Università Ca'Foscari Venezia

Corso di Laurea magistrale in Scienze Ambientali

Tesi di Laurea

Mapping Past and Future Commercial Shark Populations in the Mediterranean and Analysis of Possible Consequences.

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1. Introduction

Elasmobranchs are some of the most interesting fish in any ocean, surviving extreme environments for more than 400 million years (Abdulla, 2004; Melendez *et al.*, 2017). They are agile hunters with sensory systems perfected for the most efficient kill and survival. They have an influence on every ecological community structure they are in (Frid *et al.*, 2008). Elasmobranchs, or more specifically sharks, in most cases are among the highest trophic level in the ecosystem they dwell in which ranges from extremely cold environments to even fresh water for some species. They inhabit almost every marine body of water in the world and are highly migratory species resulting in difficultly studying these fish. Elasmobranchs have been seen to just leave the environments that no longer suit their preference because of their active nature and this is why it is important to note the environmental factors they prefer (Schlaff *et al.*, 2014). Sharks have long life histories with their k-selected lifestyle, meaning that they sexually mature later in life, have a low fecundity, and they grow slowly (Ferretti *et al.*, 2013; Abdulla, 2004; Dixson *et al.*, 2015). This difficult characteristic means that many elasmobranchs may be at risk of depleting populations with the rapid change of fishing efforts and anthropogenic factors. In some cases, this trait has made it difficult for juvenile species that often stay close to the location to which they were born or hatched (Tunnah *et al.*, 2016).

Why elasmobranchs are so important to marine ecosystems is due to their apex predator status in most all environments. They have the ability to shape the behaviours of the other fish in the environment around them (Ligas *et al.*, 2013). They are needed as a species to mediate marine biodiversity in their ecosystem and without their presence there could be some increased competition for other species within these systems (Ferretti *et al.*, 2005). If there is a change in the survival of the apex predator of an ecosystem, there are problems to be had with the trophic cascade of the environment (Baum & Worm, 2009). Noting how sharks affect an environmental can also help in predicting the trophic cascades of other marine populations.

These fish contain many different organs that may be affected by the sudden changes in environmental factors like temperature, salinity, primary production, chlorophyll, and phytoplankton. It is well known that elasmobranchs have complicated sensory systems, but more importantly they have a high adrenergic stress response to the changing factors around them

(Tunnah *et al*., 2016). The olfactory systems of elasmobranchs are one of the most superior in the world, they rely on this system for mating, detection of threats, navigation, and localization of food (Dixson *et al*., 2015; Portner & Farrell, 2008).

Sharks are a species of fish that is often caught but rarely the main objective of fisheries in the Mediterranean. Many different species are caught as by-catch on tuna and swordfish lines as this is a common type of prey for the larger pelagic sharks (Santos & Coelho, 2018). According to literature, in the Mediterranean elasmobranchs are showing clear declines in populations from fishery data, as well as the fact that due to the high demand from fisheries, this vast area is at risk for overexploitation (Ligas *et al.*, 2013; Company *et al.*, 2008). However, there are many species that are well documented in their value for meat, fins, and skin including *Galeorhinus galues, Lamna Nasus,* and *Squalus acanthais* (Stevens *et al.*, 2000). And it is known that majority of elasmobranchs are demersal species of fish and that in recent years bottom trawls have become more popular (Ferretti *et al.*, 2010) resulting in larger landing of these bottom dwellers.

What is happening in recent years in terms of climate change, has caused a struggle in understanding how organisms are responding to these changes. In sharks, with all of these sensitive systems, it is expected that they will see behavioural changes with decision making, changes in olfactory cues, and response to other cues like homing ability and habitat selection just looking at how their biology is affected (Dixson *et al.*, 2015). All species of sharks with the exception of the family Lamnidae are ectotherms so it is clear that the external environmental factors are important to their wellbeing (Schlaff *et al.*, 2014). Looking at future prediction maps can lead to more knowledge of where these fish will move in the future and this can help in the conservation and protection of the sharks.

In the last 50 years, fishing efforts have impacted all marine life in the Mediterranean. Known as a shark hotspot, the Mediterranean is home to at least 84 different species of elasmobranchs that have declines 88% in the last 20 years (Navarro *et al.*, 2014; Ferretti *et al.*, 2005). Of these 84, 46% are labelled by the IUCN Red list as endangered or vulnerable (Lauria *et al.*, 2015). Models that predict what the future will look like state that the surface air temperatures will increase by 2°-5° by 2100 (Rosa *et al.*, 2014). As well as, clear literature showing increased trends of both temperature and salinity in the thermohaline stable Mediterranean (Cartes *et al.*, 2013). All living organisms live within a specific range of factors that is optimal for survival, climate change will only add stress to every species that has a narrow tolerance of preference for their biogeographical location, and those with r-selected lifestyles are at greater risk (Portner & Farrell, 2008). In this paper, using modelling software, geographical data for the future will be predicted for the 16 different species of sharks. Modelling can help with conservation management and in understanding the species survival (Lauria *et al.*, 2015). The Mediterranean is a perfect model for understanding how the affect climate change to sharks will change the probability of presence. If there is better understanding of such a small amount of diversity like 84 species of sharks, how will more populated places like Caribbean or Australian waters cope with this. Using the RCP8.5 trajectory, this paper will examine the predicted future of these 16 elasmobranchs and analysis the possible reasons for the outcome.

This thesis is using Maxent software and QGIS to map the future habitats of 16 species of shark in the Mediterranean to see what factors affect sharks the most and possible other factors that can go into the future species richness of these IUCN red listed sharks.

2. Methods and Materials

Study area

The Mediterranean Sea was used in this thesis because although there is not a massive presence of large predatory sharks, there is a large selection of fisheries that depend on the presence of many types of sharks for their survival As well as the fact that like many other fish in the Mediterranean, overfishing and climate change are drastically changing the populations of all marine life. The Mediterranean is a sea completely surrounded by land with only the Straight of Gibralter connected to the Atlantic Ocean. The Mediterranean contains some of the most threatened species of sharks in the world according to the IUCN (Ferretti *et al*., 2008).

Dataset Collection

For this paper, 16 sharks species were selected from the *International Union for Conservation of Nature* (ICUN) Red list with habitats in the Mediterranean Sea; *Alopias vulpinus, Centroscymus coelolepis, Carcharhinus plumbeus, Dalatias licha, Etmopterus spinax Galeorhinus galeus, Heptranchias perlo, Isurus oxyrinchus, Lamna nasus, Mustelus mustelus, Oxynotus centrina, Prionace glauca, Squalus acanthias, Scyliorhinus canicular, Scyliorhinus stellaris,* and *Sphyrna zygaena*All species were cross-referenced with biodiversity data from the Global Biodiversity

Information Facility open source database (GBIF) to ensure there was also a reasonable occurrence rate of sightings throughout the years being analyzed as well as the presence in the Mediterranean. In this thesis, GBIF provided occurrence datasets of each shark and from there all species were run through the program R, an environmental statistics program, to clean up the data by deleting null points and obtaining the csv. file format of only the data points in the Mediterranean to be run through Maxent, a program for predicting habitat models based on varying parameters.

Fishing data from Seaaroundus (http://www.seaaroundus.org/) between the years of 1950 and 2014 was used to make times series graphs of fishing catches in tonnes per year for all years included. This information was only taken from the Mediterranean countries who reported catches for each shark in the years shown. Using this data, it can be seen that only some Mediterranean countries reported data for each year, as well as each shark. Furthermore, there was more data in later years due to an increase in reporting. These time series graphs were made for each shark to show the temporal trajectory of catches that could be considered a sort of proxy for the abundance of each shark species over the 64-year time scale.

Maps and Predictions

Maps were created for the shark species to make the present habitat for each and then to predict the future distribution in the Mediterranean Sea. To achieve the present maps, each known coordinates of the species were downloaded from the GBIF website at https://www.gbif.org/. These presence records were run through R to be put into Maxent with the environmental factors of mean Temperature in °C, mean Salinity in PSS, mean Chlorophyll in mg.m-3, mean Phytoplankton in umol.m-3, and mean Primary Productivity in g.m-3.day-1. Maxent, or maximum entropy modelling, is an environmental program that predicts habitats using the occurrence of a species and specific environmental parameters. Using Maxent, the location data of each species and biotic and abiotic factors in these environments can be combined to create a Habitat Suitability Models (HSM). This type of model allows for the suitability of an area to be predicted for future climates and can help in the conservation of future populations by assuming if the area is not suitable, the species will not be there. With this information, it is possible to see what factors impact the sharks the most and also where their future habitat may be. The environmental factors were taken from the Bio-ORACLE dataset at https://www.bio-oracle.org/ which gave GIS raster outputs of the environmental parameters in marine ecosystems for ecological modelling. These specific variables were used due to either the significance they have on a sharks ability to thrive in a specific environment or indirectly affect the environment, making it optimal for the sharks to thrive.

To obtain the future prediction maps, the additional step to add future scenarios was implemented. Using the representative concentration pathway (RCP) from the Intergovernmental Panel on Climate Change (IPCC) under the UN, the 4^{th} scenario RCP8.5 was used to predict the future environmental factors for Temperature and Salinity. RCP8.5 represents the maximum amount of greenhouse gas to be released into the environment, therefore the one that shows the most drastic change for these sharks as well as the environmental variables.

The Maxent software itself is used to show models of suitable habitats in relation to the environmental variables for the individual species in this paper. The percent contribution calculated by the program of each environmental variable shows specifically how each one is affecting each shark. In every mapping case, the Maxent output was used to look at how the variable affected the species as well as how each variable was affected by the other variables present, which can be seen by both the percent contribution and the jackknife calculations. The jackknife calculations are a method of running multiple datasets while excluding one variable every time to determine how the environmental parameters are affecting the HSM of the species. The percent contribution of the parameters was essential for determining what is affecting the species and how this may change in the future according to the RCP8.5 scenario as they drive the model. Every time the program was run, it was run with a random seed of 25.

Once each shark had both a Maxent map of present and of the future predictions, the maps were imported into the geographic information system QGIS to calculate maps. The formula used to achieve these maps was:

$$R = \frac{Future}{Future + Present}$$

These maps were used to show the habitat suitability models of each species. Warmer colours indicate the environments with an r value less than 0.5, which implies that the present data is more suitable than the future scenario RCP8.5 has predicted. Cooler colours indicate that the future has more of a probability of the species presence, an r value more than 0.5. Out of the 16 sharks 9 can be classified as showing and $r < 0.5$ in the Mediterranean based on the factors used.

3. Results

Alopias vulpinus

The time series graph of *A. vulpinus* shows that over the time scale looked at, the presence of fishing catches from the Mediterranean increases at an average rate until about the late 1980's. After this point, with a few exceptions of higher catches in 1994 and 2001, the overall catches begin to decrease until 2013.

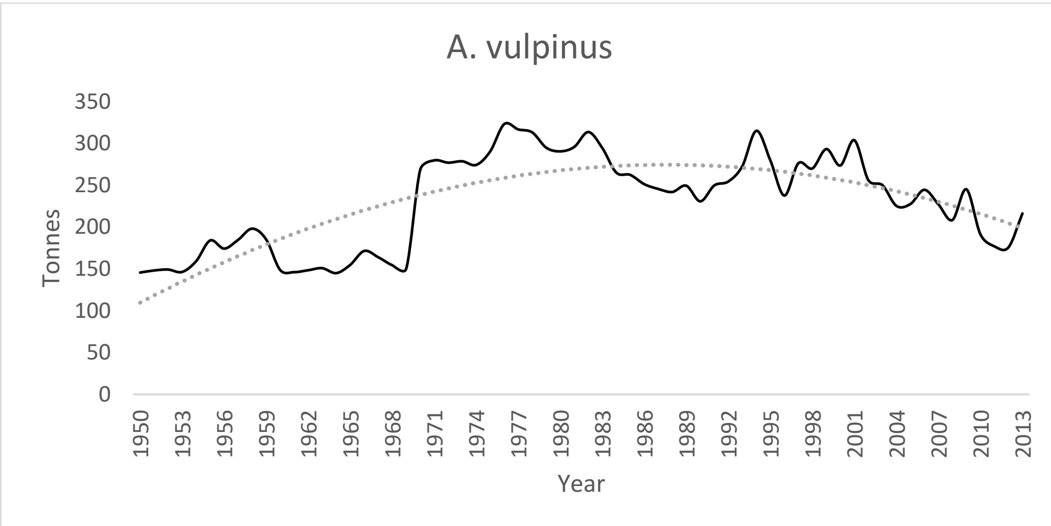

FIGURE 1: TIME SERIES GRAPH OF A. VULPINUS FROM 1950 - 2014

Using Maxent it can be shown that the reliability of the model is higher than the random prediction value of AUC = 0.5. The closer the value is to 1, the more accurate the model is said to be for predicting the future. This method will be used throughout the results. With an AUC of 0.916, this indicates that the model is a good model to be used for the prediction of the species.

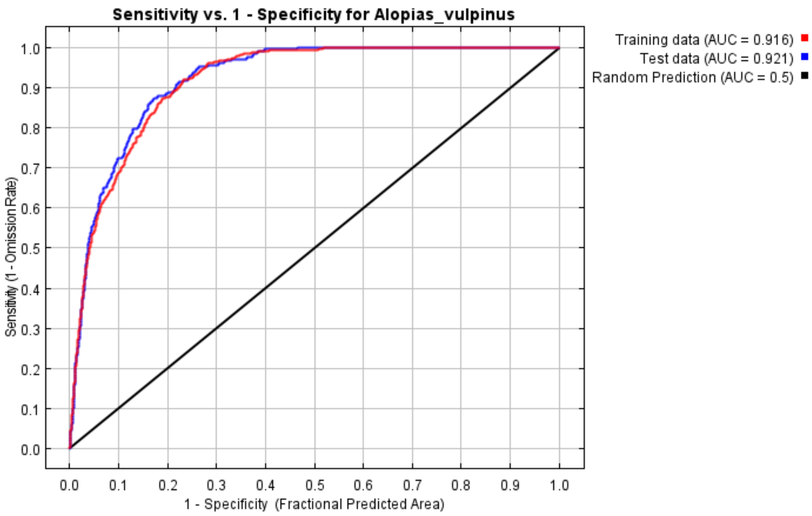

FIGURE 2: MAXENT AUC GRAPH INDICATING ACCURACY OF THE MODEL.

The table of percent contribution of this specific species shows that the most important factors for *A. vulpinus* in the future is primary productivity followed by temperature. The least important variable to this model is salinity. The percent contribution shows that primary productivity and temperature contributed more to the model, but that temperature and chlorophyll have a more important role in determining the probable distribution in the future.

TABLE 1: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE FOR A. VULPINUS

Variable	Percent Contribution	Permutation Importance
Primary productivity	38.6	9.6
Temperature	37.4	45.5
Chlorophyll	12.9	26.7
Phytoplankton	7.2	16.4
Salinity	3.8	1.8

The Jackknife test furthers this conclusion by showing that primary productivity by itself has the most importance in the test, but that temperature has the greatest impact on the AUC if it is left out of the model.

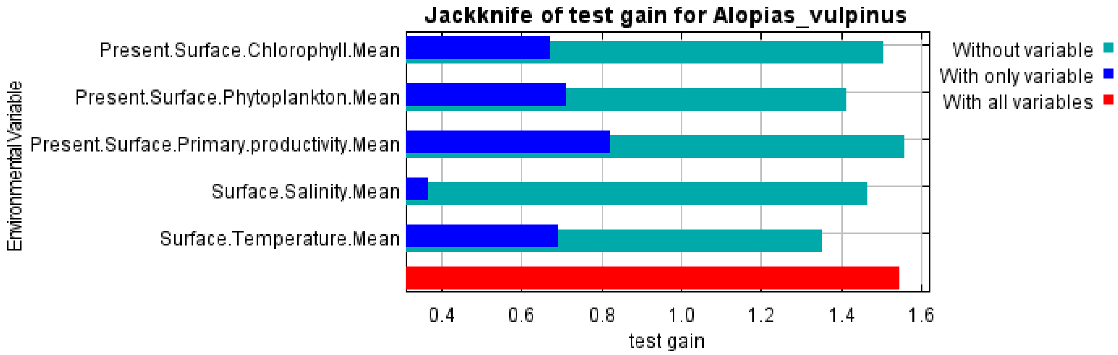

FIGURE 3: JACKKNIFE RESULTS OF THE TEST GAIN FOR A. VULPINUS

Using the Maxent results in QGIS we can see that the future prediction for *A. vulpinus* shows a mix of colours between 0.50 and 0.75, however there are few spots with warmer colours in the northern Adriatic and between Greece and Turkey.

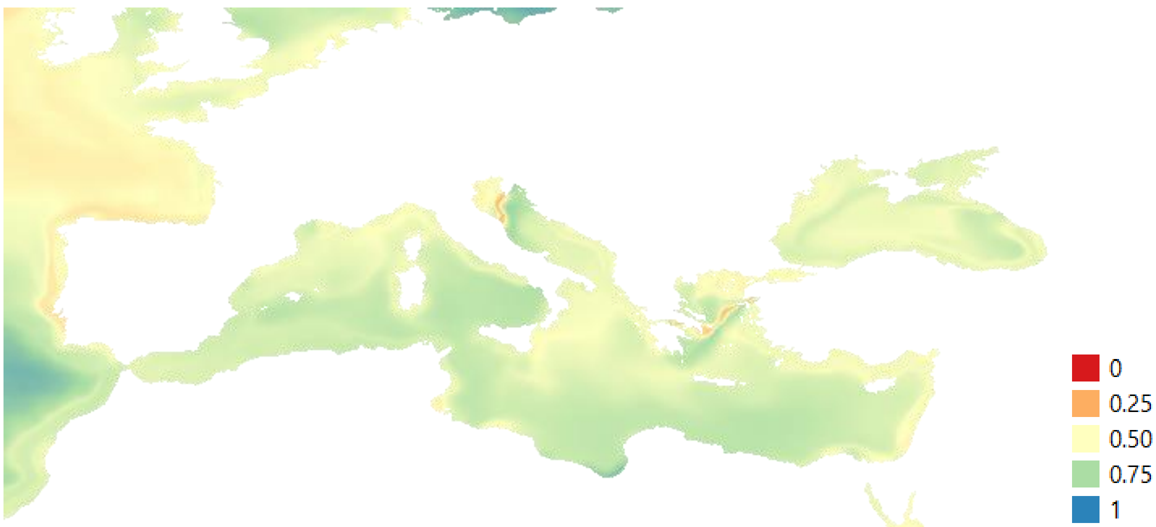

FIGURE 4: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF A. VULPINUS.

What the results communicate about the future predictions of *A. vulpinus* is that according to the time series, the catches of *A. vulpinus* have been steadily declining since the late 1980's based on the reports of the fisheries across the Mediterranean. It is shown that the most important variables affecting this specific population of sharks is primary productivity as well as temperature, and salinity has the least affect on the probable prediction of the species. QGIS indicates that the main areas to be affected by the future RCP8.5 scenario is the northern Adriatic and the area around

Greece and Turkey, but the rest of the Mediterranean does not seem to be too affected by RCP8.5 scenario. According to the IUCN red list, *A. vulpinus* is listed as vulnerable.

Centroscymus coelolepis

The time series graph of *C. coelolepis* is an example of when the reporting of a specific shark was not implemented until the 2000's. This deep-water shark has been present in the Mediterranean based on scientific literature, however, the catches or proper identifications is not until later, as seen by the time series.

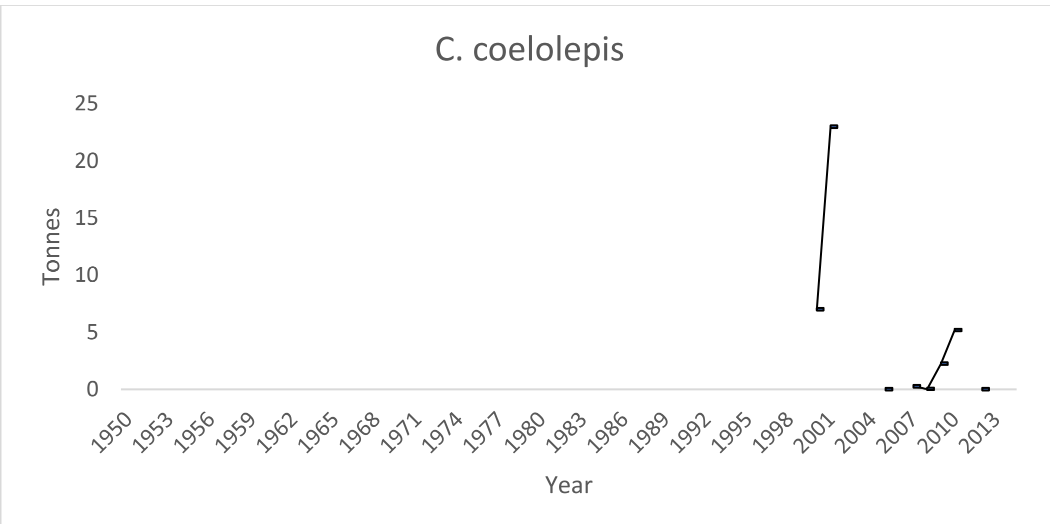

FIGURE 5: TIME SERIES GRAPH OF C. COELOLEPIS FROM 1950 - 2014

The Maxent output of C. coelolepis has a higher value of AUC of 0.946. This implies that the model is highly accurate given the data put in the software.

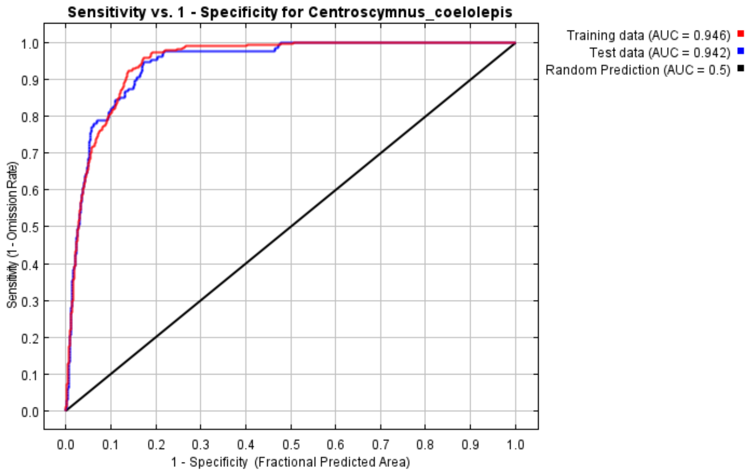

FIGURE 6: MAXENT AUC GRAPH INDICATING ACCURACY OF MODEL.

The jackknife test of C. coelolepis shows that the two most important values for this species commonly found around Portugal is temperature and to a lesser extent Primary productivity. It can also be seen that the Permutation Importance puts value on temperature and second most important is chlorophyll. What this indicates is that independently temperature and chlorophyll have a meaningful impact on the species habitat preference.

TABLE 2: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE FOR C. COELOLEPIS.

Variable	Percent Contribution	Permutation Importance
Temperature	71.7	64.7
Primary productivity	15.9	2.3
Salinity	8.3	8
Chlorophyll	2.8	21.2
Phytoplankton	1.3	3.8

This can also be seen in the Jackknife of the test gain, showing that temperature is the most important factor that affects this species.

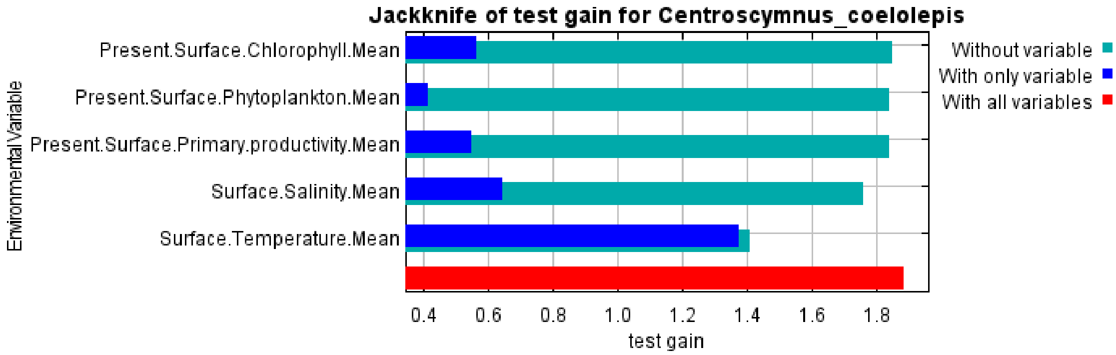

FIGURE 7: JACKKNIFE RESULTS OF THE TEST GAIN FOR C. COELOLEPIS.

The QGIS map shows mostly warm colours in the western basin of the Mediterranean, where the species is mostly found and also fished for. This indicates that the future predictions of this species of shark are more likely to be at risk in these warmer regions of the Mediterranean.

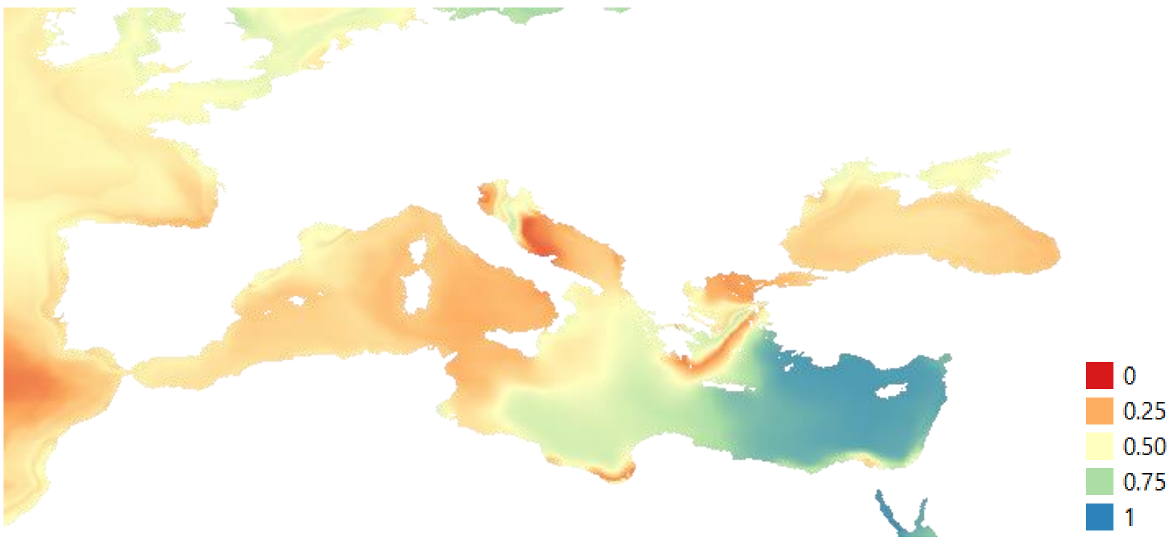

FIGURE 8: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF C. COELOLEPIS.

What we can summarize about *C. coelolepis* is that future predictions of RCP8.5 for this species are at risk, especially in the areas where they are commonly fished, being Portugal and France. On the IUCN Red list, this species is classified at Near Threatened. However, there may not be enough information on the past population on the species as the fishing catches have only been recorded since the year 2000.

Carcharhinus plumbeus

The time series graph of *C. plumbeus* shows a steady catch rate of this species of shark, however, in 2009 there is a significant increase of the intake. All but two years of these catching's are made by Algeria. The one major spike in 2009 is made by Spain, and another milder catch was made by Portugal. This allows us to see that this species can be found in the western part of the Mediterranean.

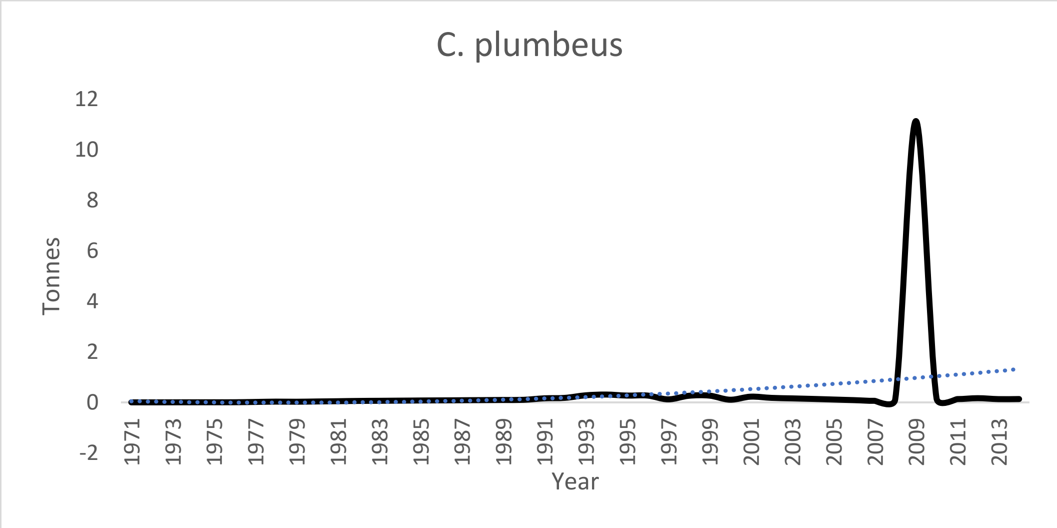

FIGURE 9: TIME SERIES GRAPH OF C. PLUMBEUS FROM 1971 – 2014.

The Maxent AUC value for C. plumbeus is 0.940, meaning this model is accurate to predict the future outcome of this species.

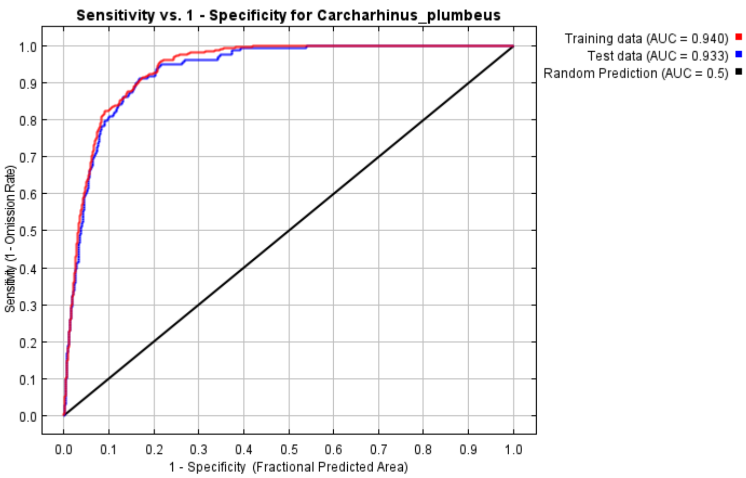

FIGURE 10: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important variables to *C. plumbeus* are considered to be temperature and primary productivity according to the Maxent model. If the permutation importance is looked at as well, it can be seen that along with temperature and primary productivity, that chlorophyll also plays a role in the preference of habitat for this species.

TABLE 3: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE FOR C. PLUMBEUS.

Variable	Percent Contribution	Permutation Importance
Temperature	53.2	54.6
Primary productivity	25.5	18.2
Phytoplankton	12	12
Chlorophyll	5.9	14.4
Salinity	3.3	0.9

The jackknife of the test gain confirms these contributions visually. However, the only difference between the regularized training, as seen above and the test gain is that there is more importance put on Salinity as a contribution individually.

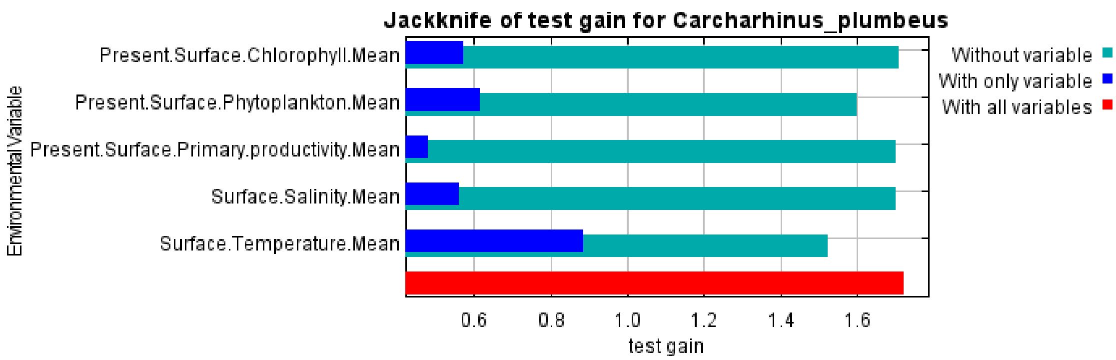

FIGURE 11: JACKKNIFE RESULTS OF THE TEST GAIN FOR C. PLUMBEUS.

The QGIS map of the prediction for the future of this species shows that, in fact, this species is not of real risk in the future. Majority of this map is a green colour (r ~ 0.75), implying that future is better suited for the species to exist.

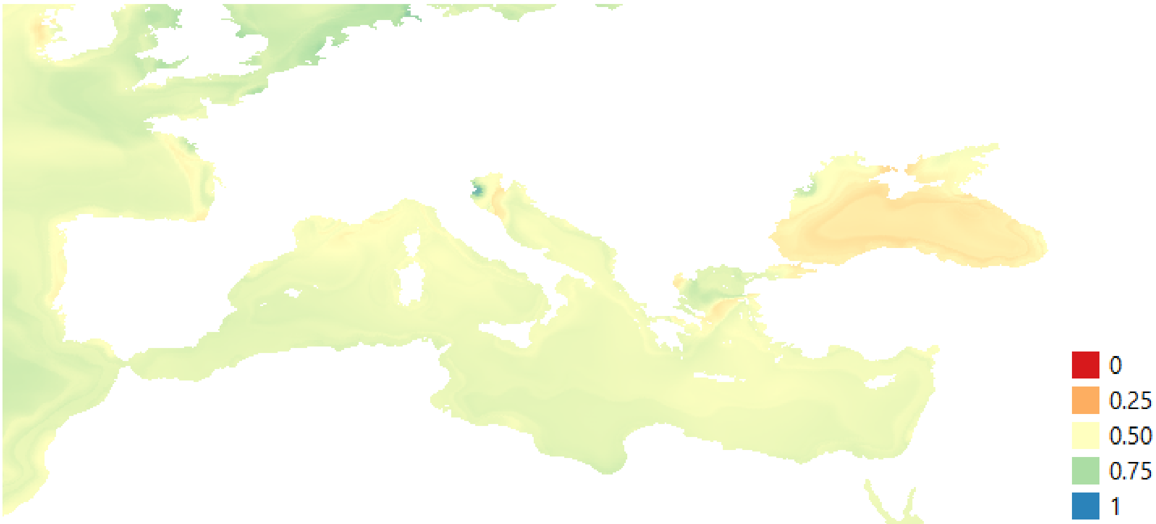

FIGURE 12: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF C. PLUMBEUS.

In summary, *C. plumbeus* is a species commonly found in the farthest western part of the Mediterranean. It is affected mostly by temperature and primary productivity according to the Maxent results. And concern for the future of this species based on the QGIS results show be low, as the RCP8.5 predictions does not seem to have a great impact on the species in terms of environmental factors. However, according to the IUCN Red list, this species is classified as Vulnerable.

Dalatias licha

The time series of *D. licha*, made from the Sea Around Us data, shows that this species is, on average, increasing with time. However, until 2007, only Algeria was a common fishing country of this species. This increase in the catches after is due to the new reporting of Spain, Portugal, and France. It should also be noted that the sudden drop in 2014 is not due to lack of data as al countries reported catches in this year.

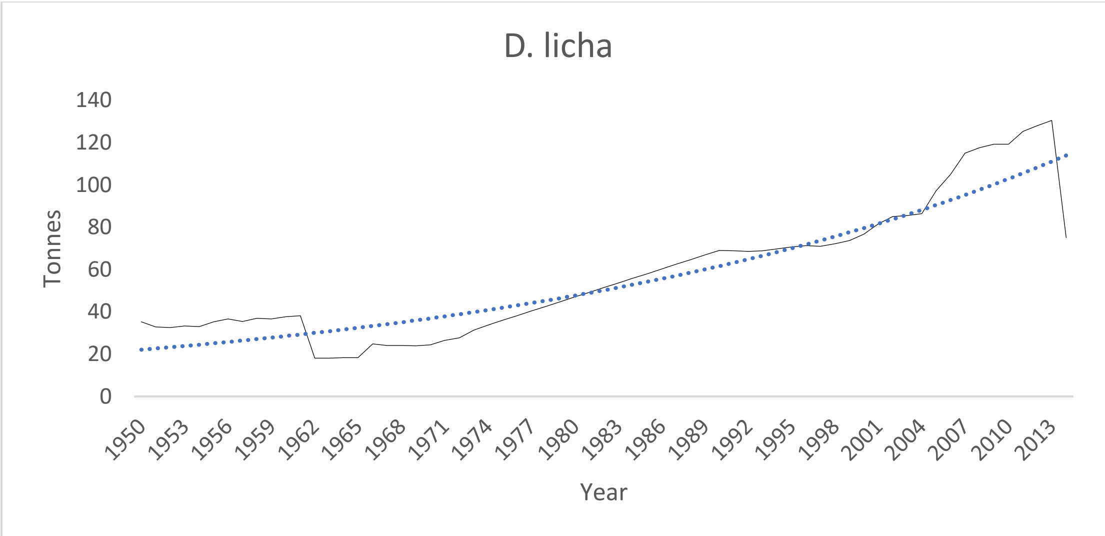

FIGURE 13: TIME SERIES GRAPH OF D. LICHA FROM 1950 - 2014

According to the Maxent model, the AUC is 0.910, implying that this model is a good fit for predicting the future of this species.

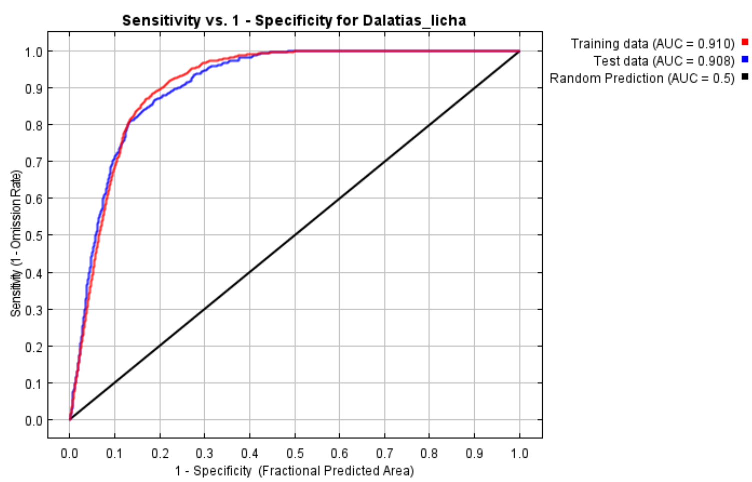

FIGURE 14: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important variables to *D. licha* according to Maxent is temperature and primary productivity, with chlorophyll coming in third. However, the most important individual variables are temperature and chlorophyll.

TABLE 4: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE FOR D. LICHA.

Variable	Percent Contribution	Permutation Importance
Temperature	54.4	54.9
Primary productivity	33.2	2.8
Chlorophyll	10.1	34.1
Salinity	1.3	1.6
Phytoplankton	0.9	6.6

The Jackknife of the test gain shows that the variable with the least importance is Salinity, but still confirms that Temperature is the most important.

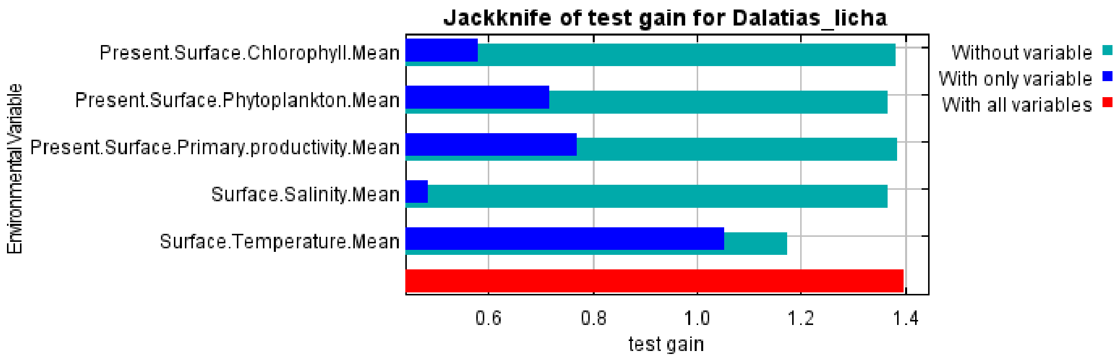

FIGURE 15: JACKKNIFE RESULTS OF THE TEST GAIN FOR D. LICHA

QGIS predicts the future scenario of RCP8.5 as slightly at risk. The majority of the map is showing a warm orange colour, meaning the value is around 0.25 on average. This means that's the species will be affected in the future by the environmental factors in 2050.

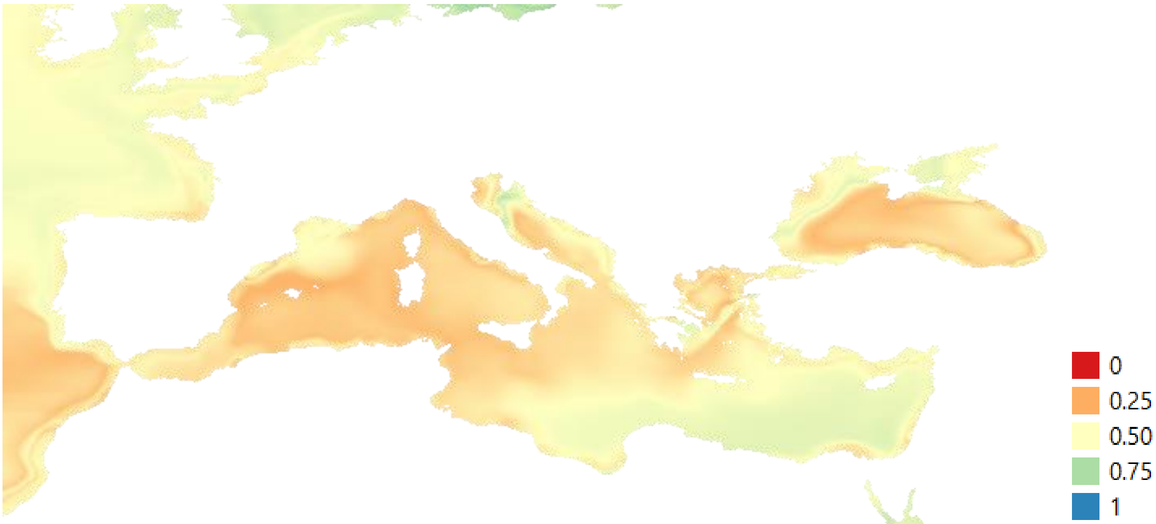

FIGURE 16: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF D. LICHA.

In summary, the future of *D. licha* according to the predictions of Maxent shows a slight risk for the populations. Majority of this species of shark is caught by France, Spain, Algeria, and Portugal. In these areas of the map, it can be seen that these habitats will prove to not be preferable for the species. According to the IUCN Red list, the species is listed as Vulnerable.

Etmopterus spinax

The time series of *E. spinax* shows that there is a steady increase in the catches throughout the years until the late 2010's where the catches begin to fall to similar populations of the 1980's, which is already half of the population size from the data.

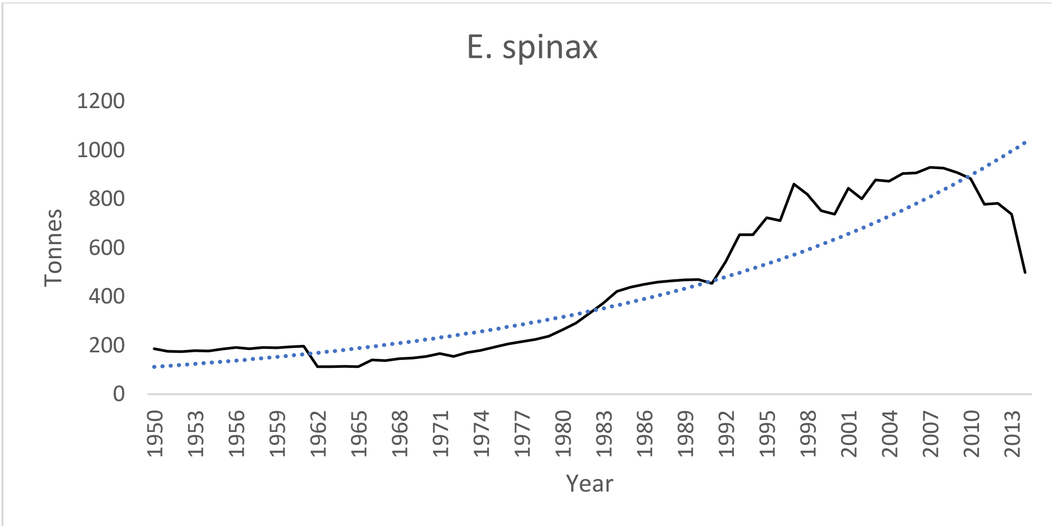

FIGURE 17: TIME SERIES GRAPH OF E. SPINAX FROM 1950 - 2014

The Maxent results show that the model is accurate in predicting the future of the species because the AUC = 0.66.

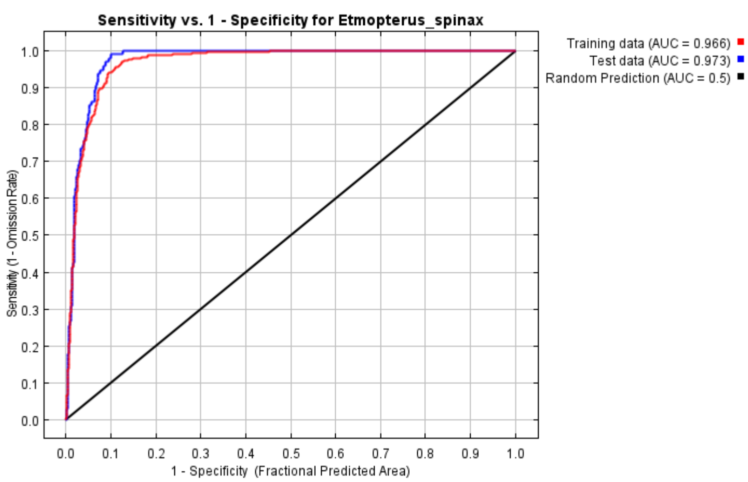

FIGURE 18: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important value to *E. spinax* seems to be temperature and salinity. It should be noted that temperature and primary productivity are the most important variables independently but primary productivity is less important.

TABLE 5: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE FOR E. SPINAX.

Variable	Percent Contribution	Permutation Importance
Temperature	45.1	51.1
Salinity	26.6	9.8
Chlorophyll	12.6	3.7
Phytoplankton	9.9	18
Primary productivity	5.8	17.3

The test gain result from Maxent confirms that temperature is the most important variable individually. But that chlorophyll and phytoplankton have large impacts when combined with the other factors.

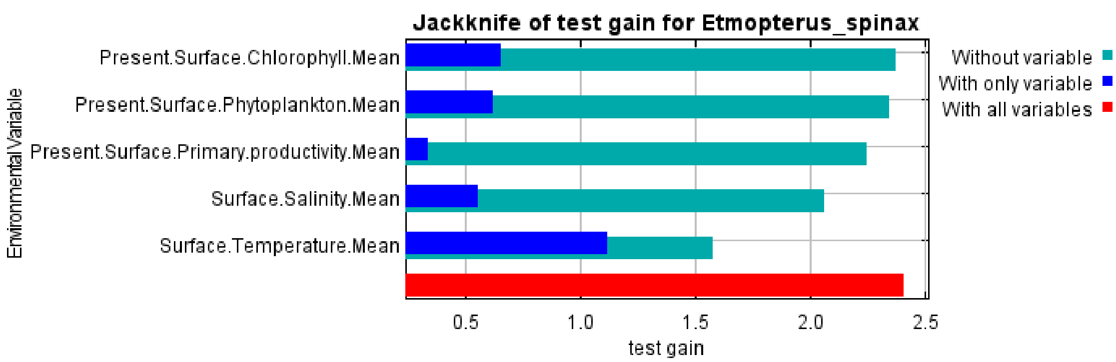

FIGURE 19: JACKKNIFE RESULTS OF THE TEST GAIN FOR E. SPINAX

The QGIS prediction map shows that in the future, this species will be at risk of environmental stress. With the map being mostly orange, r ~ 0.25, especially around the countries that fish for this species showing the most risk.

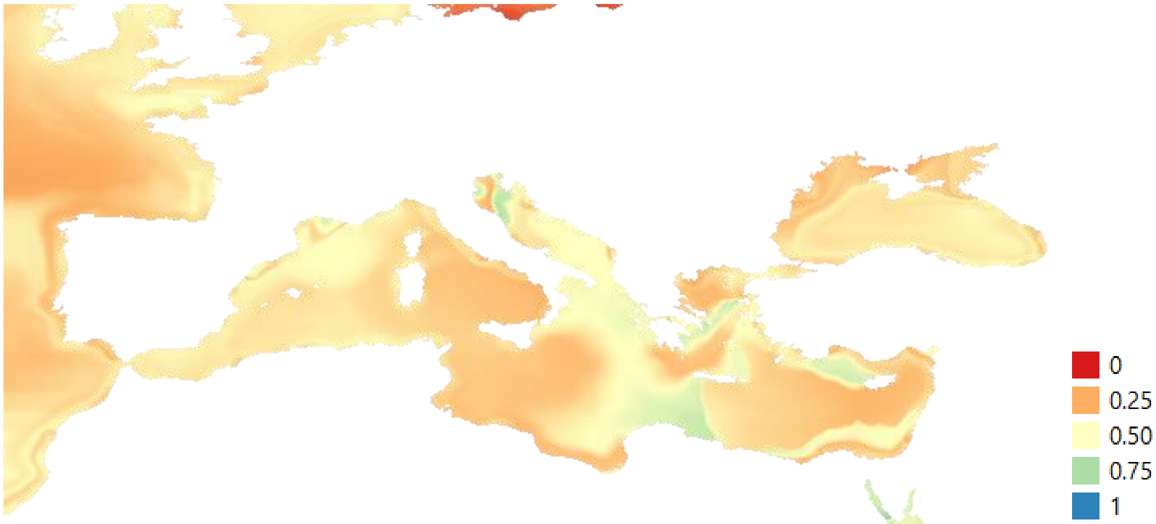

FIGURE 20: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF E. SPINAX.

In conclusion, *E. spinax* shows a decrease in catches starting in the 2010's based on fishing data and with the future predictions it can be shown that the future scenario is suggesting that the Mediterranean will provide problematic conditions for this bottom dwelling fish. The IUCN Red list classifies this species as Least Concern.

Galeorhinus galeus

The time series of *G. galeus* shows a consistent amount of catches per year, with significant increase starting in 2004 and again in 2009. This is due to multiple Mediterranean countries reporting catches for this species. This implies the habitat of *G. galeus* is found from Spain to Turkey.

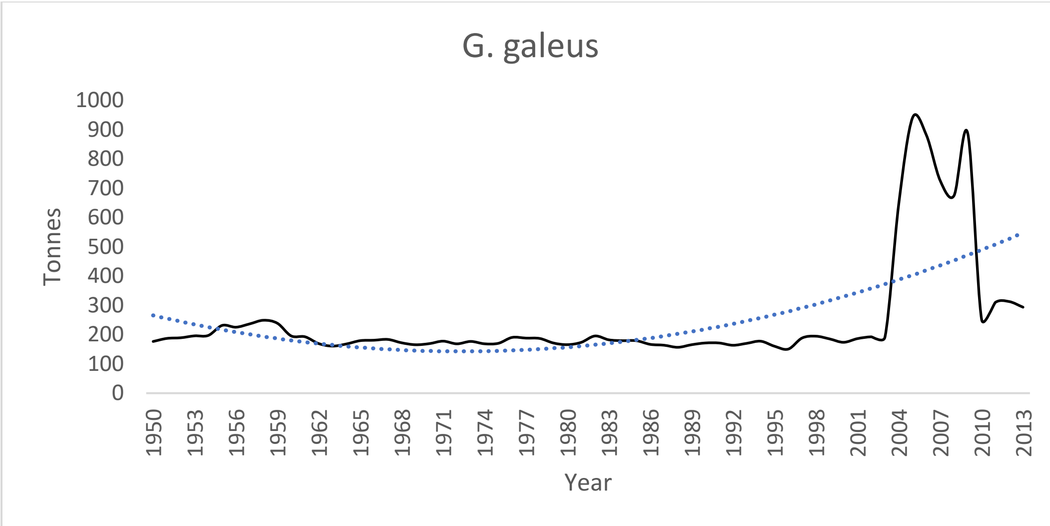

FIGURE 21: TIME SERIES GRAPH OF G. GALEUS FROM 1950 - 2014.

The maxent result for this shark species is lower than the others included in this paper with AUC = 0.856. However, this value still implies some accuracy to the model.

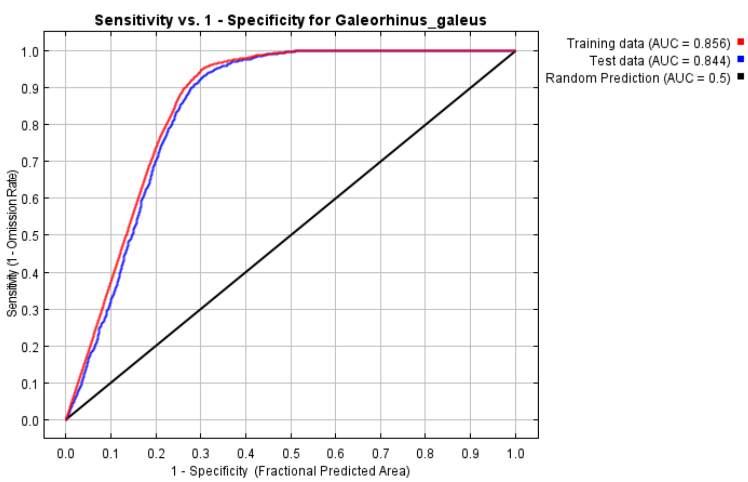

FIGURE 22: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important environmental variable to G. galeus according to Maxent is temperature and primary productivity. The most important individual factor is actually Chlorophyll, with temperature being second. Almost none of the other factors have an impact on the model individually, it should be noted.

TABLE 6: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Temperature	42.3	45.7
Primary productivity	37.1	0.3
Chlorophyll	18.6	46.8
Phytoplankton	1.2	6.6
Salinity	0.8	0.6

However, according to the Jackknife of the test gain, when included with all the variable, salinity plays an important role, but the least important individually.

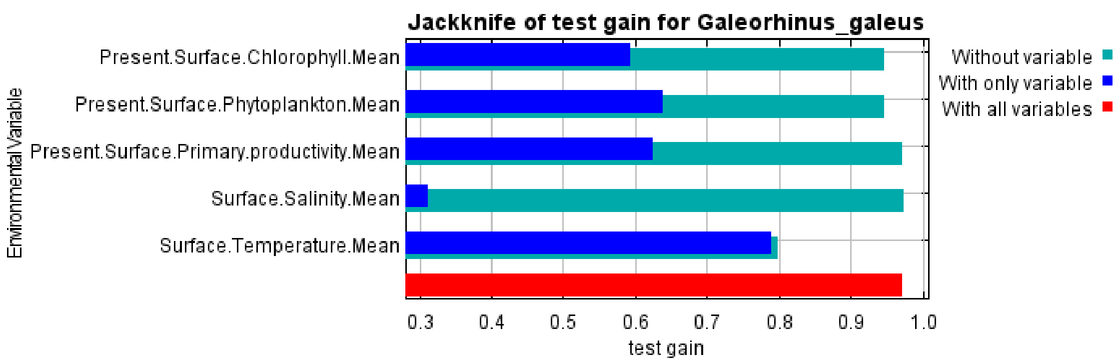

FIGURE 23: JACKKNIFE RESULTS OF THE TEST GAIN FOR G. GALEUS.

Looking at the QGIS map of the future prediction, the majority of the colour is orange, implying an average r ~ 0.25. What this means is that the future is less suitable for this species of shark according to the environmental factors used. It can also be seen that the habitat of this species is relatively consistent throughout all of the Mediterranean.

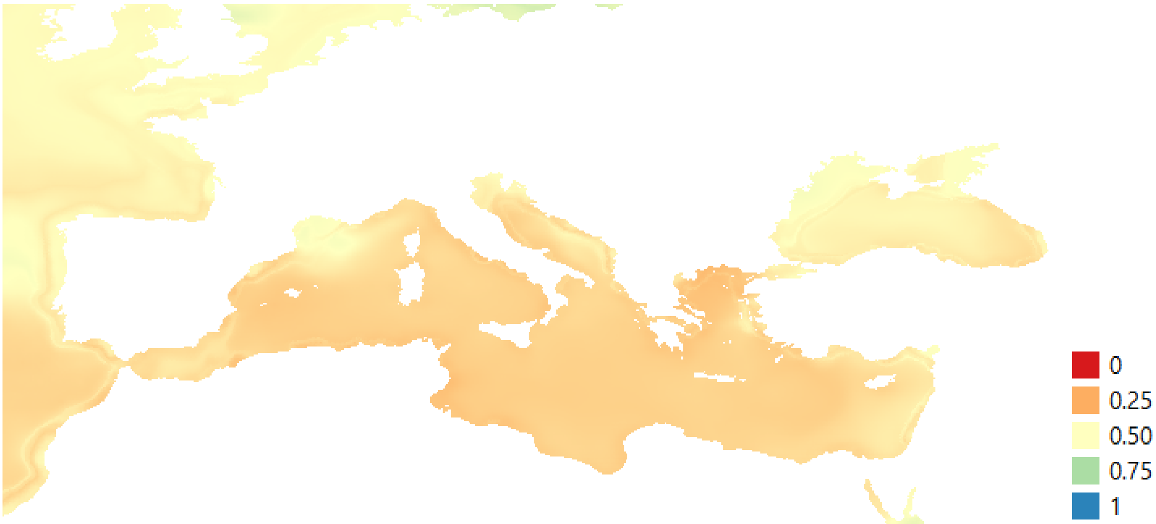

FIGURE 24: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF *G. GALEUS*.

In conclusion, *G. galeus* shows that the habitat is consistent throughout the Mediterranean through the map, as well as the time series which reported catches from east to west. The suitability of the future prediction for this species is about 0.25, which implies that is not ideal for the species. The IUCN Red list also classifies this species as Vulnerable.

Heptranchias perlo

The times series graph of *H. perlo* shows that there is a low amount of catches of this species in the Mediterranean until about 2008. After this time, more countries began catching this species resulting in the increase of landings. Compared to the other species in this paper, even though the trend seems to be going up, the landings are still relatively low in comparison to the others.

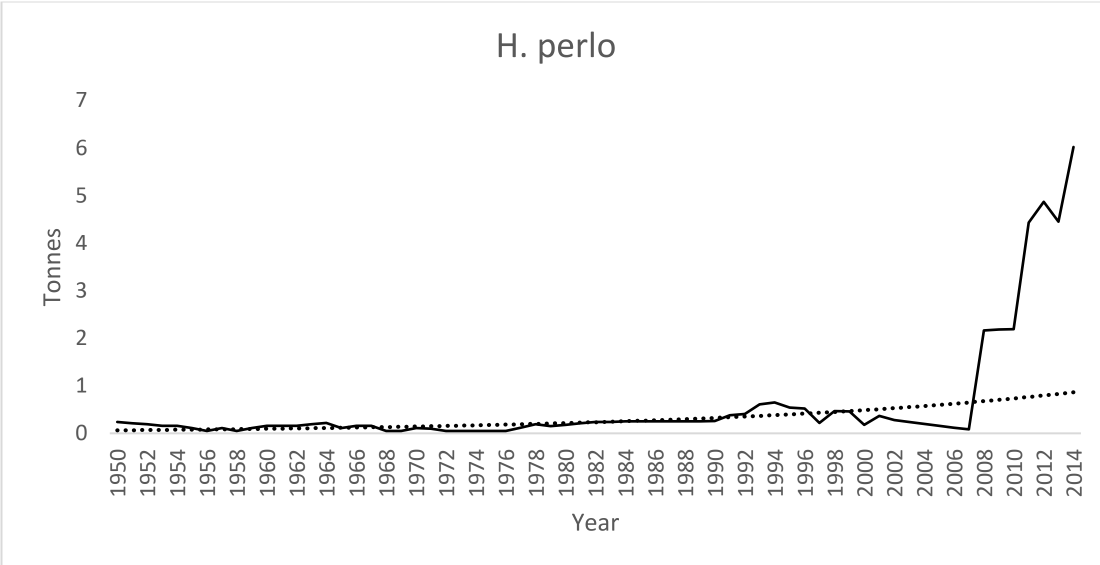

FIGURE 25: TIME SERIES GRAPH OF H. PERLO FROM 1950 - 2014.

The Maxent output of the model shows a high AUC = 0.941, concluding to the results being accurate based on the parameters used.

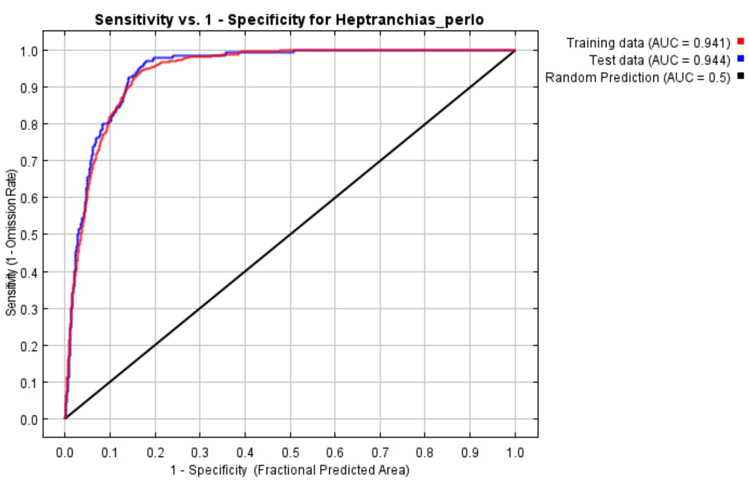

FIGURE 26: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important variables to H. perlo are temperature and primary productivity. The most important independent variable is that of temperature.

TABLE 7: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance

Temperature	37.5	41.9
Primary productivity	35.3	14.7
Chlorophyll	18.9	29.4
Phytoplankton	7.1	12.9
Salinity	1.3	1.1

The Jackknife of the test gain shows that the most important independent variable is actually Primary productivity, which differs from the above table.

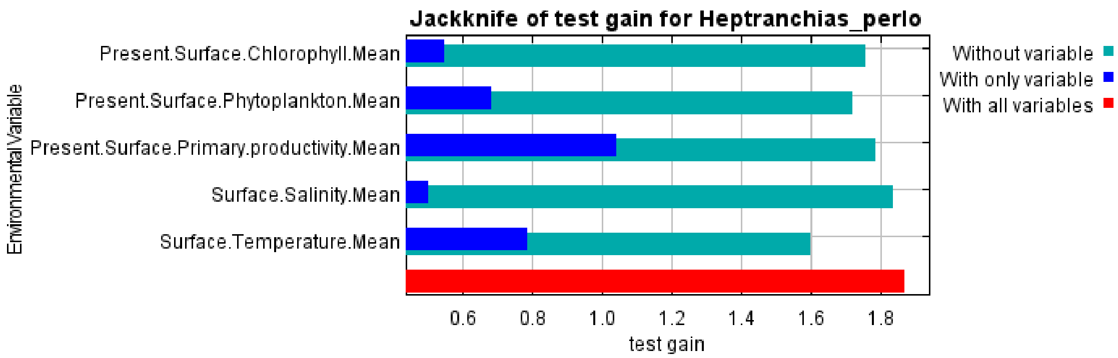

FIGURE 27: JACKKNIFE RESULTS OF THE TEST GAIN FOR H. PERLO.

The QGIS results show that based on the model, the future prediction of *H. perlo* is not really at a significant risk, there are many areas that imply they will be suitable habitats for the species to thrive.

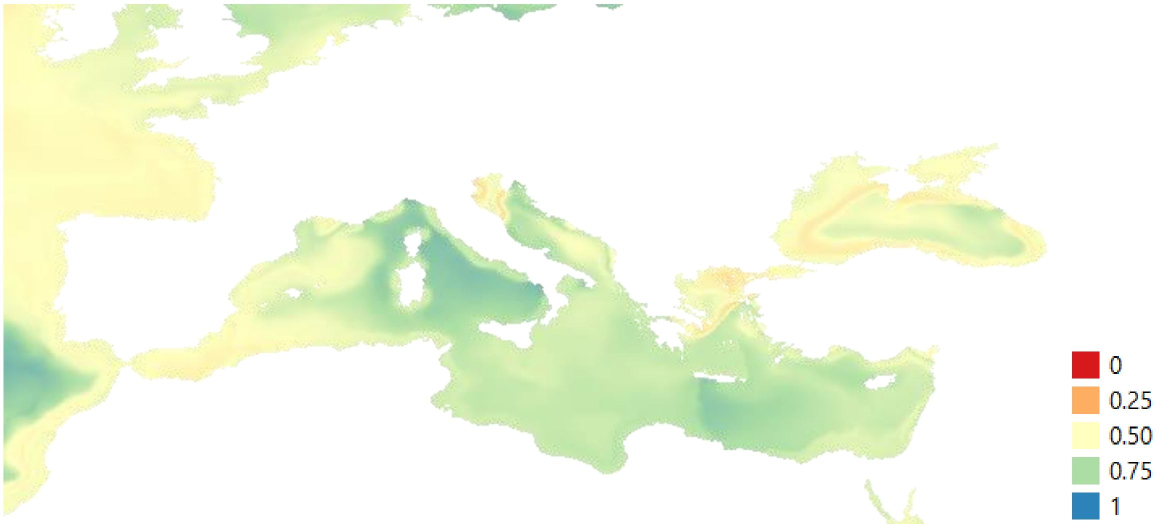

FIGURE 28: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF H. PERLO.

In summary, *H. perlo* has an increasing trend pattern as shown from the time series graph. More countries are showing landings. However, it is important to note that the countries that reported landings include Algeria, Spain, and Malta. The future prediction does show that the habitat for areas around Algeria and Spain could be better. The IUCN Red list does classify the species as Near Threatened. So, the prediction of this species not including environmental factors can be a major impact on the future of the survival.

Isurus oxyrinchus

The times series of *I. oxyrinchus* shows a large spike in the landing numbers after the late 2000's. After this point there is a very large increase in the landing, however not due to the number of countries reporting the data.

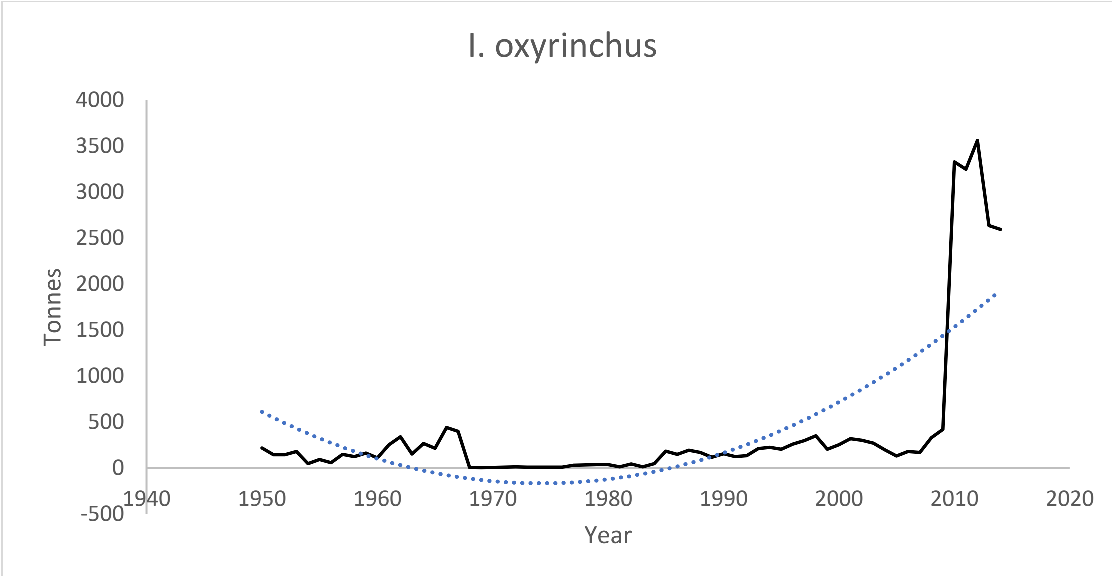

FIGURE 29: TIME SERIES GRAPH OF I. OXYRINCHUS FROM 1950 - 2014.

The Maxent model has an AUC value of 0.872. This implying that the model is accurate but still has room to be improved.

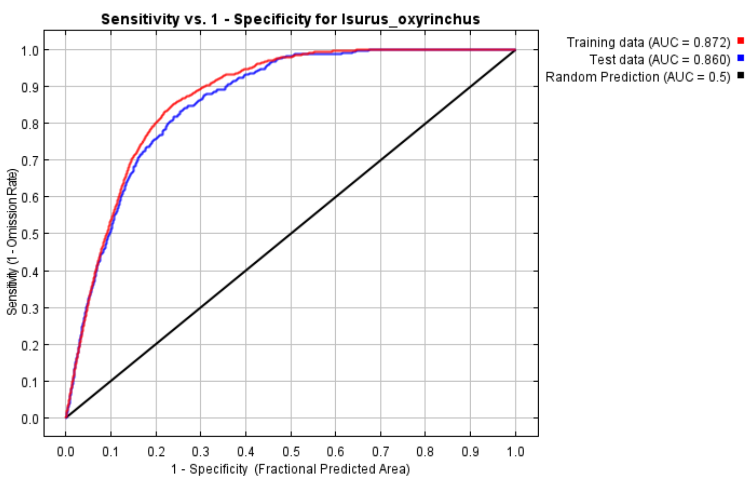

FIGURE 30: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important variables to *I. oxyrinchus* are temperature and to a lesser extent, primary productivity. Temperature is the most important individual variable as well.

TABLE 8: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance

Temperature	54.7	39.9
Primary productivity	19.3	7.2
Chlorophyll	10.9	29.7
Salinity	9	6.7
Phytoplankton	6	16.4

An interesting outcome of the Maxent model in the Jackknife of the test gain is that Salinity is the most important individual variable, with temperature next.

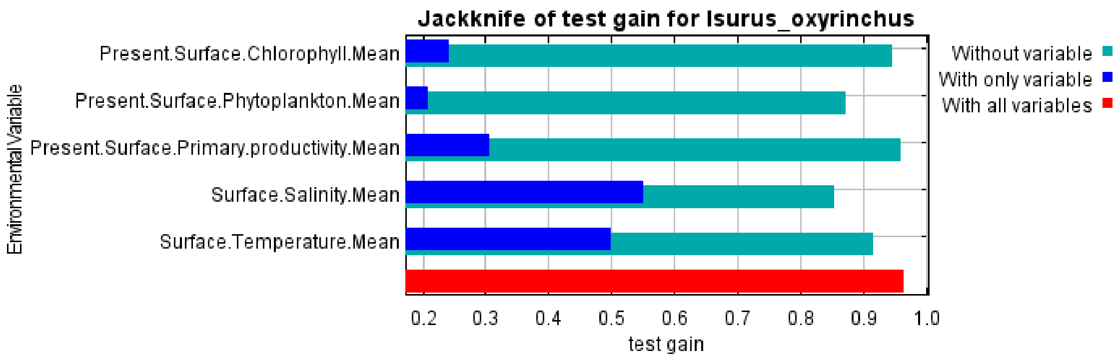

FIGURE 31: JACKKNIFE RESULTS OF THE TEST GAIN FOR I. OXYRINCHUS.

The QGIS map shows an average prediction of *I. oxyrinchus* near the coasts on the western side is a sight orange colour. However, on the eastern side this species does not show any risk in the future.

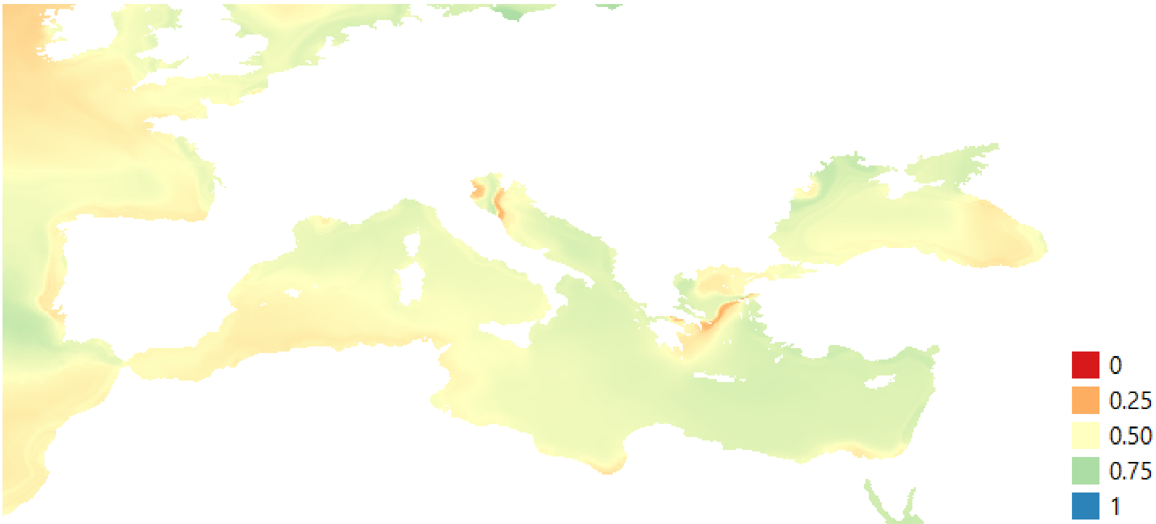

FIGURE 32: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF I. OXYRINCHUS.

In conclusion, *I. oxyrinchus* has shown an increase in landings in recent years. This species is mostly affected by temperature and primary productivity. Even if the species is not significantly affected by environmental factors in the future, there is a huge change in the landing efforts that suggest that they are at risk from being over fished at the least. According to the IUCN Red list, this is the only species on the list that is classified as Endangered.

Lamna. nasus

The time series of *L. nasus* shows that there is a lot of fluctuation of catches of this shark. However, it is clear that the trend had a peak in the late 1980's and then began to steadily decrease, and lower than it was initially in the 1950's.

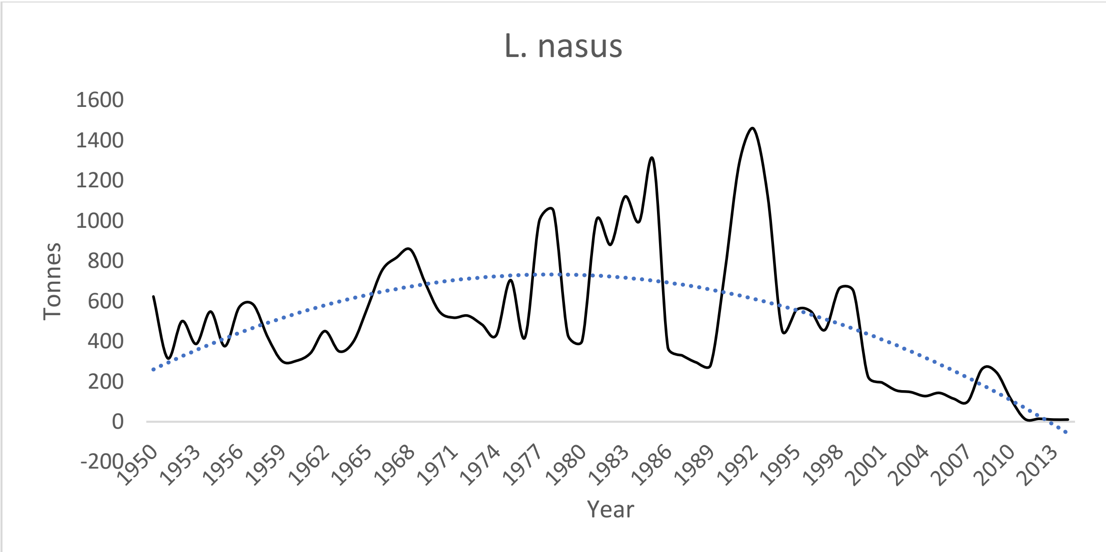

FIGURE 33: TIME SERIES GRAPH OF L. NASUS FROM 1950 - 2014.

The Maxent model for *L. nasus* has a high AUC, with it being 0.929. This can be a clear model of what the future will look like to this species based on these factors.

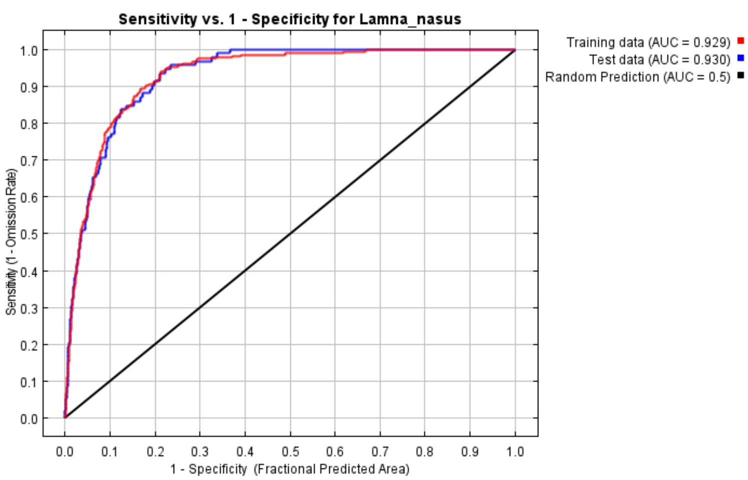

FIGURE 34: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

It is clear, according to Maxent, that the most important factors for *L. nasus* are temperature, with chlorophyll and primary productivity having strong influences as well. The least important environmental variable is salinity in both the Percent Contribution and Permutation Importance.

TABLE 9: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Temperature	45.2	35.1
Chlorophyll	21.3	30.7
Primary productivity	20.5	16.6
Phytoplankton	7.5	14.2
Salinity	5.5	3.4

The Jackknife furthers this conclusion with temperature showing the most important individual, however, phytoplankton also has a contribution according to this model when combined with other factors.

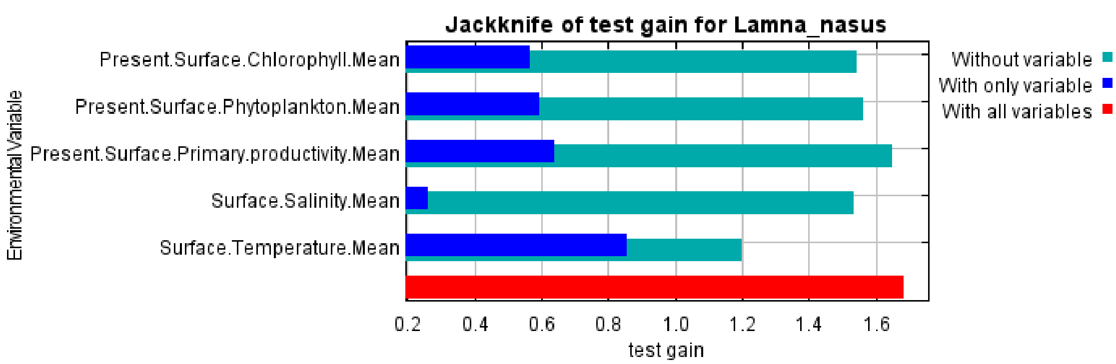

FIGURE 35: JACKKNIFE RESULTS OF THE TEST GAIN FOR L. NASUS.

The QGIS map of the future scenario for *L. nasus* shows most of the Mediterranean is relatively ideal for this species. However, there are some distinct areas around the Northern Adriatic and around the Aegean Sea near Greece, that are clearly red, which is the worst predictions of the species in this area.

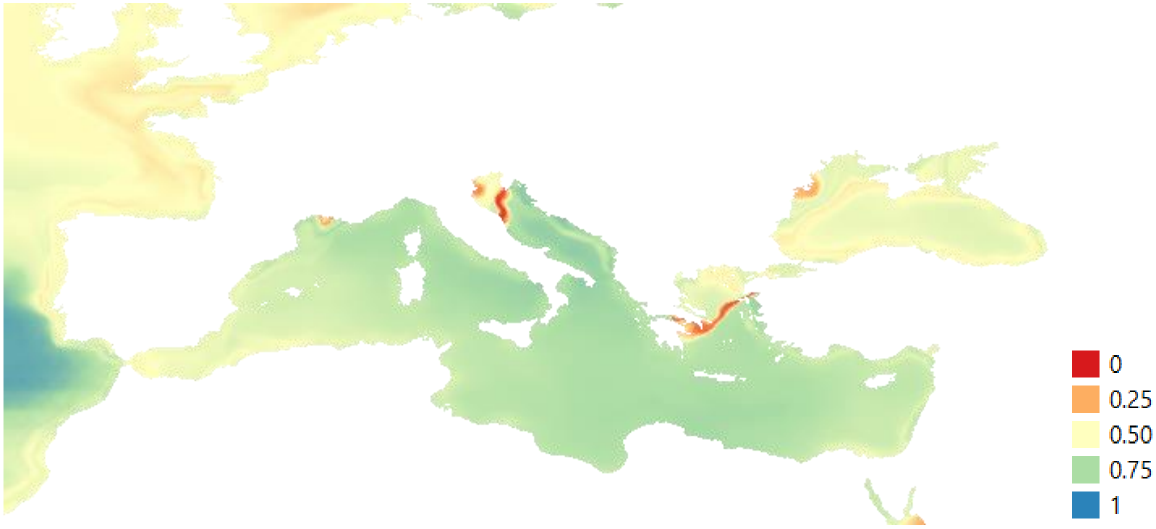

FIGURE 36: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS OF L. NASUS.

What can be seen about *L. nasus* is that the landing has been steadily dropping since the 1980's, it can also be seen that this species has distinct areas that will not be there in the future. This is troublesome for Italian fisheries because majority of the landing were from Italy. According to the IUCN Red list, this species is classified as Vulnerable.

Mustelus mustelus

The time series of the tonnes per year for *M. mustelus* shows there is a slight incline of landings however in 2009, there is a very large increase in the catches. There is no clear reason for this, but it should be noted that the catches of this species span from Spain to Turkey.

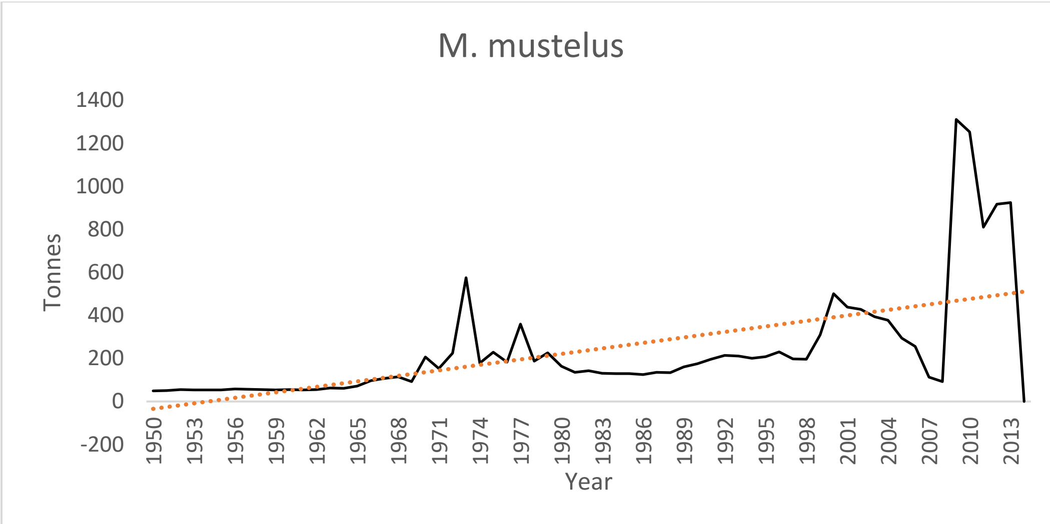

FIGURE 37: TIME SERIES GRAPH OF *M.* MUSTELUS FROM 1950 - 2014.

Maxent predicts this model to be very accurate given the information, with an AUC = 0.969.

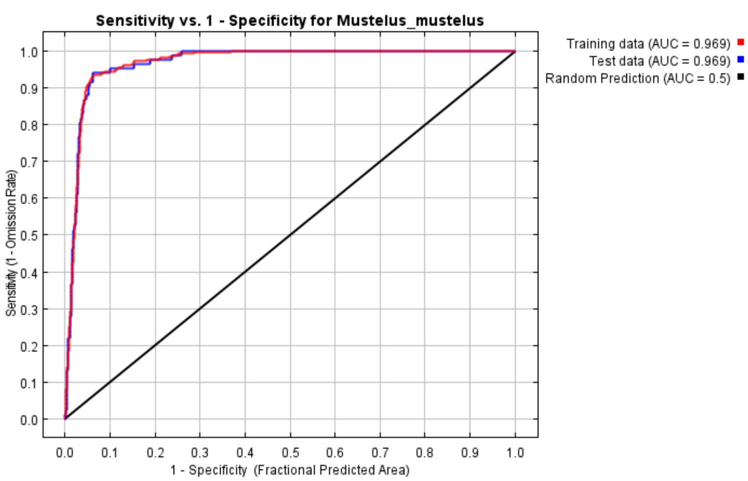

FIGURE 38: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important environmental factor for *M. mustelus* differs from the rest of the species in this paper, with primary productivity and salinity. Temperature does still seem to be the most important based on the Permutation Importance.

TABLE 10: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Primary productivity	37.1	23

Salinity	29.4	13.1
Temperature	27.6	57.6
Chlorophyll	4.4	4.9
Phytoplankton	1.5	1.4

This differs with the test gain test because it shows that salinity has a much less importance individually than shown above. As well as, temperature is no longer the most important individually.

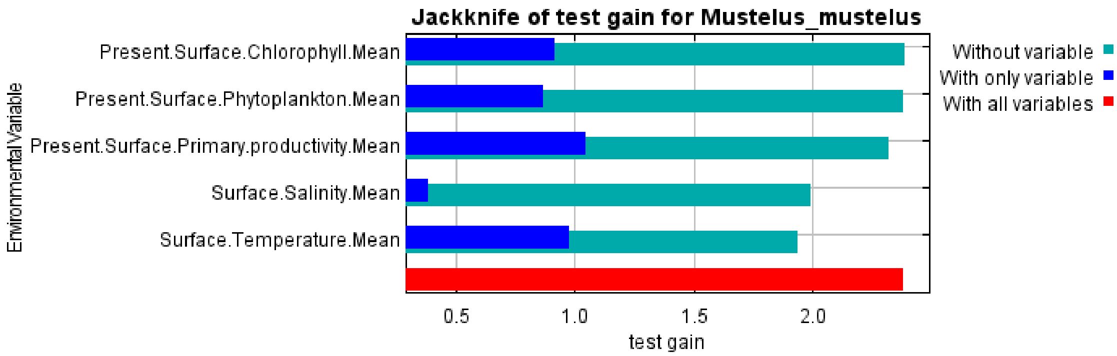

FIGURE 39: JACKKNIFE RESULTS OF THE TEST GAIN FOR M. MUSTELUS.

The QGIS map is largely in the warmer scale of colours, from here is can be concluded that the future scenarios based on RCP8.5 shows that the Mediterranean will not be ideal based on environmental factors for this species.

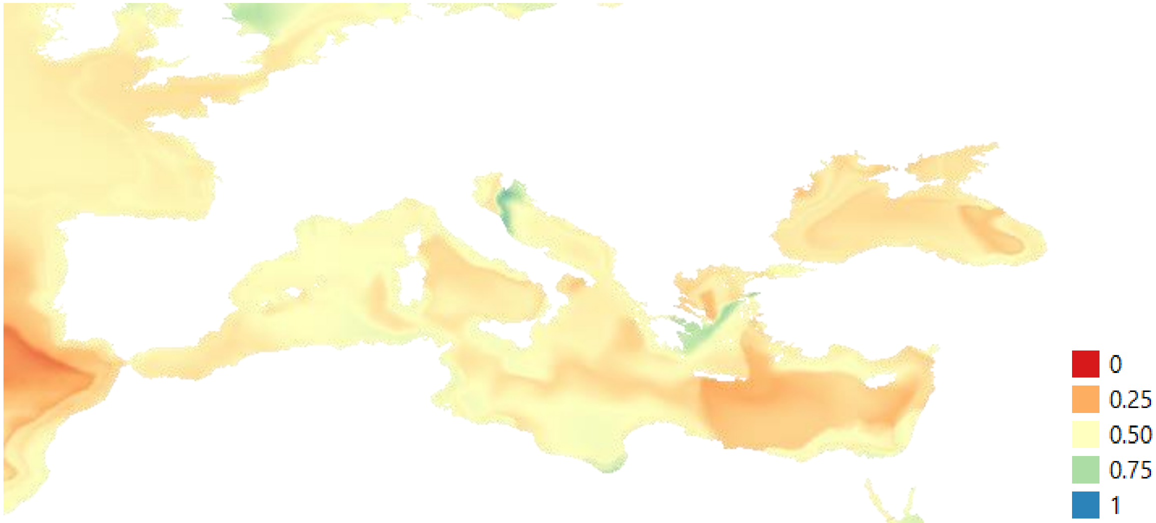

FIGURE 40: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS FOR *M. MUSTELUS*.

What can be concluded for *M. mustelus* is that although there are few spots in the Mediterranean where the species will have ideal conditions, the main areas where they are commonly caught like Algeria, Spain, Syria, and the Gaza Strip are clearly affected according to the predictions. It is also clear that there is not a large consistent population since the time series is so fluctuant. According to the IUCN Red list, this species is classified as Vulnerable.

Oxynotus centrina

The time series graph for *O. centrina* shows that there is a small increase over the years in the Mediterranean, however this is a dip in 2014 where the landing is almost half as the peak caught.

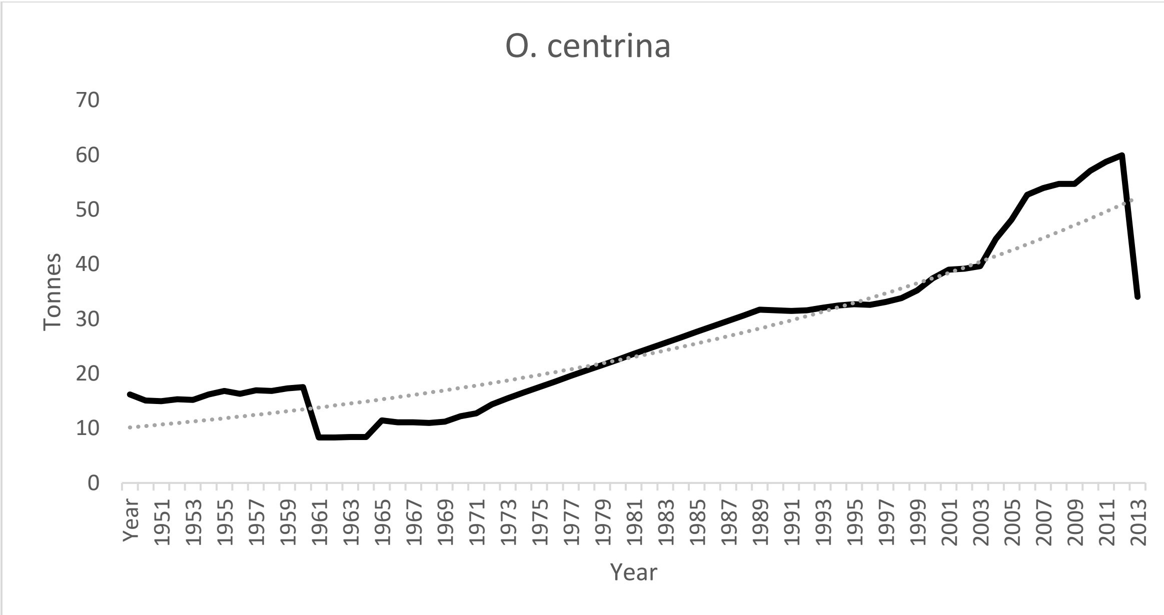

FIGURE 41: TIME SERIES GRAPH OF O. CENTRINA FROM 1950 - 2014.

According to Maxent the prediction of this model is very accurate and this can be proven with the AUC value that is very high, 0.978, being the highest value seen throughout all the sharks in this paper.

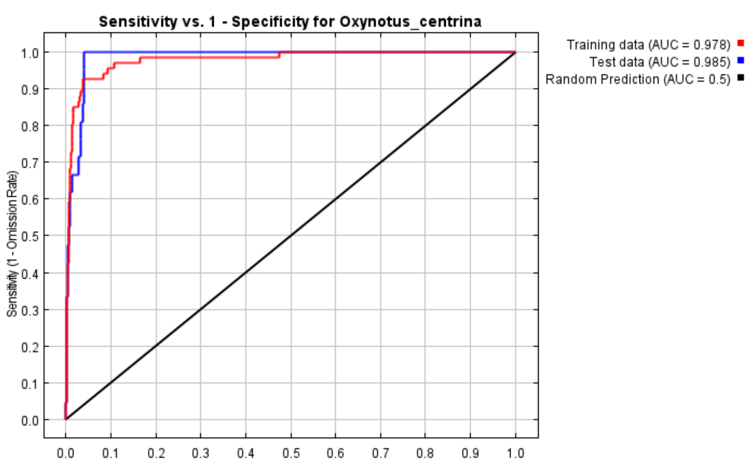

FIGURE 42: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important environmental variable to *O. centrina* is temperature, with primary productivity and salinity still being relatively high on the importance they have.

TABLE 11: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Temperature	35.2	59.7
Primary productivity	31.8	14.2
Salinity	28.6	16
Chlorophyll	3.3	7.3
Phytoplankton	1.1	2.8

However, this differs from the test gain, as primary productivity seems to me more important that temperature individually.

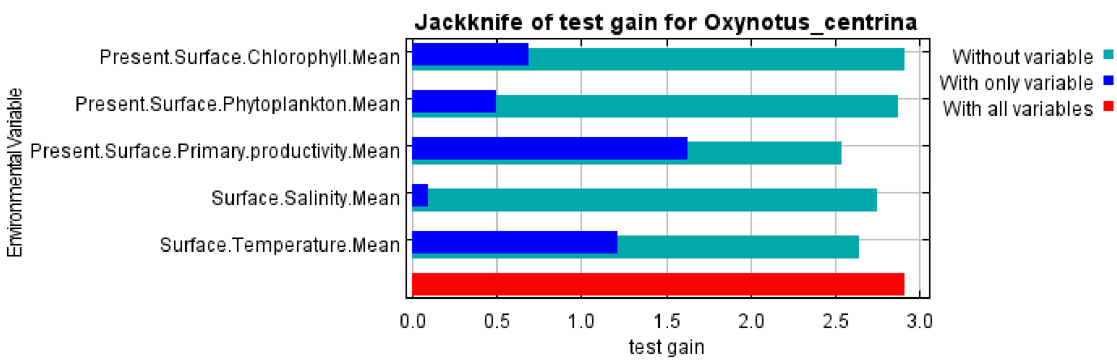

FIGURE 43: JACKKNIFE RESULTS OF THE TEST GAIN FOR O. CENTRINA.

The QGIS map of the future scenario for *O. centrina* looks to be not very at risk in the future, there are some areas that are more unsuitable than others but over all this is a least concern type of outcome.

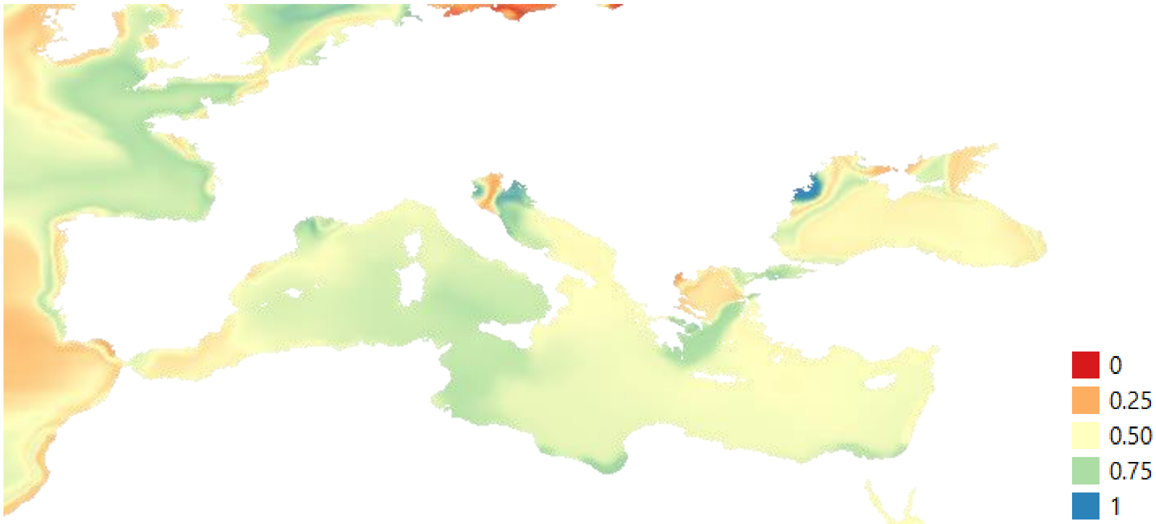

FIGURE 44: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS FOR *O. CENTRINA*.

In conclusion, *O. centrina* seems not to be at a very high risk of environmental unsuitability in based on the future scenarios. The time series dip in catches in 2014 is not enough evidence to prove a decline in population. However, the ICUN Red list does classify the species to be Vulnerable.

Prionace glauca

The time series for *P. glauca* is consistently increasing over time, however this is hard to see as in 2010 and 2011 there is a dramatic increase in landings. This drastic increase is due not to the amount of countries that are reporting catches but actually to one specific landing from a Spanish longline that caught more than 4000 tonnes.

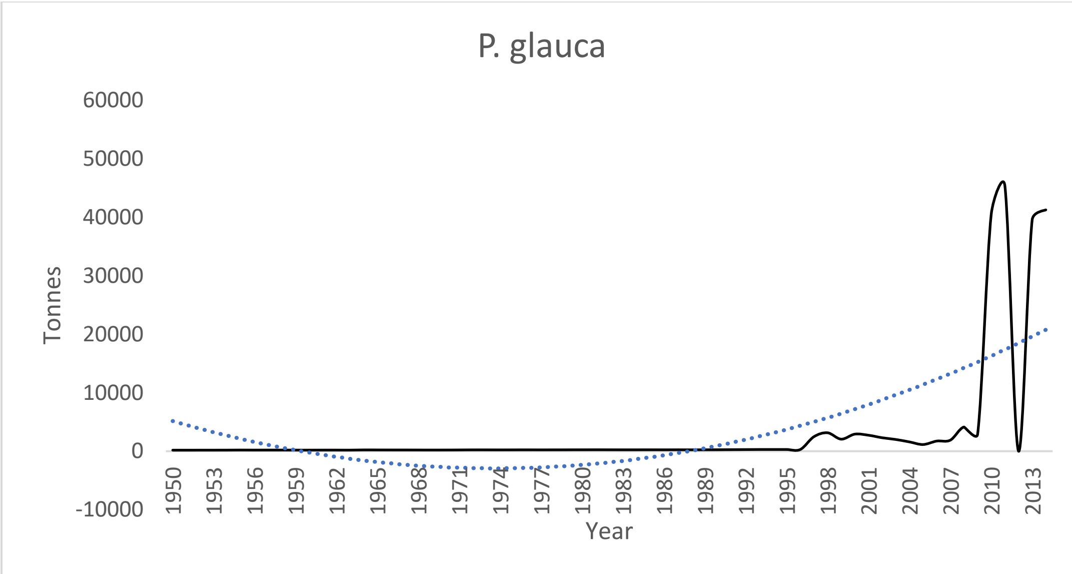

FIGURE 45: TIME SERIES GRAPH OF P. GLAUCA FROM 1950 - 2014.

Maxent has produced a model that is on the lower end of being high quality with an AUC = 0.828. However, still relatively high.

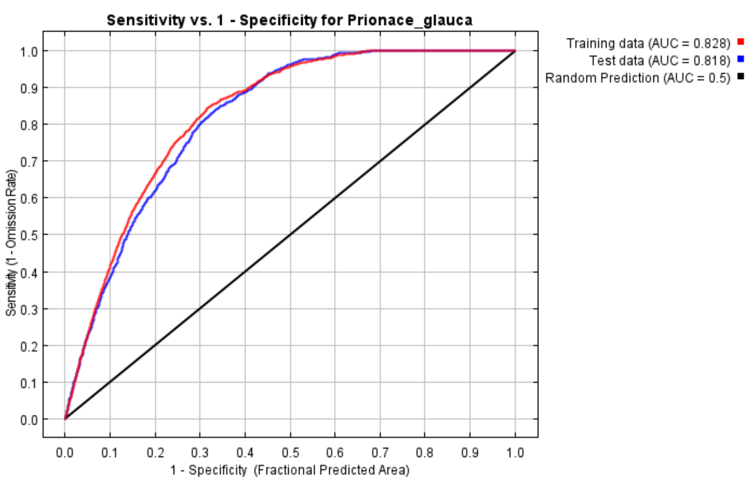

FIGURE 46: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important environmental variable for *P. glauca* is by far temperature, with no other factor making a significant impact. Even the most important individual factor is temperature.

TABLE 12: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Temperature	62.3	44
Chlorophyll	17.7	28
Salinity	8.1	6.2
Phytoplankton	7.4	18.3
Primary productivity	4.4	3.6

What is good to note from the test gain Jackknife test is the difference in the individual importance of the salinity and also the importance of chlorophyll and primary productivity.

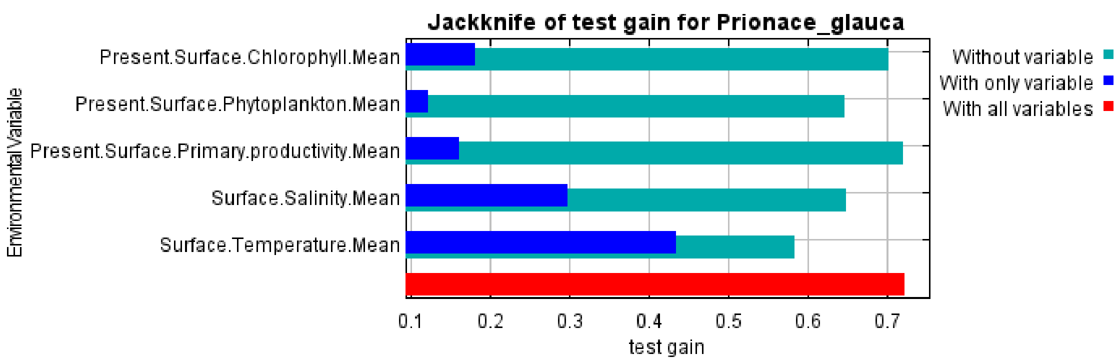

FIGURE 47: JACKKNIFE RESULTS OF THE TEST GAIN FOR P. GLAUCA.

According to the prediction map from QGIS, there are two areas in the Mediterranean that are affected the most, the Northern Adriatic and the Aegean Sea. Generally, the map is more of an orange colour, implying that r ~ 0.25 in most areas of the Mediterranean.

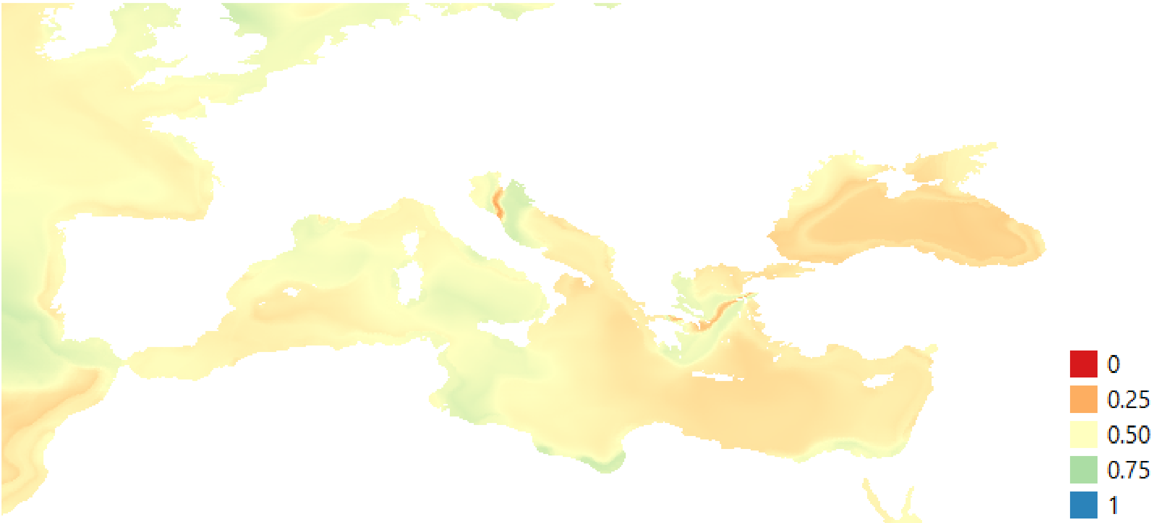

FIGURE 48: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS FOR P. GLAUCA.

What can be concluded from *P. glauca* is the consistent landings from multiple countries but extremely drastic landings with longlines. Temperature seems to be the only important environmental factor for this species of shark. In the future, they seem to not have very ideal habitats in the areas where they have been most commonly caught in the past 64 years, including near Italy, France, Algeria, and Spain. According to the IUCN Red list, the species is classified as Near Threatened.

Squalus acanthias

The time series for *S. acanthias*, with the exception of a few years like 1979, 1982, and 1989, the general trend of this species had a peak and is now decreasing.

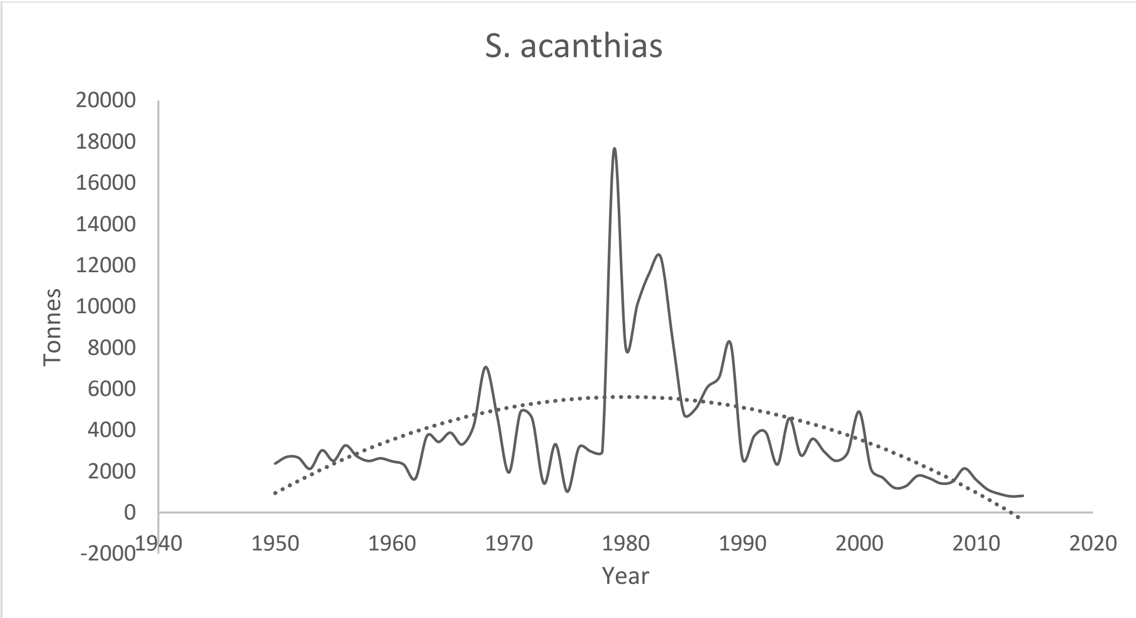

FIGURE 49: TIME SERIES GRAPH OF S. ACANTHIAS FROM 1950 - 2014.

According to Maxent, this model is the least accurate one in this paper, with an AUC = 0.762.

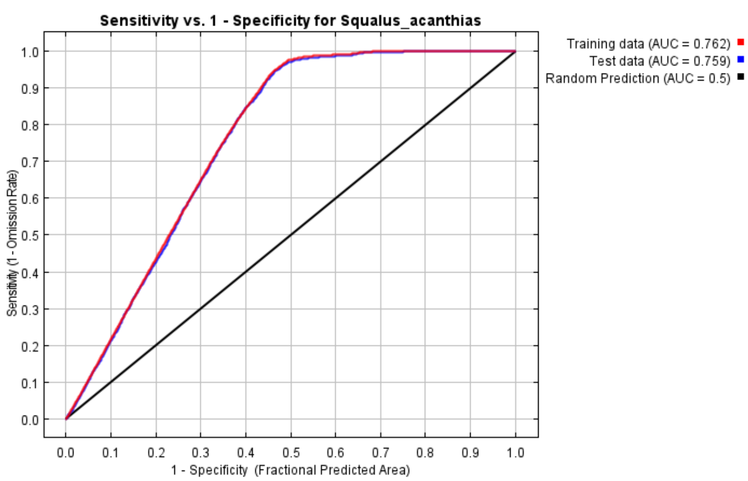

FIGURE 50: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important variable for *S. acanthias* is temperature, followed by chlorophyll. With these two also being the most important individually as well. Surprisingly, salinity has little to no effect on the species.

TABLE 13: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Temperature	49.2	48.5
Chlorophyll	43.7	42.1
Phytoplankton	4.2	2.4
Primary productivity	1.9	6.2
Salinity	1	0.9

The Jackknife of the test gain furthers the importance of the temperature however it differs with the importance of phytoplankton.

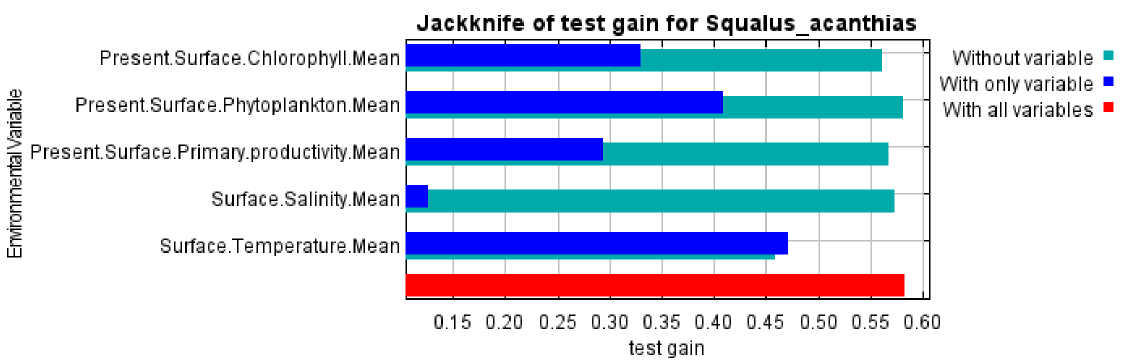

FIGURE 51: JACKKNIFE RESULTS OF THE TEST GAIN FOR S. ACANTHIAS.

The QGIS prediction map shows that there is a change in suitability of this species around the western part of the Mediterranean, mostly affecting Spain and Algeria. However, around Italy, not including the Northern Adriatic, the suitability is much better than in other places.

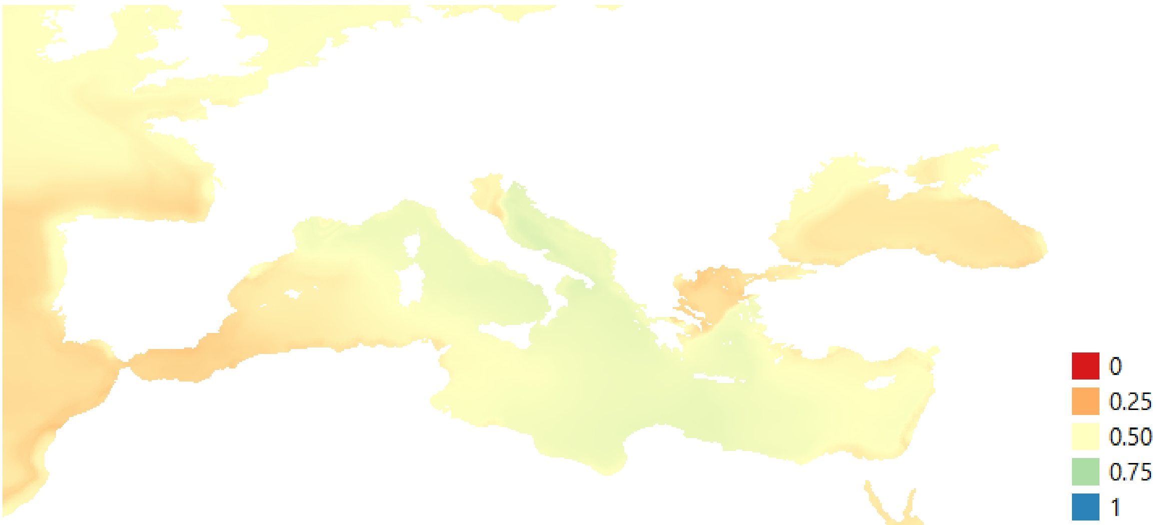

FIGURE 52: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS FOR S. ACANTHIAS.

In conclusion, *S. acanthias* shows that there is a drop in landings in recent years minus a few spikes in the landings. The areas that will suffer the most with this prediction is Spain, Turkey, and France, as most of the landings are from these countries. The IUCN Red list classifies this species as Vulnerable.

Scyliorhinus canicula

The time series of *S. canicula* shows that there is a steady increase of this species in the Mediterranean. In 2013, however, it does start to decrease but the reason for this are unknown because it is only two years and can be a natural dip.

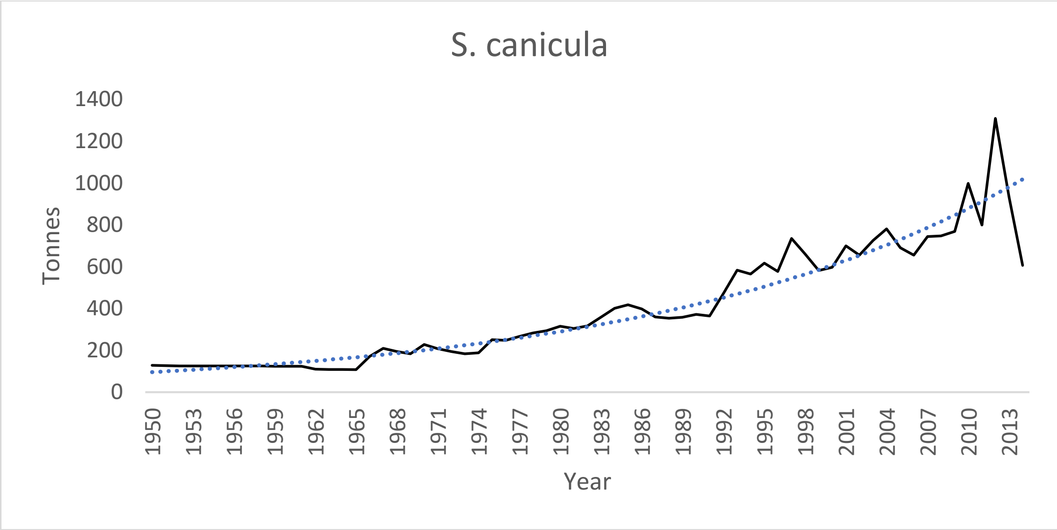

FIGURE 53: TIME SERIES GRAPH OF S. CANICULA FROM 1950 - 2014.

The Maxent model shows that the accuracy of the predictions will be ideal since the AUC is 0.926.

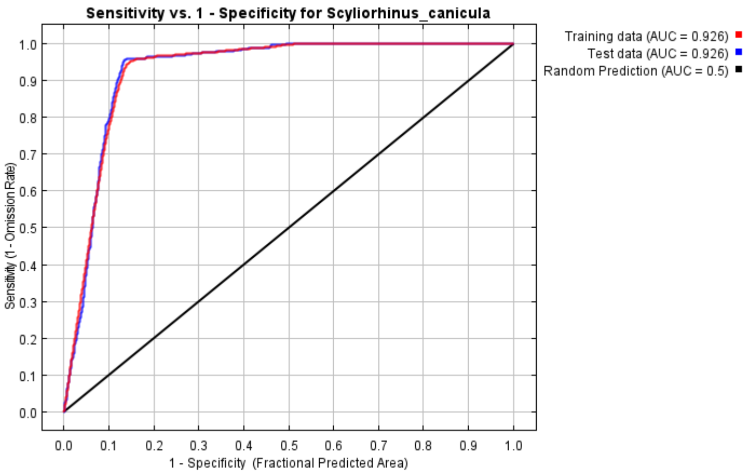

FIGURE 54: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

According to Maxent, the most important variable is temperature, followed by chlorophyll.

TABLE 14: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Temperature	51.3	53
Chlorophyll	31.9	17.2
Salinity	11.5	5.7

Phytoplankton	2.7	15.8
Primary productivity	2.5	8.3

The test gain differs from the above table because there is a larger importance on phytoplankton.

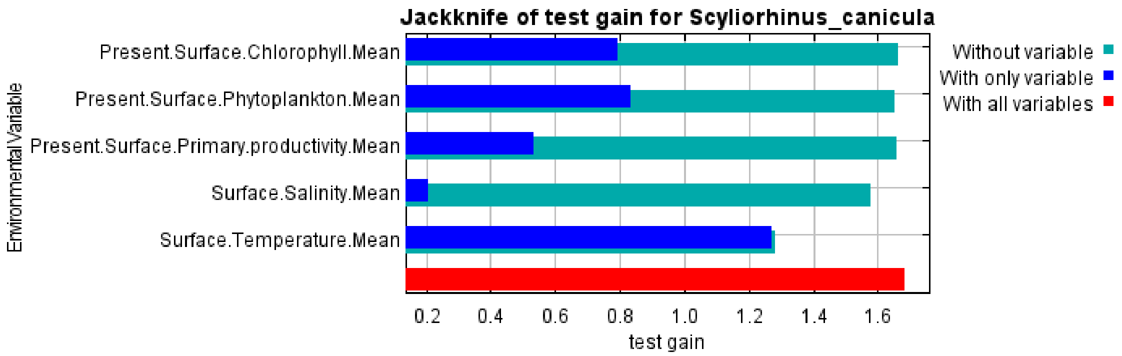

FIGURE 55: JACKKNIFE RESULTS OF THE TEST GAIN FOR S. CANICULA.

The QGIS map based on the future scenario RCP8.5, the map is very orange, implying that the future is not looking very suitable for *S. canicula*. The most common places that this species is found are Malta, Italy, France, and Spain. In these areas, there is a majority of r ~ 0.25 so it can be concluded to be not ideal for the future of this species.

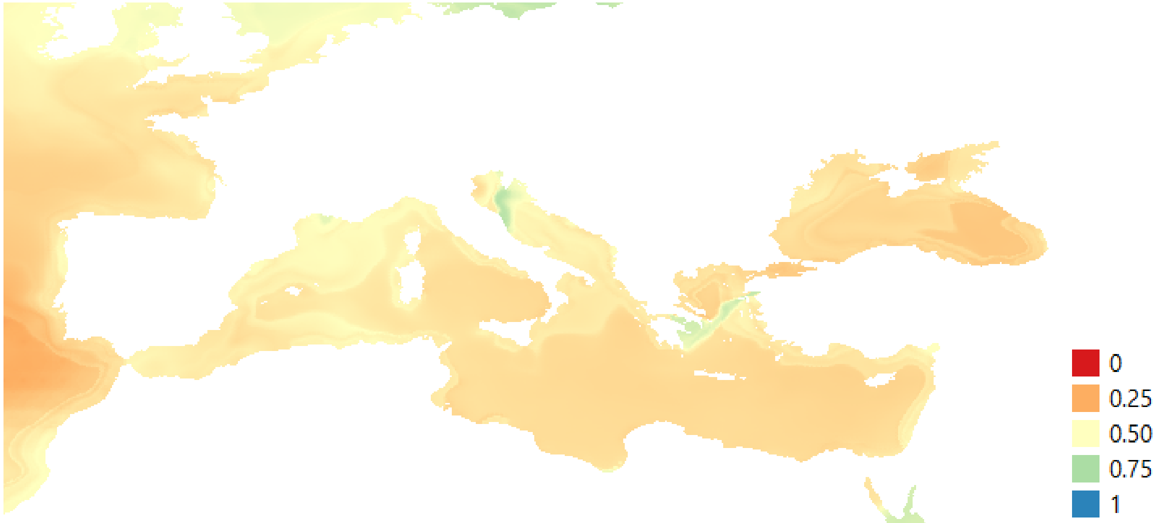

FIGURE 56: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS FOR S. CANICULA.

In summary, this species seems to be increasing steadily based on landings throughout the years. But the future prediction of *S. canicula* looks to be risky as the majority of the map is showing a less than ideal habitat for them based on environmental factors and the environmental predictions. According to the ICUN Red list, this species is classified as Least Concern.

Scyliorhinus stellaris

Apart from the later years in this time series, *S. stellaris* does not have a very high number of landings. However, starting in 2008 in the areas where these landings most commonly occur, it can be seen that there is a significant increase in landings and this is due to the use of longlines.

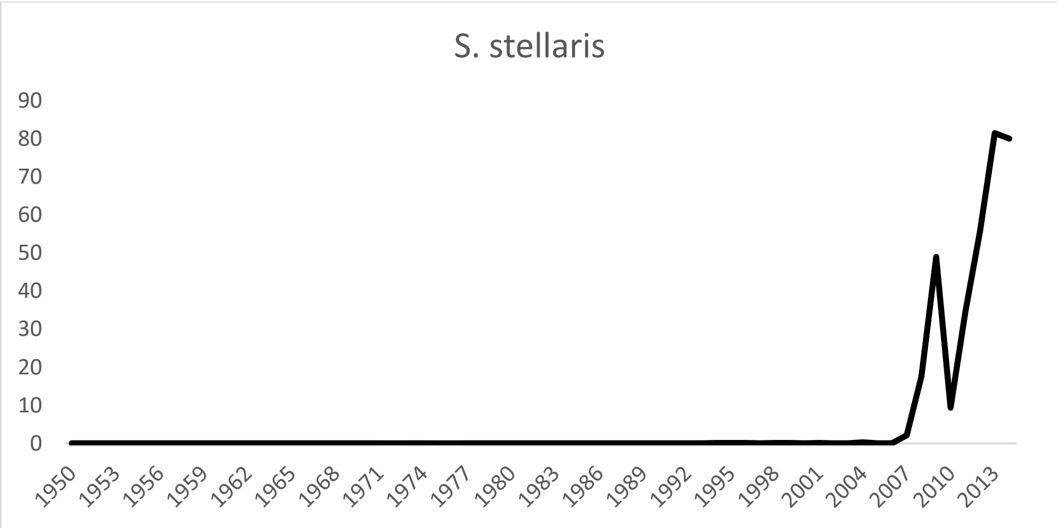

FIGURE 57: TIME SERIES GRAPH OF S. STELLARIS FROM 1950 - 2014.

According to Maxent, the model seems to be an accurate fit for predicting the future with an AUC = 0.971.

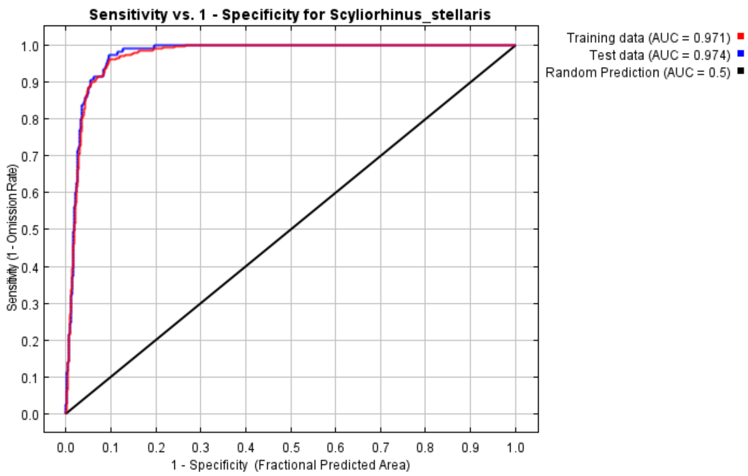

FIGURE 58: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important variable to *S. stellaris* according to Maxent is temperature and chlorophyll. This is also the same as individual variables.

TABLE 15: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Temperature	42	58.5
Chlorophyll	36.3	25.2
Salinity	18	8.3
Primary productivity	2.9	7.4
Phytoplankton	0.7	0.6

The test gain of the Jackknife shows that phytoplankton has a much greater importance than the above table shows. However, temperature is still the most important variable.

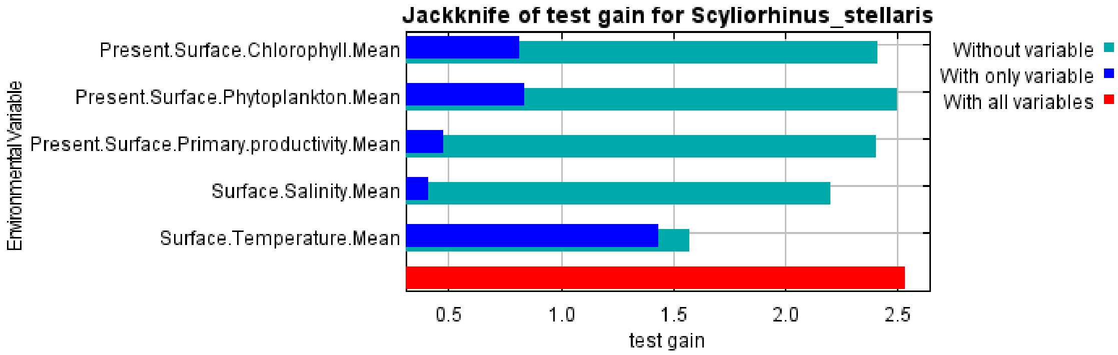

FIGURE 59: JACKKNIFE RESULTS OF THE TEST GAIN FOR S. STELLARIS.

In QGIS, it can be seen that there is a large area in the Mediterranean that is clearly not predicted well to be an ideal habitat for this species. This map is unique as there are many areas that seem to predict an ideal environment that differ from the other maps in this paper.

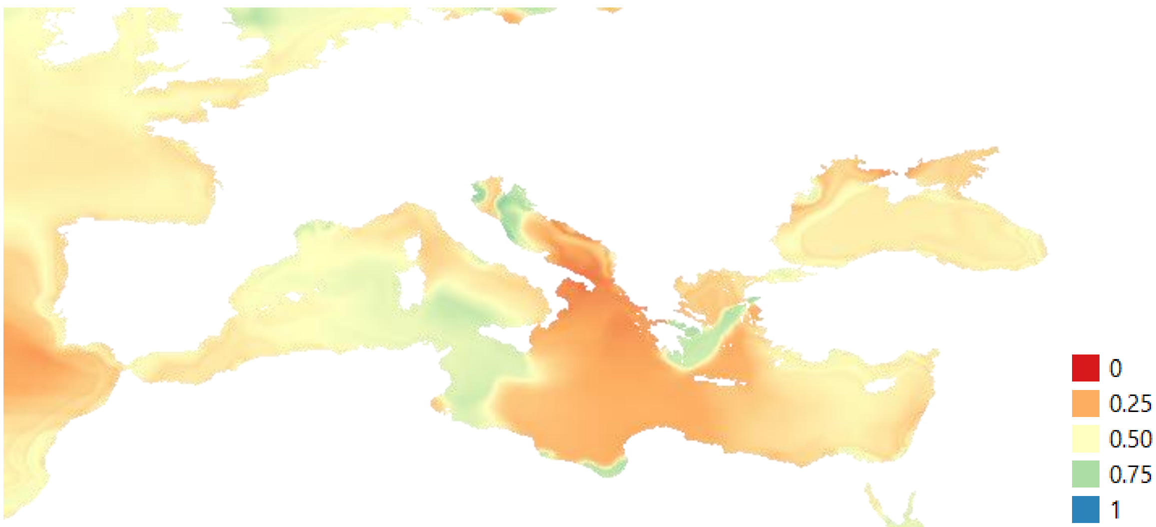

FIGURE 60: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS FOR S. STELLARIS.

In summary, it can be seen that *S. stellaris* is not a very large landing for the countries that do target it. However, the countries that do target this species are the least affected by the predictions of the QGIS map as they are Spain, Algeria, and France. It shows be noted that when the longlines were used though, that the number of landings increased massively. According to the IUCN Red list, this species is classified as Near Threatened.

Sphyrna zygaena

The time series graph of *S. zygaena* shows that the catches of the species are not notable until around 1997 where the use of longlines were used and this is the reason for the spikes in landings. Majority of these catches are for recreational purposes according to the data.

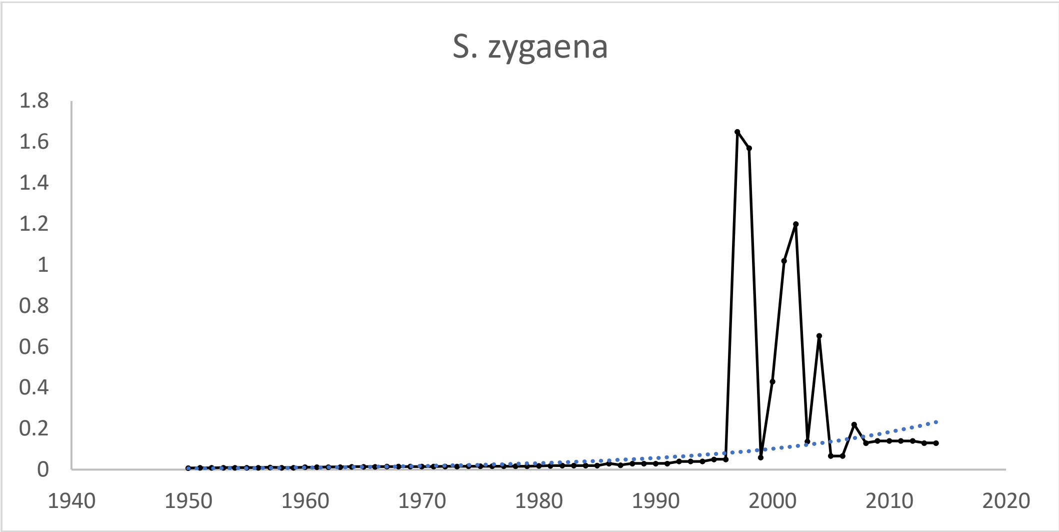

FIGURE 61: TIME SERIES GRAPH OF S. ZYGAENA FROM 1950 - 2014.

The Maxent model shows that the accuracy of this prediction is quite high with and AUC of 0.932.

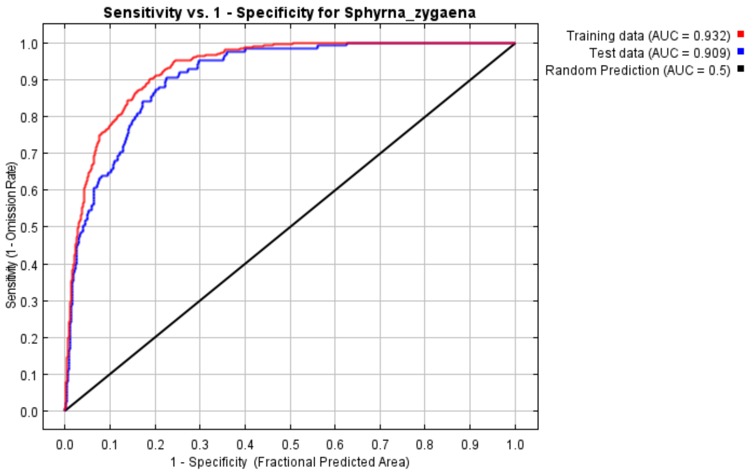

FIGURE 62: MAXENT AUC OUTPUT INDICATING ACCURACY OF MODEL.

The most important environmental variable to *S. zygaena* is primary productivity followed by temperature. However, temperature is the most important individual factor that influences the species in this model.

TABLE 16: MAXENT OUTPUT WITH THE VARIABLES AND THEIR PERCENT IMPORTANCE.

Variable	Percent Contribution	Permutation Importance
Primary productivity	50.2	31.9
Temperature	36.9	60.4
Chlorophyll	8.4	2.7
Salinity	2.8	1
Phytoplankton	1.6	4.1

The test gain of the Jackknife seems to agree very closely to the table above except in this case, the most important independent variable is primary productivity.

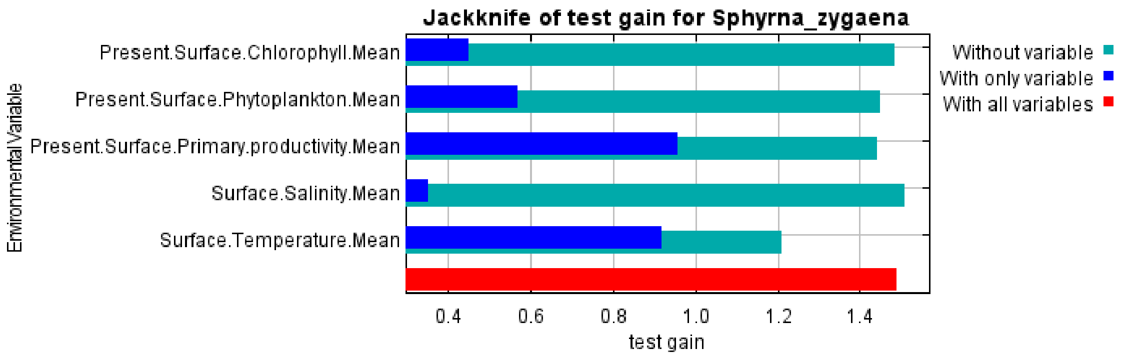

FIGURE 63: JACKKNIFE RESULTS OF THE TEST GAIN FOR S. ZYGAENA.

The QGIS map seems to look more ideal than less ideal for this species. The only questionable areas for this species are closer to the Western area of the Mediterranean. Which is actually where the only landings of this species are located. According to the future scenario of RCP8.5, the outlook for this species of shark is better than most in this paper.

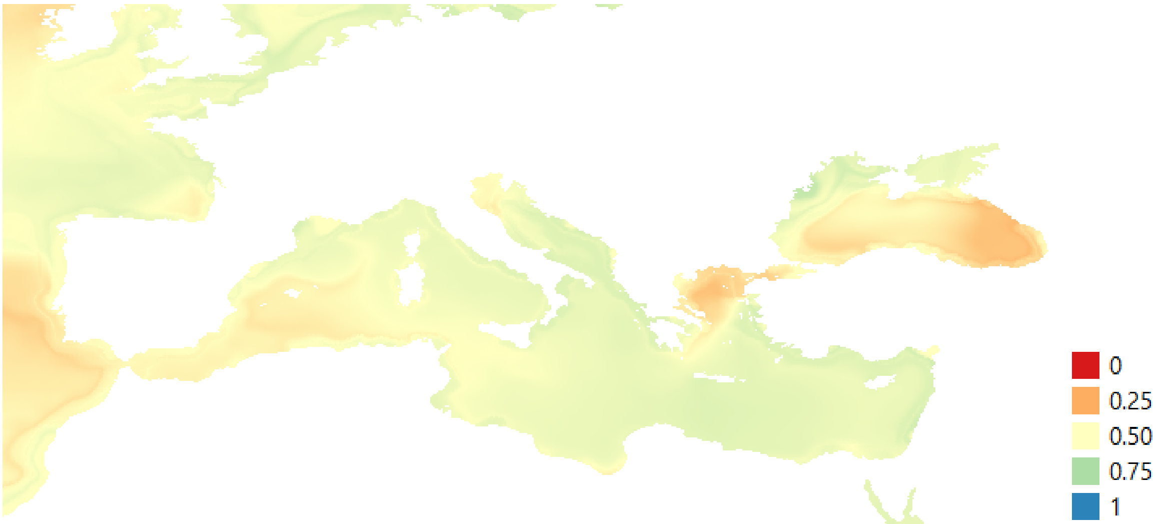

FIGURE 64: QGIS OUTPUT MAP SHOWING THE FUTURE PREDICTIONS FOR S. ZYGAENA.

In summary, *S. zygaena* shows that they are a very vulnerable species to long lines, however the total landings are still relatively low compared to the other sharks included in this paper. It is important to note that the only questionable area of suitability for this species based on the scenario in the future are the very places that are landing this fish, around Spain and Portugal. According to the IUCN red list, *S. zygaena* is listed as Vulnerable.

TABLE 17: SUMMARY OF ALL SHARKS.

Order	Family	Species	QGIS	ICUN	Reproduction	Depth	Outcome
Lamniformes	Alopiidae	A. vulpinus	r > 0.5	Vulnerable	Ovoviviparous	pelagic, coastal/oceanic	
Squaliformes	Somniosidae	C. coelolepis	r < 0.5	Near Threatened	Ovoviviparous	demersal, coastal/oceanic	Declining
Carcharhiniformes	Carcharhinidae	C. plumbeus	r > 0.5	Vulnerable	Viviparous	benthopelagic, coastal	
Squaliformes	Dalatiiae	D. licha	r < 0.5	Vulnerable	Ovoviviparous	demersal, oceanic	Declining
Squaliformes	Etmopteriidae	E. spinax	r < 0.5	Least Concern	Viviparous	demersal, oceanic	Declining
Carcharhiniformes	Triakidae	G. galeus	r < 0.5	Vulnerable	Ovoviviparous	demersal, coastal	Declining
Hexanchiformes	Hexanchidae	H. perlo	r > 0.5	Near Threatened	Ovoviviparous	demersal, coastal/oceanic	
Lamniformes	Lamnidae	I. oxyrinchus	r < 0.5	Endangered	Ovoviviparous	pelagic, coastal/oceanic	Declining
Lamniformes	Lamnidae	L. nasus	r > 0.5	Vulnerable	Ovoviviparous	pelagic, coastal/oceanic	
Carcharhiniformes	Triakidae	M. mustelus	r < 0.5	Vulnerable	Viviparous	pelagic, coastal	Declining
Squaliformes	Oxynotidae	O. centrina	r = 0.5	Vulnerable	Ovoviviparous	demersal, coastal/oceanic	
Carcharhiniformes	Carcharhinidae	P. glauca	r < 0.5	Near Threatened	Viviparous	pelagic, oceanic	Declining
Squaliformes	Squalidae	S. acanthias	r < 0.5	Vulnerable	Ovoviviparous	demersal, coastal/oceanic	Declining
Carcharhiniformes	Scyliorhinidae	S. canicula	r < 0.5	Least Concern	Oviparous	demersal, coastal/oceanic	Declining
Carcharhiniformes	Scyliorhinidae	S. stellaris	r < 0.5	Near Threatened	Oviparous	Coastal/oceanic	Declining
Carcharhiniformes	Sphyrnidae	S. zygaena	r > 0.5	Vulnerable	Viviparous	demersal, coastal/oceanic	

4. Discussion

The results of this paper will show each species of sharks seem to be experiencing different future risk based on the Maxent future predictions. Ten of the sixteen species will be at risk in the future based on the environmental factors used, especially Primary Productivity and Temperature. This can be seen from (*Table 17*). Each species dwells in specific areas of the Mediterranean with only a few exploring the entire Mediterranean based on the Sea Around Us landing data and literature. Looking at the sharks separately it can be seen that there is a trend within the species, and not so much a consistent one throughout all sharks, this can also as can be referred to as species-specific behaviour. The hypothesis of this paper is to see if 16 different elasmobranchs in the Mediterranean are affected by abiotic factors such as temperature and salinity as well as biotic factors like primary productivity. Most of these sharks are affected by both temperature and primary productivity, with salinity, phytoplankton and chlorophyll affecting only a few.

4.1 Temperature and Salinity

Similar to most marine life elasmobranchs are at the mercy of abiotic stressors in the environment for their survival. Factors considered in this paper include temperature, salinity, primary production, chlorophyll, and phytoplankton. Throughout this paper it can be seen that the most important factors that effect sharks are temperature and primary productivity, and against hypothesis, salinity has a mild impact on almost all the sharks included. Temperature and salinity are thought to be very important environmental factors for the optimal survival of sharks and closely correlate in some cases (Schlaff *et al.*, 2014). Elasmobranchs are often compared to teleost's when it comes to understanding how they will adapt in stressful environments and literature states that if elasmobranchs respond in a similar way to that of a teleost such as ocean acidification then the future is dim for these fish (Dixson *et al.*, 2015). Sharks show species-specific trends when it comes to temperature and salinity preference according to their differing abilities to adapt (Heisler, 1988; Schlaff *et al.*, 2014). This explains why there is not a clear trend to describe the sharks in this paper. *A. vulpinus, D. licha, L. nasus, I. oxyrinchus, H. perlo* and *S. acanthias* all share the same reproduction style (*Table 17*), but do not all have the same outcome for their futures and also are affected by different abiotic and biotic factors.

Sharks can adapt to various salinities for short periods of time as the result of constant osmoregulation. Without this ability sharks would experience difficulty metabolizing efficiently along with other necessary bodily functions (Heisler, 1988). Elasmobranchs will keep their internal osmoregulatory very close to that of the surrounding water and in most cases slightly higher (Pang *et al.*, 1977; Price & Daiber, 1967; Schlaff *et al.*, 2014). This is because the tissues of the shark must contain higher osmolarity to avoid the loss the osmotic water within the cells (Pang *et al.*, 1977). In sharks, the main organs responsible for this osmoregulation are the rectal gland and the kidneys, aiding in the biochemical changes related to salinity changes in the specific environment (Pang *et al.*, 1977; Price & Daiber, 1967). The kidney and rectal gland control the regulation of urea and sodium chloride respectively (Price & Daiber, 1967; Tunnah *et al.*, 2016). Dixson and others (2015), conducted the first study on the effects of osmoregulation on elasmobranchs. What they found was that when exposed to the 2100 predicted levels of CO_2, the species (*Mustelus spp.*) was unable to differentiate between vital cues of survival. When the species did recognize food, it was less aggressive in its predation. *M. mustelus* is one of the three species of shark in this paper to be affected by salinity (Table 10). It may be possible that this specific species is highly sensitive to salinity, however this seems unlikely based on their vast range in the Mediterranean and the low effect of temperature.

There are conflicting ideas of the importance of salinity to the selection of habitat made by sharks. The research of Lauria and others (2015) show factors like temperature and especially salinity are significantly less important to sharks compared to depth. This paper did not look at depth as a factor for the prediction model but the depths of the species are all included in (*Table 17*). They found in their models of habitat selections of sharks that there was a positive curvilinear relationship between temperature and the abundance of sharks in that area (Lauria *et al.*, 2015). They found that salinity played a very small role in habitat selection of sharks similar to the results in this paper for the reason that ranges of salinity in the Mediterranean are not very large (Lauria *et al.*, 2015). The results clearly show throughout a surprising lack of importance or impact from salinity adding to *M. mustelus* only two additional species, *O. centrina* and *E. spinax* sharks showing results of salinity as a major influence on the species in the future (Table 5, Table 11). It should be noted that for each of these species, salinity has the least amount of importance based on the Maxent model jackknife test (Fig. 19, Fig. 39, Fig. 43). *E. spinax* and *M. mustelus* are both more effected by environmental factors than fishing, whereas *O. centrina* is more effected by fishing than environmental patterns based on these results.

Temperature is known to be a factor that drives sharks in their habitat preference (Lauria *et al.*, 2015; Schlaff *et al.*, 2014). The major reason for this is because sharks, with the exception of the family Lamnidae (e.g. *L. nasus, I. oxyrinchus*) (*Table 17Table 17*), are ectotherms (Schlaff *et al.*, 2014). Elasmobranchs are known to use a method called behavioural thermoregulation, in which they will travel to cooler or warmer environments to conserve energy (Schlaff *et al.*, 2014). Some sharks (e.g. *A. vulpinus, P. glauca*) (*Table 17Table 17*) will dive to great depths to cool down, others (e.g. *S. canicula*) use the change in temperature so they can reduce their energy costs associated to hunting called "hunt warm, rest cool" (Schlaff *et al.*, 2014). Temperature and primary productivity are closely related and this conclusion agrees with the results of this paper that all sharks are affected by temperature and 11 are affected by primary productivity (Lauria *et al.*, 2015).

4. 2 Primary Productivity

Primary productivity is the rate of production of organic matter in an ecosystem. This factor is significant to the results of this paper as almost every shark included are majorly affected by this proxy. Knowing that most of the species of elasmobranchs are the top predators of their ecosystems, it can be assumed that their need for primary productivity is essential for their survival as tertiary consumers. The Mediterranean Sea is an oligotrophic basin that has seasonal periods of high and low productivity, higher in winter and lower in summer (Rahav *et al.*, 2013). This may be because temperature and primary productivity are very closely related and temperature was an influencing factor for these species. So, it is clear that if the sharks are mostly affected by temperature, and these two biotic and abiotic factors are related that the primary productivity has an impact. An important fact about primary productivity in the Mediterranean is that there is literature implying that it is higher in the Western basin (Rahav *et al.*, 2013). This is proven by the results of this paper as most of the QGIS maps so no warm colours ($r < 0.5$) in the west. Primary productivity is one of the most fundamental factors in fisheries and strongly relates to the catchability of sharks when looking at the nutrients and water content of the surrounding (Brown *et al.*, 2010). For demersal species, the sinking of organic matter is a primary source of food for them to survive. Many of the species in this paper are demersal and this will affect them in the future (e.g. *C. coelolepis, D. licha, H. perlo*) (*Table 17Table 17*) (Company *et al.*, 2008; Ligas *et al.*, 2013). Time series data shows that the best reporting for primary productivity is not until the early 90’s and onward, but anything before could be not as reliable due to improper techniques, making the reliability of this section of the time series difficult to analyze (Ligas *et al.*, 2013). There is some debate on how exactly primary productivity effects elasmobranch communities in terms of top-down or bottom-up but it is clear that the primary productivity effects every shark except *E. spinax, P. glauca, S. acanthias, S. canicula, and S. stellaris* (Richardson & Schoelman, 2004). It is important to note that all of these species are predicted to have harsher environments in the future, so regardless of the important of primary productivity, they are now and will in future all be at risk.

4.3 Reproduction

The composition and variables effecting water are very important factors to elasmobranchs because they can affect the metabolic pathways as well as the reproductive systems (Pang *et al.*, 1977). Since it is very clear that the K-selected lifestyle effects every species of shark, knowing how different environmental factors may effect this essential step is important for conservation and education. There are three main modes of reproduction in sharks:

oviparous – the offspring is born via egg and hatches out of the womb;

ovoviparous - the pup is born in an egg first and hatches within the mother and then born live

viviparous - the pup is birth via live birth from internal fertilization (Price & Daiber, 1967).

In some ways temperature can affect the development of the embryo and change the rate of gestation. Schlaff and others (2014), found that in a surrounding with a higher than average temperature, the rate of development and gestation period was faster. Achieving full embryonic development in warmer waters can be very advantageous for elasmobranchs because their slow gestation is an important factor in their inability to adapt to hits in population or to major and rapid changes in environment. For some ovoviviparous species (e.g. *S. acanthias*), the pup will remain in the womb for up to 24 months before being born (Abdulla, 2004; Price & Daiber, 1967). Additionally, *S. acanthias* surround their pups with urea for 3/4's of the gestation (Pang *et al.*, 1977). It is possible that the increased rate of gestation from warmer climates may not be the desired amount of time for all of the sensory systems to develop properly. Salinity is a strong factor on elasmobranchs, effecting specific processes like sensory systems directly (e.g. Ampullae of Lorenzini and the lateral line). In the viviparous species Mustelus, the pups during gestation are surrounded with a high urea fluid in the uterus the entire duration (Pang *et al.*, 1977, Price & Daiber, 1967). In this paper there are no trends between the three reproduction styles. Not all of the viviparous species have the same outcome based on the predictions of Maxent (*Table 17*).

4.4 Discussion of each shark

I) Alopias vulpinus

A. vulpinus or the common thresher shark is a large migratory shark that is commonly found in the Adriatic; but also found all over the Mediterranean and the world (Finotto *et al.*, 2016). It is a coastal pelagic species included in the lamnoid sharks (Lyons & Lowe, 2013). Based on the time series data (Fig. 1), the overall majority of the landings of this species are as expected based on other scientific papers, in Italian waters. What is interesting about this species is that majority of the catches are noted to be juveniles with low weight and more often the catches of this species are due to by-catch (Finotto *et al.*, 2016). An explanation of this could be the primary prey of the species being sardines and anchovies, causing the risk for the species especially during the juvenile stage of life when they require the most energy (Finotto *et al.*, 2016). A possibility in the decrease in the species, noted by Baum and others (2003) to be as high as 80% just outside of the Mediterranean could be due to the catch and disorientation of these ram ventilator species that need to be constantly moving to survive. If the species is often caught in by-catch it is possible that the juveniles are suffering after being released, causing a risk to their survival. The reproduction of this species plays an important factor to their survival as well, since they only reproduce about one pup at a time (Gilmore, 1993).

Based on the results of Maxent and QGIS, *A. vulpinus* is mostly affected by primary productivity and temperature (Table 1, Fig. 3, Fig. 4). The future predictions of this species show that even with the RCP8.5, they are mildly effected by the future environmental factors. Even with this lack of environmental pressure on the population in the future, it is clear that the species is experiencing pressure from over fishing and exploitation based on the time series. Further proven by the classification of Vulnerable by the IUCN (ICUN 2020).

II) Centroscymus coelolepis

C. coelolepis, or known commonly as the Portuguese dogfish, is a deep-water squalid shark (Veríssimo *et al.*, 2003; Girard, M., & Du Buit, M.H., 1999). As the name suggests it is most often found in the waters surrounding Portugal and Spain. The species is mostly caught with deep water longlines and bottom trawls as by-catch, since the species is not highly sought out as a key commercial species (Clò *et al.*, 2002). Based on other scientific literature, there has been data on this species in the Mediterranean for a while, with a peak in population in 1996, however the results of the time series does not see any landings until the 2000's (Girard, M., & Du Buit, M.H., 1999) (Fig. 5).

The time series of this species does not give a lot of information on the species and in this case, using alternative methods of gaining insight on the population in the Mediterranean. The two countries that do indicate landings of this species are Portugal and France.

Looking at the Maxent and QGIS results it is clear that this species will not be thriving in the future based on the RCP8.5 predictions, with the majority of the map showing an average r = 0.25, especially in the western area of the Mediterranean (Fig. 8). If the two main countries that report information about this shark, according to Sea Around Us being France and Portugal, this future prediction is putting these fleets at a major risk for catching this species. Based on the literature, it seems that catching this species is not a priority and perhaps the major risk for this species it the environmental factors of their habitat. Based on the IUCN, this species is Near Threatened.

III) Carcharhinus plumbeus

C. plumbeus, the sandbar shark, is a bottom dwelling shark that prefers temperate and tropical waters (Dragicevic *et al.*, 2010). The species has not been known to dwell in the Adriatic Sea until recent years, the species is most commonly found in the southern part of the Mediterranean (Dragicevic *et al.*, 2010; Lipej *et al.*, 2008). The reproductive style of the sandbar shark is viviparous, with evidence that they may use the Adriatic Sea as a nursery (Dragicevic *et al.*, 2010) (*Table 17*) as well as a very low fecundity with reproduction happening every 2 years (Lipej *et al.*, 2008).

The time series of *C. plumbeus* shows that there is a consistent but relatively low landing of the species with the exception of one or two years. During these extremely higher than average landings, a longline was used, in this case by Spain (Fig. 9).

According to Maxent and QGIS the future of this species is mostly affected by temperature and primary productivity (Table 3) and based on the RCP8.5 prediction the species is relatively unaffected (Fig. 12). The map can show that there is a slight risk for the species in the Adriatic Sea with an r in the range of 0.50 – 0.25 northern in the Adriatic Sea. What should be noted about this species is the classification of Vulnerable by the IUCN. Within the Mediterranean, the only hypothesis based on the literature is if the Adriatic Sea is in fact a nursery for the species, in which case, the future poses to be problematic for this shark.

IV) Dalatias licha

D. licha, or the kitefin shark, is a deep-sea shark that is thought to be quite rare. It is most commonly found in the western basin of the Mediterranean and regardless of its size, is known to prey on smaller sharks (Navarro *et al.*, 2014). The benthic species is most often found in the water surrounding Turkey and Greece (Ergüden *et al.*, 2017). Unfortunately, it is often caught as by-catch by bottom trawls and deep-sea long lines (Ergüden *et al.*, 2017).

This is confirmed by the data from Sea Around Us as majority of the catches are through bottom trawls (Fig. 13). There is a differing result of the location of this species as most of the landings are reported from Algeria along with a few from Spain, Portugal, and France. It can be concluded that the species is found throughout the Mediterranean including Turkey.

From the Maxent results and the QGIS map, it can be seen that in the future the most important environmental variable is predicted to be temperature and primary productivity (Table 4). The prediction map for the future with the RCP8.5 parameters shows that in the area that has the most catches, the environment is less than optimal for the species to survive (Fig. 16). Near Turkey and Greece, where the scientific literature implies, they are most common, the environment is not as risky for the future. According to the IUCN red list, the kitefin shark is listed as Vulnerable. What can be taken from this data is that in the future the species is at risk due to environmental conditions, and to a lesser extent, by-catch.

V) Etmopterus spinax

E. spinax, the velvet lantern shark, differs greatly from the other shark species in this paper as it has the unique trait of bioluminescence. The deep-sea shark is the only deep-sea species in this paper that has this ability (Claes, J., & Mallefet, J., 2009). It is important to note that bioluminescence in this species is controlled by hormones, often used as a camouflage mechanism or even as a form of mating (Claes, J., & Mallefet, J., 2009).

Using the time series graph it can be seen that even though this species is a deep-sea fish, it is caught quite often and even increases over time (Fig. 17). According to Wiecaszek and others (2018), there is no clear evidence of any decrease in population to this species, however it can be seen from the data of Sea Around Us that there is. After 2010, there is a dramatic and consistent decrease in the landings of this shark.

On the Maxent and the QGIS map, the species is most effected by temperature and salinity (Table 5, Fig. 19). Both of these environmental factors play a direct role in the bioluminescence of the species since it is known that hormones can be effected by both temperature and salinity (Trivett *et al.*, 2001). The future of this species based on the QGIS map implies that the species is at risk living in an RCP8.5 predicted future (Fig. 20). Therefore, regardless of the lack of the interest in this species for consumption the risk to the survival is dependent on the changes of temperature and salinity. The IUCN red list shows this species is classified as Least Concern.

VI) Galeorhinus galeus

G. galeus, or the school shark, is a large species of shark found around the world. It is commonly found in tropical waters and is among the hound family (Bitalo *et al.*, 2015). This shark is also found in multiples areas of the Mediterranean from west to east.

Based on the data from Sea Around Us, the time series shows that there is a consistent landing rate of this species, apart from a couple years where there were reported catches from all over the Mediterranean including Turkey and Spain (Fig. 21).

The most important environmental variable to *G. galeus* is temperature and primary production according to the Maxent results (Table 6, Fig. 23). The QGIS map for this species of shark does not seem to have an optimal future based on the RCP8.5 predictions (Fig. 24). In this case, even though the shark can be found throughout the Mediterranean, the future predictions show that the whole Mediterranean for this species is not ideal. According to the IUCN red list is Vulnerable, this is likely due to the fact that all over the world the species is being targeted by fisheries.

VII) Heptranchias perlo

H. perlo, or the sharp nose seven gill shark, is an interesting species of shark as it belongs to the order Hexanchiformes which implies that there are more than the normal five gills for these sharks (Ferrando *et al.*, 2017). This species of shark is known to be a bottom dweller and also the group is considered to be a more primitive species of shark (Ferrando *et al.*, 2017; Başusta, N., 2016).

The benthic shark has a very low catch rate in the Mediterranean according to the data from Sea Around Us, until about 2008 when there is an increase in the catches only due to the fact that Algeria is no longer the only country reporting data for this species (Fig. 25).

The most important environmental factors that effect *H. perlo* based on Maxent and the future predictions are temperature and primary productivity (Table 7, Fig. 27, Fig. 28). Looking at the QGIS map, it is clear that the species is not too effected by the future RCP8.5 predictions (Fig. 28). Even though the species is not at a risk environmentally, the IUCN does classify the species as Near Threatened.

VIII) Isurus oxyrinchus

I. oxyrinchus, or the shortfin mako, is an extremely active species of shark found along coasts as well as in oceanic areas (Kabasakal, H., 2015). This species is often caught for both recreational purposes and commercial purposes, however they are also caught as by-catch due to the fact that their main prey is tuna and swordfish (Schrey, & Heist, 2003; Kabasakal, 2015). This species of shark is a Lamnoid like the great white shark and has a maximum of 9 pups per litter (Gilmore, R., 1993). Mako sharks are known for their ability to jump out of water, similar to when Great White sharks breach water and their control of internal body temperature allows them to activate muscles required for very powerful bursts of energy (Carey, & Teal, 1969).

According to the time series graph, the Sea Around Us data reports sightings of this shark in the western half of the Mediterranean, but according to Kabaskal (2015), the shortfin mako is also commonly found in Turkish waters (Fig. 29). It is very well known that Mako sharks are found all over the world, which implies that the Sea Around Us data is heavily dependent on which countries are reporting.

The Maxent and QGIS results for this species of shark imply that temperature is the most important environmental variable than any other one (Table 8, Fig. 31). Knowing that this species of shark utilizes its own internal temperature in order to effectively hunt than its dependency on temperature is obvious. The QGIS prediction of the future shows that the Mediterranean is more or less average for the mako (Fig. 32). In areas around the west it seems to show more of an environmental risk than on the east side. What is important about this prediction is that around the Greek islands and the Northern Adriatic, there are hints of red that can strongly affect the fishing efforts from these areas. The IUCN red list does classify this species as Endangered and this could be more due to anthropogenic forcing's in current times, rather than the environmental conditions of the future.

IX) Lamna nasus

L. nasus, or the porbeagle shark is another lamnoid shark in this paper. Along with the shortfin mako, these species can retain their body heat with the help of the retia mirabilia (Carey, & Teal, 1969). What is different about this lamnoid than the mako is the number of pups born per litter, usually between 2-4 pups (Gilmore, R., 1993; Francis, & Stevens, 2000). The porbeagle, according to some literature is not very common to be found in the Mediterranean, but is often sought after for their skin (Francis, & Stevens, 2000).

Looking at the time series graph it can be seen that, in fact, this species of shark is found a lot in the Mediterranean and also that the population of the species oscillates between the year (Fig. 33). The majority of the catches of this shark are from Italy and Malta and the overall trend of the species after the 1980s is declining in population.

Along with the other lamnoid, Maxent and QGIS shows that the most important environmental factor is temperature supported by both the percent contribution and the jackknife test (Table 9, Fig. 35). Different from the Mako shark, the future of this species on the map shows that it is completely green (r ~ 0.75), with the exception of the same areas around the Northern Adriatic and the Greek islands (Fig. 35). According to the IUCN red list, the species is classified as Vulnerable and since the future of this shark looks opportunistic, this classification may be due to exploitation.

X) Mustelus mustelus

M. mustelus, or the common smooth hound is the most abundant hound shark found in the Mediterranean (Saïdi, 2008). The species is found all over the world and is exploited for their meat (Rossouw *et al.*, 2016). The bottom dwelling sharks are often caught by demersal gillnets, subjected to trawls and longlines as by-catch and are often found in large groups (Saïdi *et al.*, 2008; Rossouw *et al.*, 2016). The common smooth hound is largely known for being highly exploited commercially.

The time series graph of this species shows that the species known to be found all over the world, is also found all over the Mediterranean (Fig. 37). The landing from Sea Around Us is reported from Spain to Turkey implying the species is able to survive in the multiple climates of the Mediterranean. The slight incline of the population is cut short in 2013-2014, however, there is not enough data to take this as a serious trend for the species and more date would be needed.

According to Maxent and the QGIS map, the most important environmental variable for this species is primary production followed by salinity, but temperature does seem to play an important role as well when looking at the permutation importance (Table 10, Fig. 39). The future RCP8.5

prediction for this species shows that there is an ecological risk to the species survival in the future. Majority of the map shows an r between 0.50 – 0.25 (Fig. 40). The species shows that in the future, other than the Northern Adriatic and around the Greek islands, the Mediterranean is not looking ideal. The IUCN red list labels this shark as Vulnerable, and with the information of the prediction as well as the high importance commercially, the future of this species is not optimistic.

XI) Oxynotus centrina

O. centrina, or the angular rough shark is a bottom dwelling shark that is not often caught because it is found up to depths of 700 meters and is not a very active shark (Koehller, 2018). The species is thought to be very rare, with little information about it due to the lack of landings.

The time series shows that there is an increase of this species around the beginning of the 60's, but still relatively low (Fig. 41). This connects to the same timeline that deep trawls were implemented in fisheries as a common way to fish (Kousteni, & Megalofonou, 2016). It is important to note that even within the literature about *O. centrina*, it is most commonly found around Greece and Turkey but the data reported is only from the western Mediterranean.

According to the Maxent data, the most important environmental variable for this species is temperature and primary productivity (Table 11, Fig. 43). Considering that this species is a bottom dweller that often feeds on smaller creatures and even shark egg sacks, it is clear that the angular rough shark is very much dependent on the activity around it (Fig. 44). The QGIS map shows that this species is only at a degree of risk in the eastern part of the Mediterranean and the Northern Adriatic. However, the species is classified as Vulnerable by the IUCN red list, and this means that with the information we have, the most likely cause of this is fishing efforts after deep sea lines were used.

XII) Prionace glauca

P. glauca or the blue shark, is one of the most abundant sharks in the world that is most often caught as by-catch as the result of long lines (Nykänen, M., 2018). This oceanic species is found all over the world and it is known in literature that the population of the blue shark in the

Mediterranean is declining (Megalofonou et al, 2009). In fact, the decrease of landing in the last 20 years is known to be about 38.5%, especially due to the fact that this species is heavily exploited by Italian fisheries with their 1200 fishing vessels (Megalofonou *et al.*, 2009).

Looking at the time series graph it can be seen that the species is not often caught, which is not in line with the literature about this species. The large peak in landings by longline does explain the mass amount of 4000 tonnes caught in one year (Fig. 45). It is important to note that with the data of Sea Around Us the overall trend of the blue shark is that it is increasing.

The Maxent data suggests that this species of shark is more affected by Temperature than any other external environmental factor (Table 12, Fig. 47). The QGIS map with the prediction of the future implies that there is more of a risk for the species spanning the entire Mediterranean, especially in the eastern part including the Adriatic Sea (Fig. 48). Since it is clear that there is a decline of Mediterranean blue sharks due to overfishing, the risk of the ecosystem in the future suggests that the blue shark is at a great risk. According to the ICUN, the blue shark is Near Threatened.

XIII) Squalus acanthias

S. acanthias, or the spiny dogfish is a squaloid species of shark that is distributed around the world, mostly on continental shelves (Veríssimo *et al.*, 2010). This species of shark is one of the most common deep-water sharks that is victim of by-catch of deep-water fishing efforts (Dunn *et al.*, 2013). They are thought to be an opportunistic predator even when temperature changes their preferred temperature is at the bottom (Dunn *et al.*, 2013).

On the time series graph, the species had a peak of landings in the mid-80's but has since decreased in population completely (Fig. 49). It is possible that due to the peak of catches in the few years that in fact, the species is remaining the same but there was an exception in landings since the Sea Around Us data did not lead to any other conclusions. Between the years in question and the other years that the catches were the same, there is no change in the amount of countries reporting on different methods of fishing styles.

The most important environmental variables for *S. acanthias* from the Maxent program are temperature and chlorophyll (Table 13, Fig. 51). It is important to note that this is one of the few species on the list that does not have primary productivity as a major influence, in fact is almost negligible to the species, along with salinity and phytoplankton. The QGIS map shows that based on the RCP8.5 predictions, the species is not pointedly affected and there are areas that are more effected than others (Fig. 52). These areas that are affected are however, the countries that reported landings to Sea Around Us; Turkey, Spain, and France. The ICUN does classify this species as Vulnerable and with the information collected it is clear that the species is both at risk of overfishing as well as environmental changes in the places that there are reported landings.

XIV) Scyliorhinus canicula

S. canicula, or the small spotted catshark is a specific species that rests on the bottom of the sea bed (Wearmouth *et al.*, 2103). According to Ligas and others (2013), *S. canicula* is among the most resilient sharks to external pressures. In fact, in the Mediterranean, this species of shark is part of the family Scyliorhinus and this family of sharks represent around 85% of the total biomass of demersal sharks (Ramírez-Amaro *et al.*, 2018).

Looking at the time series graph, it seems that the species of shark is increasing in population (Fig. 53). The dip in the end could be due to many factors that happen naturally to populations. Comparing the literature to the time series graph, it does raise the question of what countries are not reporting, since compared to the rest of the sharks in this paper, the landings are on the low side.

Looking at the Maxent results, it shows that one of the most important environmental factors for this species is temperature (Table 14, Fig. 55). Looking at the literature it does seem that temperature would be less important if the shark is one of the most resilient. According to the QGIS prediction map in the future the entire Mediterranean has become a riskier environment for the species (Fig. 56). Perhaps the temperature predictions of the future are changing at a pace that even for this resilient shark, there is an effect. For this shark though, the environmental change is the one that will affect it the most as the IUCN classifies this shark as Least Concern.

XV) Scyliorhinus stellaris

S. stellaris, along with *S. canicula* are both sharks of the family Scyliorhinus, commonly known as catsharks. *S. stellaris* being the greater spotted catshark or nursehound. This species differs from *S. canicula* in size, it is larger and usually is found in more shallow depths (Koehler *et al.*, 2018). The species is much less spotted than its family member *S. canicula* and this is evident in the time series.

The time series shows that there is no real occurrence of *S. stellaris* until after 2008, and even after this, the species is not very abundant (Fig. 57). The increase of landing is mainly due to Spain and France now reporting catches; however, literature suggests that they are found all over the Mediterranean.

Looking at the Maxent results it can be seen that *S. stellaris* has a dependence on temperature and chlorophyll (Table 15, Fig. 59). Knowing that this species is part of the same family as *S. canicula* and is significantly less abundant it makes sense that temperature and the addition of chlorophyll is important. The QGIS prediction map shows a much more drastic looking future for this species however (Fig. 60). The Mediterranean, in the eastern part, looks like a very unlikely to be suitable habitat for this species in the future. With only few areas in the Mediterranean where the habitat seems to have less risk, it is clear that the very rare species will decline in populations in the future. This is also reflected from the IUCN, as it is labelled as Near Threatened.

XVI) Sphyrna zygaena

S. zygaena, also known as the smooth hammerhead, is the only hammerhead within this paper. The smooth hammerhead is both a coastal and oceanic shark species that is often the victim of by-catch (Rosa *et al.*, 2017). They are often caught with longlines that are mostly used for catching swordfish (Santos, & Coelho, 2018). This species of shark is also already under the observation of the International Commission for the Conservation of Atlantic Tunas (Santos, & Coelho, 2018).

Looking at the time series, it is clear that majority of the catches are done for recreational purposes, and also that there is not a large amount of the species being caught (Fig. 61) with the exceptions of a few years where longlines were used. The shark is found mainly in the western part of the Mediterranean, with landings being reported by Malta, Spain, and Morocco.

According to the Maxent results, this species is most influenced by primary productivity and temperature to a lesser extent (*Table 17*, Fig. 63). Literature of this species of shark is very limited and the vulnerability to other factors is not well known, but it is known that the species may be at a greater risk of over exploitation from fisheries more than environmental factors (Santos, & Coelho, 2018). Looking at the future predictions of the species with the QGIS map, it can be seen that there are some areas of the Mediterranean that are not ideal for the hammerhead (Fig. 64). The future is not the worst outcome compared to other species in this paper. According to the IUCN this species is classified as Vulnerable. Most likely due to fishing efforts.

4.5 Fishing Efforts

If looking at shark populations time series without the factors of this paper, it is clear that there is an additional major factor in predicting the population of sharks in the future, fishing efforts. In Australia in a 15-year period, shark populations have gone down by 49% - 89%, in South Africa they have decreased by 27% - >99% in a 20-year period, all as a result of shark netting (Ferretti *et al.*, 2013). Fisheries can target sharks for many reasons, meat and skin and fins in recent years, *G. galues, L. nasus, and S. acanthias* are all hunted for their meat and this coincides with the results in this paper, *L. nasus and S. acanthias* are both showing declines based on the Sea Around Us data (Stevens *et al.*, 2000) (Fig. 33 and Fig. 49). Elasmobranchs have the K-selected lifestyle that only enforces the vulnerability of sharks in these environments (Abdulla, 2004). It has already been proven that short bursts of fishing activity in an area can strongly affect the population resistance of the species, calculated as an Intrinsic Rebound Potential (Ferretti *et al.*, 2013). Especially if you add in the fact that in the Mediterranean, elasmobranchs take up a majority of the by-catch from trawl fishing (Ligas *et al.*, 2013; Stevens *et al.*, 2000; Ferretti *et al.*, 2005; Pennino *et al.*, 2013). The Mediterranean also is known to have one of the oldest fishing efforts in the world (Ferretti *et al.*, 2005). Note that many of the sharks in this paper are said to be by-catch of trawls since style of fishing mostly effect the demersal species. It is not only the trawls that catch sharks unintendedly. *S. acanthias, Mustelus spp*., and *Scylorhinus spp*. are known to be caught on tuna longlines (Ferretti *et al.*, 2005). All three of these species show spikes in landings by using longlines based on the Sea Around Us data. Due to the use of these longlines, the Gulf of

Lion has been a hot spot of this style of fishing resulting in the decrease of oceanic species in this area now (Abdulla, 2004; Pennino *et al.*, 2013). This is also very clear from the results of *C. coelolepis, D. licha, S. acanthias*, and *S. stellaris*, all species that are exploited by France and shows risk for their future in this area (Fig. 8; Fig. 16; Fig. 52; Fig. 60). *E. spinax* and *S. canicula* are both deep-water sharks, however, S. canicula is said to be one of the most resistant shark species to fishing efforts, *E. spinax* is unfortunately not as resistant (Ligas *et al.*, 2013; Abdulla, 2004).

5. Conclusion

It is unfortunate that sharks have become a concern for many different associations in the past couple decades and their declining population has been largely unnoticed for many years (Ferretti *et al.*, 2005). As of the late 90's fishing fleets were reduced as a result of the Common Fishery Policy for the Mediterranean (Ligas, et al 2013). There is clearly a decreasing trend of some very vulnerable species sharks. *Dalatias. licha, Galeorhinus. galeus, Isurus oxyrinchus, Mustelus mustelus, Oxynotus centrina, Sqalus acanthias*, and *Scyliorhinus stellaris* are all of the sharks in this paper that have predictions that will not be in line with their optimal preferences and that are also on the IUCN red list as either vulnerable, near threatened, or endangered. Only *I. oxyrinchus, O. centrina* and *S. acanthias* are the species in this paper that show more risk for anthropogenic forcing's than environmental ones. However, it should be noted that even if the fishing efforts were to stop immediately, theses three species would still show great risk only based on environmental factors. Changes in environmental factors, for sharks, is detrimental for their future survival. Sharks have one of the most efficient olfactory systems known to apex predators in the world. This system affects their mating, foraging accuracy, behaviour, predator detection, and many others essential abilities (Dixson *et al.*, 2015). What can be seen from these results is that each shark is at risk in the future, either from fishing pressure or environmental pressures. Temperature and primary production effect more than just a habitat selection for elasmobranchs, they also effect the biochemistry of the species putting them at serious risk in the future after looking at how these factors effect their reproduction as one example.

There are many reasons why sharks are important, their economic value to fisheries, their ability to control ecological communities, their biological importance. There needs to be more pressure put on countries that can monitor the population of sharks in the Mediterranean. Of course, this task comes with many complications like requiring every country to follow the same policies, and of course because elasmobranchs are so migratory monitoring them is difficult (Stevens *et al.*, 2000). Sharks have had some attention in the past in terms of policy making, however, if there is to be any improvement in the future there will need to be more strict policies. In 2009, there was talk among the European Commission to aid in rebuilding the stocks of shark populations (Lauria *et al.*, 2015). There is even a Shark Specialist Group under the IUCN that looks at the sustainability of all elasmobranchs (Steven *et al.*, 2000).

Unlike what was initially thought to affect sharks the most, Lauria and others (2015), found depth (e.g. slope and rugosity) to be one of the most prioritized factors for habitat selections, with an optimal depth range being 200 – 300 meters and this should be taken into account for future studies. This thesis shows that many species are at risk based on the RCP8.5 scenario and this specific scenario is the most extreme of the projections, elasmobranchs are at a much greater risk than other marine species due to the additional fishing pressures. In order to protect and conserve the fish in the Mediterranean, efforts need to be made with respect to both climate change as well as, fishing activity. Future research should look more into how the changing biotic and abiotic factors will affect pup in the future to fully understand how climate change is altering essential abilities of these fish.

6. References

Finotto, L., Barausse, A., & Mazzoldi, C. (2016). In search of prey: the occurrence of Alopias vulpinus (Bonnaterre, 1788) in the northern Adriatic Sea and its interactions with fishery. *Acta Adriatica*, *57*(2), 295–304.

Lyons K. & Lowe C. (2013). Mechanisms of Material Transfer of Organchlorine Contaminants and Mercury in the Common Thresher Shark (Alopias Vulpinus). Canadian Journal of Fisheries and Aquatic Sciences. 70. 1667-1672.

Baum, J., Myers, R., Kehler, D., Worm, B., Harley, S., & Doherty, P. (2003). Collapse and conservation of shark populations in the Northwest Atlantic. *Science (New York, N.Y.)*, *299*(5605), 389–392.

Gilmore, R. (1993). Reproductive biology of lamnoid sharks. *Environmental Biology of Fishes*, *38*(1-3), 95–114.

Veríssimo, A., Mcdowell, J., & Graves, J. (2010). Global population structure of the spiny dogfish Squalus acanthias, a temperate shark with an antitropical distribution. *Molecular Ecology*, *19*(8), 1651–1662.

Veríssimo, A., Gordo, L., & Figueiredo, I. (2003). *Reproductive biology and embryonic development of Centroscymnus coelolepis in Portuguese mainland waters*. *60*(6), 1335–1341.

Clò S., Dalù M., Danovaro R., Vacchi M.. Segregation of the Mediterranean population of Centroscymnus coelolepis (Chondrichthyes: Squalidae): a description and survey, 2002 NAFO SCR Doc. 02/83. 3.

Girard M., Du Buit M.-H. Reproductive biology of two deep-water sharks from the British Isles, Centroscymnus coelolepis and Centrophorus squamosus (Chondrichthyes: Squalidae, Journal of the Marine Biological Association of the United Kingdom, 1999, vol. 79 (pg. 923-931)

Dragicevic, B., Dulcic, J., & Lipej, L. (2010). On the record of the sandbar shark Carcharhinus plumbeus Nardo, 1827 (Carcharhiniformes: Carcharhinidae) in the middle Adriatic Sea. *Acta Adriatica*, *51*(2).

LIPEJ, L., B. MAVRIČ, Z. DOBRAJC, C. CAPAPÉ. 2008. On the occurrence of the sandbar shark, Carcharhinus plumbeus (Chondrichthyes: Carcharhinidae) off the Slovenian coast (northern Adriatic). Acta Adriat., 49: 137-145

Navarro, J., López, L., Coll, M., Barría, C., & Sáez-Liante, R. (2014). Short- and long-term importance of small sharks in the diet of the rare deep-sea shark Dalatias licha. *Marine Biology*, *161*(7), 1697–1707.

Deniz Ergüden, Mustafa Çekiç, Sibel Alagöz Ergüden, Ayhan Altun, & Necdet Uyğur. (2017). Occurrence of adult female Kitefin shark Dalatias licha (Bonnaterre, 1788) in Iskenderun Bay (Eastern Mediterranean, Turkey). *Commagene Journal of Biology*, *1*(1), 60–62.

Claes, J., & Mallefet, J. (2009). Hormonal control of luminescence from lantern shark (Etmopterus spinax) photophores. *The Journal of Experimental Biology*, *212*(22), 3684–3692.

Więcaszek, B., Sobecka, E., Panicz, R., Keszka, S., Górecka, K., & Linowska, A. (2018). First record of the deep-water shark Etmopterus spinax (Chondrichthyes: Etmopteridae) from the southern Baltic Sea (Pomeranian Bay). *Oceanologia*, *60*(3), 426–430.

Trivett, M., Walker, T., Clement, J., Ho, P., Martin, T., & Danks, J. (2001). Effects of water temperature and salinity on parathyroid hormone-related protein in the circulation and tissues of elasmobranchs. *Comparative Biochemistry and Physiology, Part B*, *129*(2-3), 327–336.

Bitalo, D., Maduna, S., Da Silva, C., Roodt-Wilding, R., & Bester-van Der Merwe, A. (2015). Differential gene flow patterns for two commercially exploited shark species, tope (Galeorhinus galeus) and common smoothhound (Mustelus mustelus) along the south–west coast of South Africa. *Fisheries Research*, *172*, 190–196.

Ferrando, S., Gallus, L., Amaroli, A., Gambardella, C., Waryani, B., Di Blasi, D., & Vacchi, M. (2017). Gross anatomy and histology of the olfactory rosette of the shark Heptranchias perlo. (Report). *Zoology*, *122*, 27–37.

Başusta, N. (2016). New records of neonate and juvenile sharks (Heptranchias perlo, Squatina aculeata, Etmopterus spinax) from the North-eastern Mediterranean Sea. *Marine Biodiversity*, *46*(2), 525–527.

Kabasakal, H. (2015). *Occurrence of shortfin mako shark, Isurus oxyrinchus Rafinesque, 1810, off Turkey's coast*. *8*, n/a.

Schrey, A., & Heist, E. (2003). Microsatellite analysis of population structure in the shortfin mako (Isurus oxyrinchus). *Canadian Journal of Fisheries and Aquatic Sciences*, *60*(6), 670–675.

Gilmore, R. (1993). Reproductive biology of lamnoid sharks. *Environmental Biology of Fishes*, *38*(1-3), 95–114.

Carey, F., & Teal, J. (1969). Mako and porbeagle: Warm-bodied sharks. *Comparative Biochemistry and Physiology*, *28*(1), 199–204.

Francis, M., & Stevens, J. (2000). Reproduction, embryonic development, and growth of the porbeagle shark, Lamna nasus, in the southwest Pacific Ocean. *Fishery Bulletin*, *98*(1), 41–63.

Rossouw, C., Wintner, S., & Bester-Van Der Merwe, A. (2016). Assessing multiple paternity in three commercially exploited shark species: Mustelus mustelus, Carcharhinus obscurus and Sphyrna lewini. *Journal of Fish Biology*, *89*(2), 1125–1141.

Saïdi, B., Bradaï, M., & Bouaïn, A. (2008). Reproductive biology of the smooth-hound shark Mustelus mustelus (L.) in the Gulf of Gabès (south-central Mediterranean Sea. *Journal of Fish Biology*, *72*(6), 1343–1354.

Koehler, L. (2018). New records of angular rough sharks Oxynotus centrina in the coastal waters of Malta, with observations on post-capture resilience and release behaviour. *Journal of Fish Biology*, *92*(6), 2039–2044.

Kousteni, V., & Megalofonou, P. (2016). Observations on the biological traits of the rare shark Oxynotus centrina (Chondrichthyes: Oxynotidae) in the Hellenic Seas. *Journal of Fish Biology*, *89*(3), 1880–1888.

Nykänen, M., Jessopp, M., Doyle, T., Harman, L., Cañadas, A., Breen, P., … Rogan, E. (2018). Using tagging data and aerial surveys to incorporate availability bias in the abundance estimation of blue sharks (Prionace glauca). *PloS One*, *13*(9), e0203122.

Megalofonou, P., Damalas, D., & de Metrio, G. (2009). Biological characteristics of blue shark, Prionace glauca, in the Mediterranean Sea. *Journal of the Marine Biological Association of the United Kingdom*, *89*(6), 1233–1242.

Dunn, M., Stevens, D., Forman, J., & Connell, A. (2013). Trophic interactions and distribution of some Squaliforme sharks, including new diet descriptions for Deania calcea and Squalus acanthias. *PloS One*, *8*(3), e59938.

Veríssimo, A., Mcdowell, J., & Graves, J. (2010). Global population structure of the spiny dogfish Squalus acanthias, a temperate shark with an antitropical distribution. *Molecular Ecology*, *19*(8), 1651–1662.

Wearmouth, V., Southall, E., Morritt, D., & Sims, D. (2013). Identifying reproductive events using archival tags: egg-laying behaviour of the small spotted catshark Scyliorhinus canicula. (Report). *Journal of Fish Biology*, *82*.

Ligas, A., Osio, G. C., Sartor, P., Sbrana, M., & De Ranieri, S. (2013). Long-term trajectory of some elasmobranch species off the Tuscany coasts (NW Mediterranean) from 50 years of catch data. *Scientia Marina*, *77*(1), 119–127.

Ramírez-Amaro, S., Picornell, A., Arenas, M., Castro, J., Massutí, E., Ramon, M., & Terrasa, B. (2018). Contrasting evolutionary patterns in populations of demersal sharks throughout the western Mediterranean. *Marine Biology*, *165*(1), 1–16.

Koehler, L., Smith, L., & Nowell, G. (2018). Recovered and released - A novel approach to oviparous shark conservation. *Ocean and Coastal Management*, *154*, 178–185.

Rosa, D., Coelho, R., Fernandez-Carvalho, J., & Santos, M. (2017). Age and growth of the smooth hammerhead, Sphyrna zygaena, in the Atlantic Ocean: comparison with other hammerhead species. *Marine Biology Research*, *13*(3), 300–313.

Pang, P. K. T., Griffith, R. W., & Atz, J. W. (1977). Osmoregulation in Elasmobranchs. American Zoologist, 17(2), 365–377.

Heisler, N. (1988). Acid-Base Regulation. Physiology of Elasmobranch Fishes, 215–252.

Price, K., & Daiber, F. (1967). Osmotic Environments during Fetal Development of Dogfish, Mustelus canis (Mitchill) and Squalus acanthias Linnaeus, and Some Comparisons with Skates and Rays. *Physiological Zoology*, *40*(3), 248–260.

Tunnah, L., Mackellar, S., Barnett, D., Maccormack, T., Stehfest, K., Morash, A., … Currie, S. (2016). Physiological responses to hypersalinity correspond to nursery ground usage in two inshore shark species (Mustelus antarcticus and Galeorhinus galeus). *The Journal of Experimental Biology*, *219*(13), 2028–2038.

Dixson, D., Jennings, A., Atema, J., & Munday, P. (2015). *Odor tracking in sharks is reduced under future ocean acidification conditions. (Report)*. *21*(4), 1454–1462.

Lauria, V., Gristina, M., Attrill, M., Fiorentino, F., & Garofalo, G. (2015). Predictive habitat suitability models to aid conservation of elasmobranch diversity in the central Mediterranean Sea. *Scientific Reports*, *5*(1), 13245.

Schlaff, A., Heupel, M., & Simpfendorfer, C. (2014). Influence of environmental factors on shark and ray movement, behaviour and habitat use: a review. (Report). *Reviews in Fish Biology and Fisheries*, *24*(4), 1089–1103.

Abdulla, A. Status and conservation of sharks in the Mediterranean Sea. IUCN Technical Paper. 7p (2004).

Richardson, A., & Schoeman, D. (2004). Climate impact on plankton ecosystems in the Northeast Atlantic. *Science (New York, N.Y.)*, *305*(5690), 1609–1612.

Company, J., Puig, P., Sardà, F., Palanques, A., Latasa, M., Scharek, R., & Humphries, S. (2008). Climate Influence on Deep Sea Populations (Climate Influence on Deep Sea). *PLoS ONE*, *3*(1), e1431.

Brown, C., Fulton, E., Hobday, A., Matear, R., Possingham, H., Bulman, C., Christensen, V., Forrest, R., Gehrke, P., Gribble, N., Griffiths, S., Lozano-Montes, H., Martin, J., Metclaf, S., Okey, T., Watson, R., & Richardson, A. (2010). Effects of climate-driven primary production change on marine food webs: implications for fisheries and conservation. *Global Change Biology*, *16*(4), 1194–1212.

Ferretti, F., Osio, G., Jenkins, C., Rosenberg, A., & Lotze, H. (2013). Long-term change in a meso-predator community in response to prolonged and heterogeneous human impact. *Scientific Reports*, *3*(1), 1057.

Stevens, J., Bonfil, R., Dulvy, N., & Walker, P. (2000). *The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems*. *57*(3), 476–494.

Ferretti F., Myers R.A., Sartor P., Serena F. 2005. Long term dynamics of the chondrichthyan fish community in the upper Tyrrhenian Sea. ICES CM 25: 1-34.

Pennino, M., Muñoz, F., Conesa, D., López-Quílez, A., & Bellido, J. (2013). Modeling sensitive elasmobranch habitats. *Journal of Sea Research*, *83*, 209–218.

IUCN 2020. The IUCN Red List of Threatened Species. Version 2020-2. https://www.iucnredlist.org. Downloaded on 09 July 2020.

Rahav, E., Herut, B., Stambler, N., Bar-Zeev, E., Mulholland, M., & Berman-Frank, I. (2013). Uncoupling between dinitrogen fixation and primary productivity in the eastern Mediterranean Sea. *Journal of Geophysical Research: Biogeosciences*, *118*(1), 195–202.