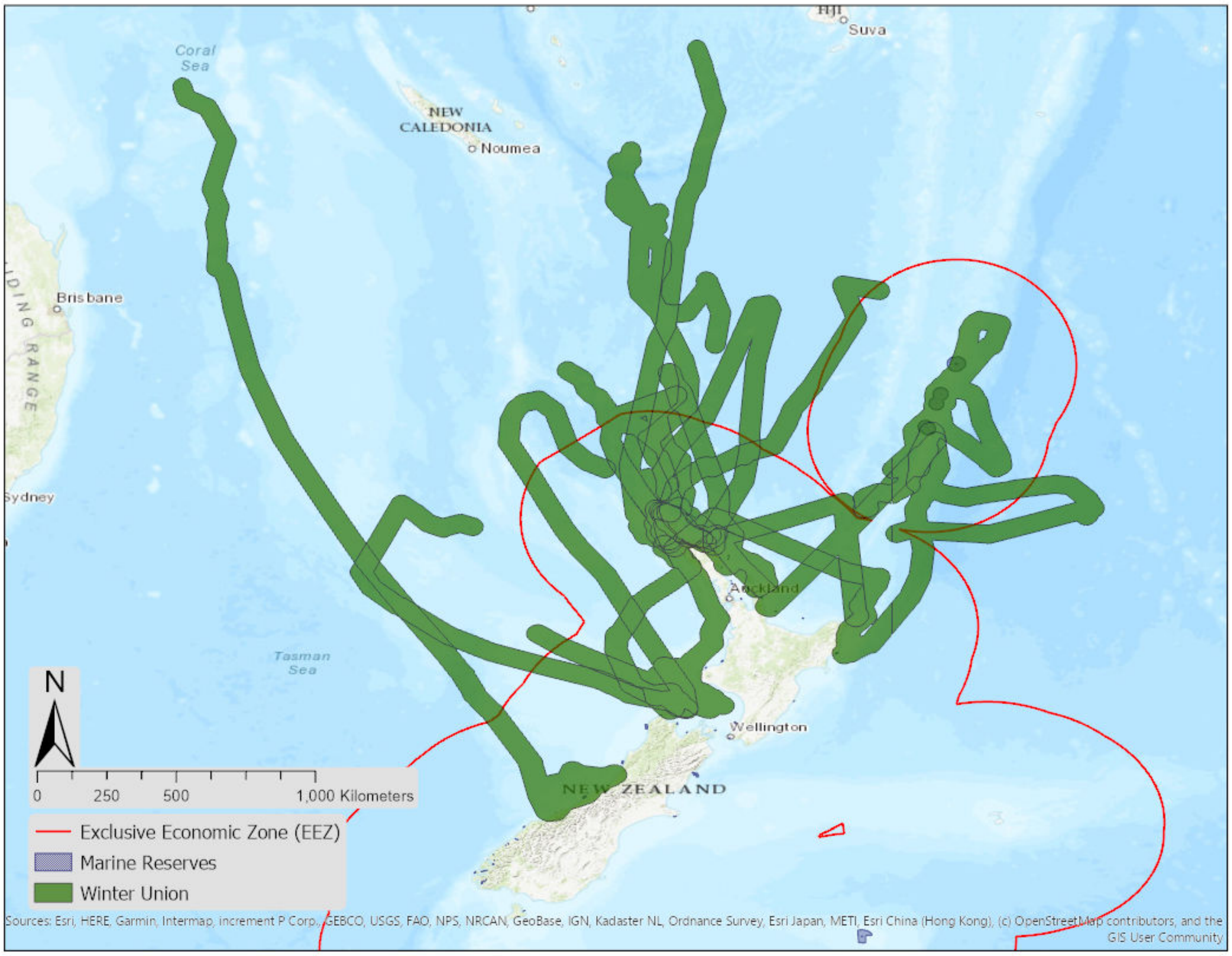
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 15. Spaghetti and Meatballs

After these centroid points are created, the next step is to overlay the original season's polygons to count how many polygons are overlapping at each point. Using the "Spatial Join" tool creates a join_count column in the meatballs attribute table which can be used later to sort out the areas with the largest count. Ensuring to choose the "one-to-one" option in the parameter box and "keep all target features", there is an option to choose how to filter via the "Field Map" parameter window. In this project, the *SHARK_ID* column was chosen as the designated identifier.

A second "Spatial Join" appends the meatball counts to each spaghetti polygon. Figure 16 shows this result for the winter season with only polygons with more than 0 count are included.

From here, choosing to display only those areas that had the required join_count number was done by simply using the "Select by Attributes" tool and creating a new query.



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

Figure 16. Union of Spaghetti and Meatballs

4.1.4. Selecting and Symbolizing Join Count

Figure 17 shows the areas where there are 2 or more sharks that overlapped, indicating the overlapped polygonal areas that are used more frequently. Figure 18 shows the same map with the areas designated as high use areas based on the fact 3 or more sharks used the area. This would inevitably become part of the final results map for the winter season. The darker red areas, just north of Auckland, show that more sharks overlapped in these particular areas than others.

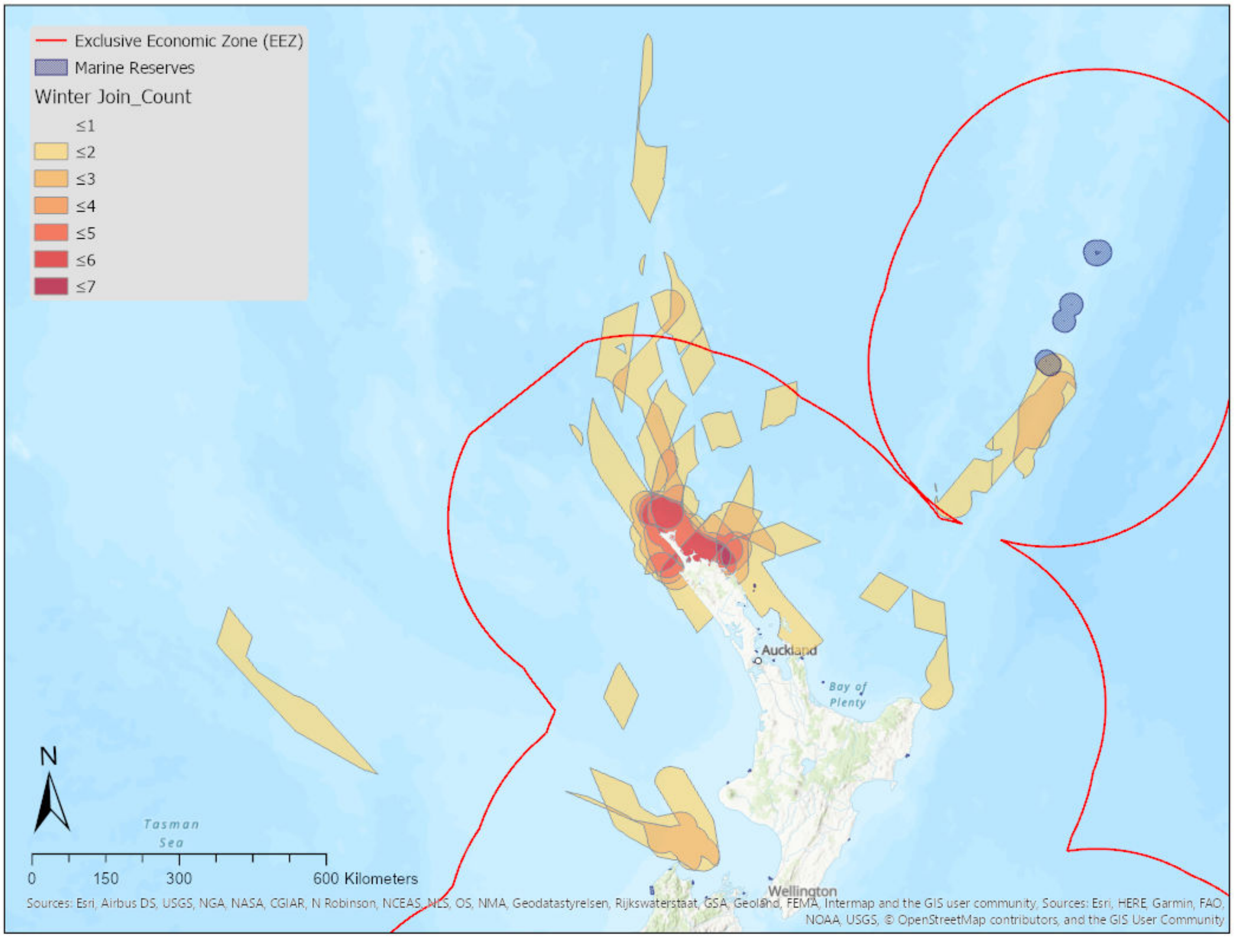


Figure 17. Winter Join Count Areas

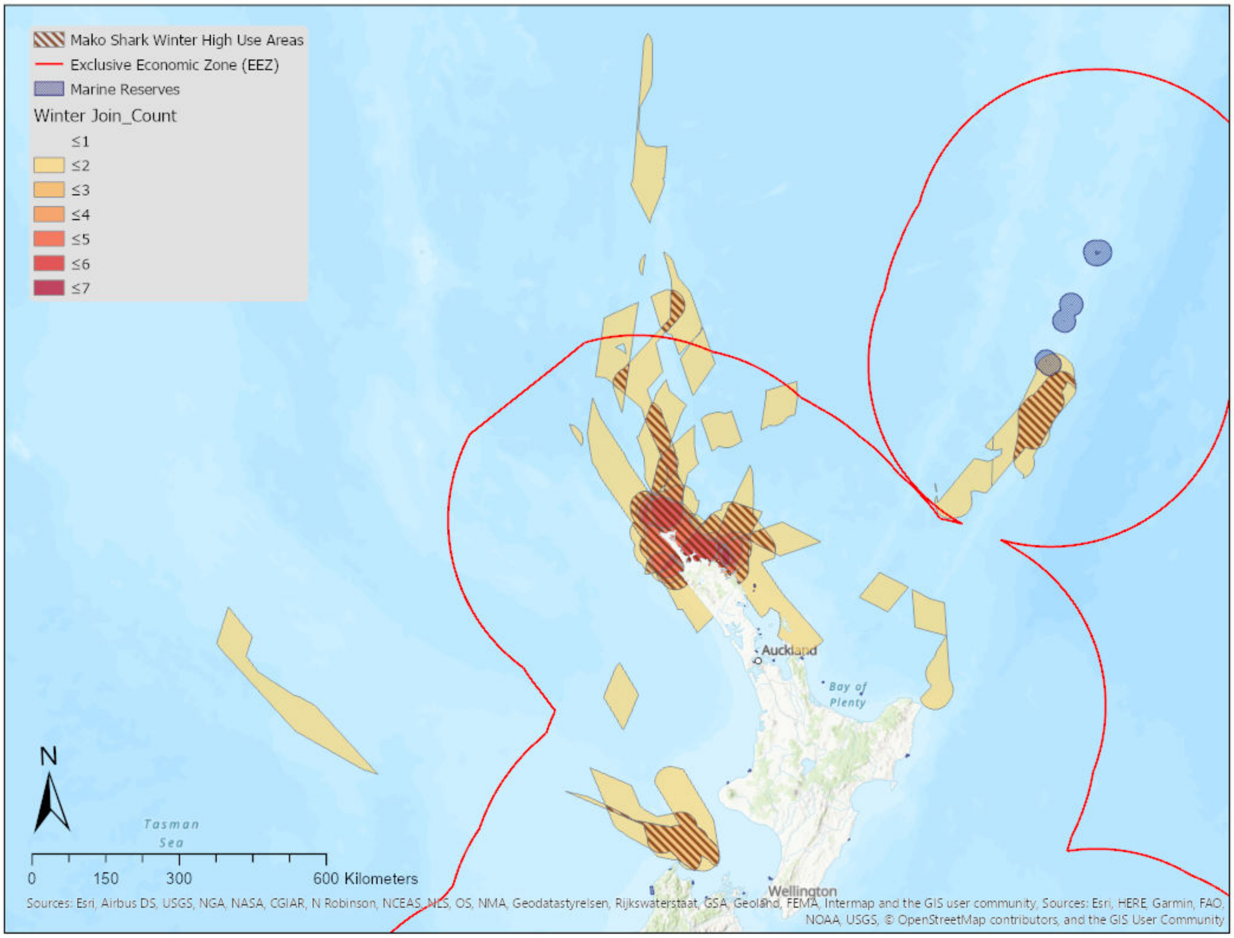
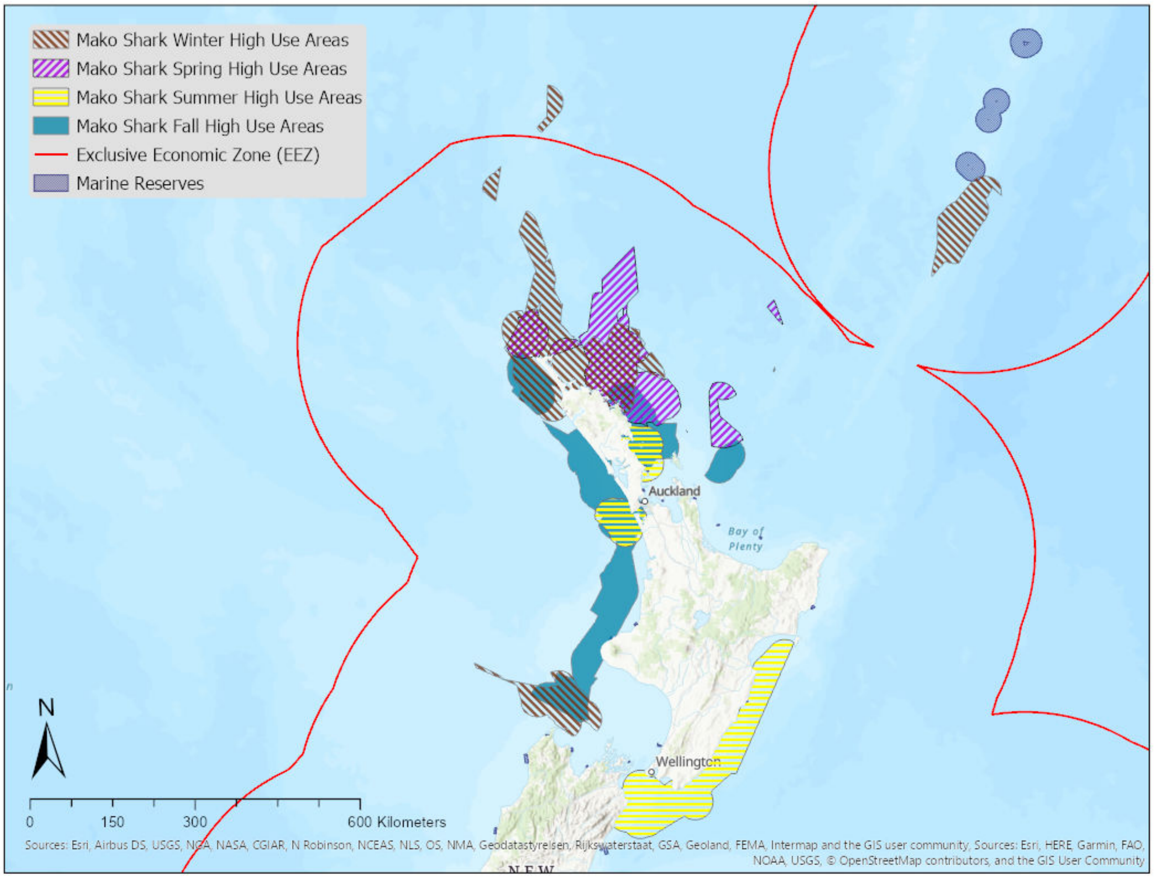


Figure 18. High Use Areas for Winter

4.2. Final Result

Once these counted areas have been isolated, a map of the high use areas was created. By selecting the overlap where 3 or more sharks converged (2 or more in summer), the highlighted regions were designated as high use areas. They could then be extracted as polygons in their own layer and symbolized accordingly. Figure 19 shows the final results of the project, highlighting each seasonal area that can be used for closures or regulations.



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

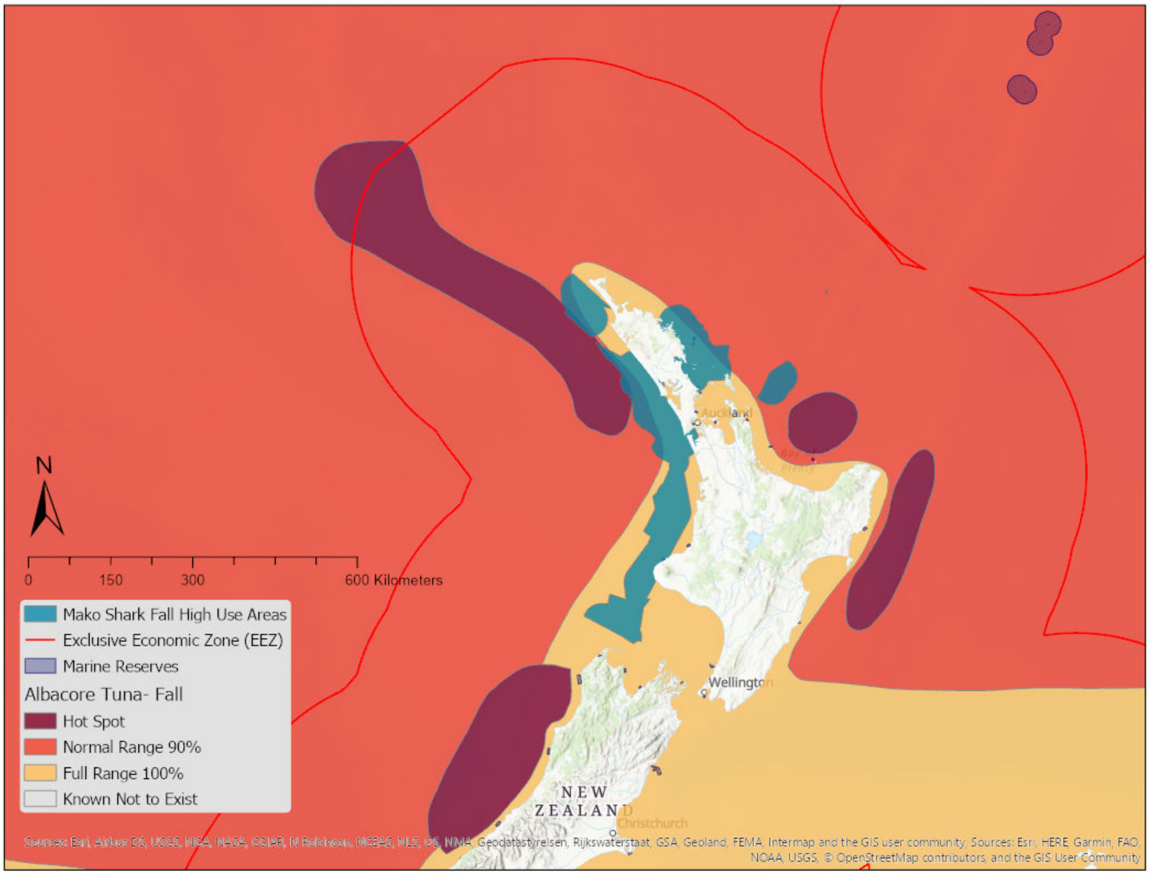
Figure 19. Seasonal High Use Areas

Each season has its own color or pattern that distinguishes it from the rest. There is some overlap as well as solidarity among use areas. For example, the areas associated with fall are predominantly close to shore and on the western side of the north island of New Zealand, whereas the summer season is predominantly on the eastern side and closer to the southern island. There is overlap of several of these polygons which indicates areas of heavy use in several seasons. North of Auckland, nearing the northern tip of the island, is an area where 3 seasons overlap.

4.3. Analysis of Results

The results of this project could indicate areas of extreme importance to mako sharks year-round, which could potentially be places these sharks breed or mate. Understanding these locations by studying behaviors or populations of the sharks, could lend more knowledge of the full life-cycle of this species of shark. These results show areas throughout the year that are most used by shortfin mako sharks off the coast of New Zealand. This is not representative of every single shark in the water, but it does show the areas that could have increased conservation efforts so that this particular species of shark is protected throughout the life-cycle.

While this project was only intended to develop a workflow for finding high use areas, it is possible to verify the results by comparing them with other spatial datasets that may corroborate the results. One way to verify the results make sense is to apply a prey dataset in conjunction with seasonal shark areas. Figure 20 shows the overlap between mako sharks and Albacore tuna in the fall season. The darker red, or maroon, spots are annual distribution location hot spots for Albacore tuna in these waters. Although this is a generalization, you can see they favor the western side of the north island and parts of the southeastern sides as well. The mako sharks overlap is minimal and may indicate that they have another desired prey in these areas during the fall months.



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

Figure 20. Fall Tuna Overlap

However, when we look at a different season, we can see that there is arguably a strong correlation between the two datasets. Figure 21 shows the same prey fish, Albacore tuna, in the spring season. Here a clear overlap of the two can be observed. The locations that are highlighted in a bright purple indicate the areas where mako sharks are most frequent in the Spring months. Paired with the maroon locations, the hot spots of the tuna, this map shows that there is significant overlap, potentially indicating that there is increased predation on Albacore tuna at this time. This indicates that there could be a strong relationship between the distribution of mako sharks and their prey, which would make sense in the overall assessment of the lifecycle of a shark. They would move and hunt in the same areas as their prey would, meaning that if you protect one you can easily protect the other species.

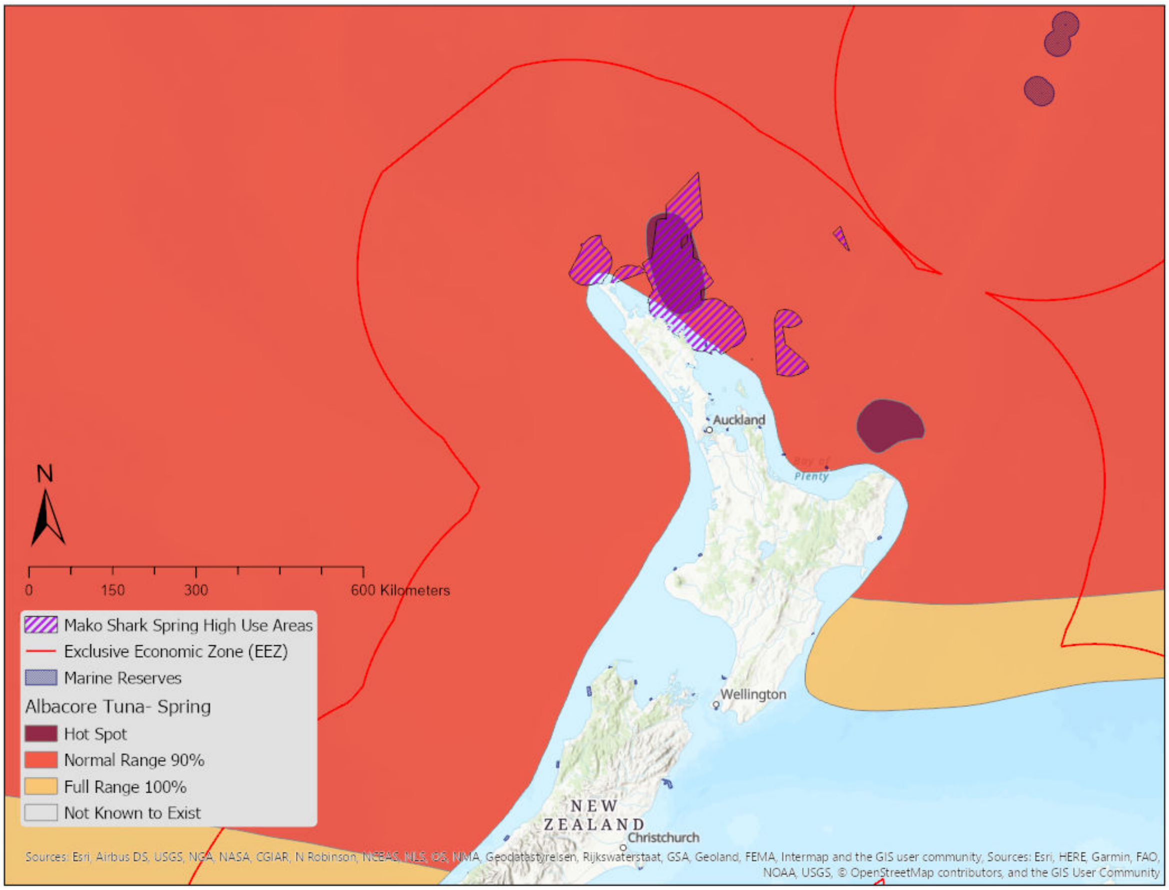


Figure 21. Spring Tuna Overlap

Again, this is only one species' annual distribution that could be used to verify the locations made sense. There are several prey species that could be used to examine other overlaps.

Chapter 5 End Results: What Does It Mean?

This project has shown that the use of GIS in identifying locations for DMPAs is not only possible but may be incredibly valuable. Using techniques in spatial mapping allows data to be visually accessible for scientists and local communities alike. This creates a bridge between the conservationists and the locals alike. Creating clear indications of zones that can be used as protected areas means that the species can be taken care of, as well as cultural traditions respected. Areas were highlighted that are used most by this pelagic species of shark, based on the data provided. Using this information, scientists and government officials could implement conservation regulations based on these findings.

5.1.1. Changes and Improvements

The first and hardest struggle with this project was finding accessible and useable data. Going back again, pairing up with an organization with access to data would have been beneficial. Focusing on an area within the US territory would also have been a good idea, but having already had background on New Zealand specifically, as well as local shark species, it was decided to continue with the original focus. Another issue that arose was finding other relevant data within the same time span and with valuable attributes. Locating accurate sea surface temperature data would have been interesting in looking at the changes in use from season to season.

The limitations within the project mainly stemmed from the lack of access to pertinent data, but also involved time issues. The late-term change in data meant that there was a lot of make-up to do quickly as well as time crunches to get the data to a workable set. More time would mean more ability to delve deeper into the dataset and discover what other questions could be answered. Some of these could center around the differences between mature adult sharks and juveniles, do they use the same areas or do they naturally separate? Do females and males patrol the same areas? These questions could be explored with more time to look into both this dataset and other existing datasets.

5.1.2. Future Work and Applications

This project only used one particular type of prey to verify the end results. Although Albacore tuna is a popular prey item for mako sharks, they feed on several different species of fish, marine mammals, and gastropods. Having been shown to be residential as well as nomadic, these sharks have a plethora of food to choose from. Using this dataset with another type of prey fish, like the marlin or swordfish, could produce different results based on the pelagic nature of both animals. Something different might be seen by using gastropod data, like that on Pacific octopus numbers, which could potentially show a far more residential behavior.

The applications for a design like this are immense, but one application seems potentially viable. Creating seasonal closure areas from spatial datasets and inputting them into a mobile platform that anyone could access means that local fisherman would know which areas have catch limits or restrictions and which areas are free to fish within. Giving only a general closure location might dissuade poachers from landing more than necessary, or the app could require a vessel to register itself and input catch numbers to be able to use it. These numbers can then be verified by government fishing agencies as necessary, or volunteers willing to make the checks themselves.

In addition to a mobile app for fisherman, locals would also be able to modify an app to include locations for recreational tourism. Knowing the areas that are frequented by certain animals could mean tourism increases in those areas, which would boost the economy. Finding the line between a booming tourism industry and overusing resources would be a necessary assessment, but it could be beneficial in many aspects. The main purpose of applications like this would be to bridge the gap between the devout scientists and the day-to-day conservationists. Hopefully everyone would want a healthier ocean so that the species within remain healthy and abundant. Creating opportunities for environmentally conscious individuals to become a part of that design would mean that more people would be interested in becoming involved.

The ability to find spatial patterns of a migratory apex predator in its environment is useful on all scales of environmental conservation, both marine and terrestrial. This is why environmental research is so important in today's world when we can clearly see significant shifts in food sources and climate changes. The works reviewed and discussed in this paper are all concerned with understanding how each organism has an effect on the environment and how they utilize their surroundings. By studying the movements of an apex predator like the mako shark within MPAs, or outside the static protection zones, we can begin to fill the gaps of knowledge about the benefits of spatial management zones and how to improve and implement them globally.

When we protect ecosystems and habitats for apex predators, the whole food chain benefits. We have seen this with wildlife control; by enabling strict hunting seasons, the population of, say white-tailed deer, has maintained a healthy number without risking extinction (McShea 2012). Wildlife reserves and state parks have provided havens for species that might otherwise be extinct. Marine protected areas have also helped to conserve marine species from being overfished or hunted.

Marine conservation, and environmental conservation as a whole, is constantly evolving and so should this project. Different methods yield different results, for this project the results that were needed were achieved, but every species has unique requirements for sustainability.

The potential for DMPAs is impressive but difficult and each year will bring new technology that can be used to better understand the marine world. Images of data overlaps, data explorations, and results will show that this project focused on the usefulness of GIS in spatially mapping specific areas for conservation. This could hold people accountable for how they interact with the ocean.

Accountability goes both ways, especially when you consider local island culture and its connection to the ocean. Governments being transparent enough to provide raw data, easily comprehended maps, and policy regulations can mean the increased and sustained involvement of entire communities. This is another reason that GIS is vital to projects that have high numbers of datasets. The ability to use large amounts of data and visually represent them in ways that are easily understood creates the accessibility that projects, like marine conservation, desperately need.

Building legislation around protected areas is difficult, as is any legislation. It takes time and resources that some countries do not have. This project aimed to show that GIS can be used successfully in marine conservation efforts, and it has achieved that. Based on the model and workflow given, similar research can be done on different species worldwide. This project does not mean that the New Zealand government will implement this DMPA, but the hope is that it could open a discussion about the gaps in pelagic species conservation and what we can do to bridge those gaps. Our focus, now more than ever, needs to be on the health of the ocean. Each step we take in species conservation is a step in the right direction. Using tools, like GIS, to create integrative maps and research to provide conservation ideas means that we continually work towards a healthier ocean.

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