Climate Variability Effects on Uruguayan Whitemouth Croaker and Striped Weakfish Fisheries

by

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B.Sc. in Biological Marine Science

Submitted in fulfilment of the requirements for the degree of

Master of Science (Research)

Deakin University

[February 2020]

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MASTER THESIS

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ANII AGENCIA NACIONAL DE INVESTIGACIÓN E INNOVACIÓN

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Table of Contents

Table of Figures.

Table of Tables.

Acronyms.

AAO-Antarctic Oscillation Index also known as Southern Hemisphere Annular Mode (SAM)

AMO-Atlantic multidecadal Oscillation

CCF- Cross correlation function

CPT- Captures per trip (captures divided trips)

CTMFM- from Spanish “Comisión Técnica Mixta de Frente Marítimo”.

DINARA-from Spanish “Dirección Nacional de Recursos Acuáticos”

ENSO- El Niño Southern Oscillation

FAO- Food and Agriculture Organization of united Nations

GAM- General Additive Model

GLM- General Linear Model

IPCC- Intergovernmental Panel on Climate Change

LM- Linear Model

ONI-Oceanic Niño Index

SAO- South Atlantic Ocean

SST- Sea Surface Temperature

SSTA- Sea Surface Temperature Anomalies

AUCFZ- Argentinian - Uruguayan Common Fishing Zone

1. Acknowledges.

To my supervisors: Walter Norbis, Robert Fagian and Victor Sposito. They guided me through the process of the thesis, they helped me to believe that the work was meaningful as well as they gave me tools to conclude it.

To the Institutions: ANII- National Research and Innovation Agency, DEAKIN University, UDELAR-University of Uruguay, FCIEN-Science University of Uruguay, DINARA-National Direction of Aquatic Resources, INA- National Institute of water (Argentina), INFOPESCA-Centre for information and advisory services on the commercialization of fishery products in Latin America and the Caribbean.

Thanks to ANII that support me with the grant that allowed me to do this thesis. DEAKIN formed me during the period, as a wonderful university in a wonderful city that is Melbourne. UDELAR and FCIEN gave me the support in Uruguay, and thanks to them I have my previous formation and excellent tutor. DINARA further than provide me information for my thesis they provide me a place to work. INA provide me with information of the Runoff crucial for my thesis as well as INFOPESCA did with fish prices.

To different people mostly of DINARA who helped me and provide me information that allow me the competition of this thesis. They are Oscar Gali, Miguel Rey, Jim Rookes (DEAKIN), Quique Paez, Carlos Mazza, Alfredo Pereira, Juan Borús, Marcelo Barreiro, Rodrigo Forsgedo, Laura Paesch, Gloria Da Silva, Oscar Pin, Gloria Scelza (INFOPESCA).

To all my family that always supported me and are always unconditionally there for me. Specially my parents, Graciela and Orlando. To my partner Victoria, that was there helping me during the process and support me in the bad period that I had. To all my friends, specially the new one that I made in Australia, that helped me a lot to complete this thesis. To the friends that have always been near me Magu, Maucho, Matu and Leo. And a lot more of friend and people that helped me that I can't enumerate them all.

2. Summary.

Worldwide fisheries are threatened by climate change, and fisheries of Uruguay do not escape from that reality. *Micropogonias furnieri* and *Cynoscion guatucupa* are the most landed and economically important fish species for this country. Therefore, this thesis is focused on the climatic drivers that affect the fishery of them. Their current habitat extends in the Atlantic Ocean from Brazil (approximately 34.00° South Latitude) to, and in, the "Río de la Plata" - a estuary formed by the confluence of the Uruguay River with the Atlantic Ocean (approximately 39.00° South Latitude).

To achieve the thesis aim, long-term data from 1982 to 2018 was compiled (when available), developed (when not available or not existing in an appropriate form) and then analysed. The climatic variables analysed included Sea Surface Temperatures (SST), Sea Surface Temperature Anomalies (SSTA) and different climatic indexes such as Oceanic Niño Index (ONI), Atlantic Multidecadal Oscillation (AMO), Antarctic Oscillation (AAO); and the runoff of "Río de la Plata". The fisheries variables were landing (named captures), natural mortality, and the number of vessels and their fishing trips. The economic variable analysed was fish market-price. To examine relationships between climatic variables and fishery landings, several methods were applied including trend analysis, autocorrelation and partial autocorrelation analysis, Wavelets Analysis and General Additive Models (GAM).

It is concluded that captures of the two species are being affected by the increase in SST and SSTA that occurred in the study area since 1997, and by other climatic indexes. Therefore, climate change impacts over these two species, are affecting, and will affect, industrial coastal fisheries that operate from Uruguay and Argentina in the study area.

Key words: *Micropogonias furnieri*, *Cynoscion guatucupa*, Siaenids, Sea Surface Temperatures (SST), "Río de la Plata".

3. Introduction.

Humankind's relationship with the sea has been one of the most significant driving forces in the development of humans since memory times. In a very long period, beginning with the time in which people first settled near or ventured into the sea, the motivation was mainly economic. Fishing, salt extraction and a lesser use of marine resources, together with the exchange of products were then the driving forces. Until the mid-eighteen centuries, all people who lived in coastal settlements, fishing villages, ports and coastal towns gained their livelihood, directly or indirectly, through an economic relationship. Since then, for several reasons, the traditional relationship has significantly expanded to include, in the early twenty-first century, economic, social, ecological, and environmental dimensions which are global in their implications (Williams, 2010; Clark, 2018).

The problems of over-fishing, pollution, and stock exhaustion, most notably in European and Atlantic waters, signal a new relationship between humankind and the sea - an ecological and environmental or 'green relationship' (Clover, 2004; Kurlansky, 2008). Large changes in fish stocks have occurred since the introduction of commercial fisheries (Jackson *et al*., 2001). Moreover, pelagic marines fish stocks sometimes exhibit sharp changes consistent with major *regime shifts* caused by modifications in key environmental, and linked, variables (Steele, 1998; Folke *et al*., 2004). Similar rapid and massive changes have also occurred in the freshwater ecosystems subject to sport fishing and the introduction of alien predators (Post et el., 2002).

The Food and Agriculture Organization of the United Nations (FAO) has repeatedly stated that guaranteeing the production of proteins to meet the needs of the present Earth's human population, and its projected growth in the medium-to-long-term, is essential (FAO, 2018; FAO, 2020). Projections related to climate variability and unfolding climatic change indicate, however, that significant potential shortages in food production will occur as well as likely declines in the natural ecosystems that provide vital services to our society (Allison *et al*., 2009; Hobday *et al*., 2016; Kellogg, 2019). It is crucial therefore to analyse how the production of food coming from different sources is being affected in the present and would be affected in the short-medium-and- long-term.

Two sciaenid species, *Micropogonias furnieri* (whitemouth croaker) and *Cynoscion guatucupa* (striped weakfish)*,* are the principal resources for the trawl coastal fisheries of the country of Uruguay, in South America. These two species are most consumed and exported in this country (DINARA, 2020; CTMFM, 2020).

The coastal region in Uruguay where these species have its habitat extends in the Atlantic Ocean from the boundaries with Brazil (approximately 34.00° South Latitude) to the "Río de la Plata" (a huge estuary formed by the confluence of the Uruguay and Parana Rivers with the Atlantic Ocean - in the coast of Argentina (approximately 39.00° South Latitude). This coastal region extends approximately 1200 kilometres of coastline (see study area in figure 5 in page 21).

Within the above context, the aim of this thesis is to examine the climatic drivers that affect the fishery of *Micropogonias furnieri* (whitemouth croaker) and *Cynoscion guatucupa* (striped weakfish*,* in the Atlantic Ocean/"Río de la Plata" coastal region.

Focusing on these species, relevant fisheries data and several climatic variables and market prices were analysed, to find relations between them. Long-term data from 1982 to 2018 was compiled (when available), developed (when was not available in a suitable form or existing) and then analysed. According to the specialised literature, many species of fishes are affected by changes in temperature (Pörtner and Peck, 2010; Pörtner and Peck, 2010; Perry *et al*., 2005; Tommasi *et al*., 2017). Therefore, several climatic variables were analysed in the thesis including SST, SSTA as well as different climatic indexes such as ONI, AMO, AAO; and the runoff of "Río de la Plata".

The fisheries variables considered were landing, natural mortality, and number of vessels and their fishing trips. The economic variable analysed was the fish market price.

Furthermore, to examine possible relationships between climatic variables and fishery landings, several methods were applied including trend analysis, autocorrelation and partial autocorrelation analysis, Wavelets Analysis and General Additive Models (GAM).

4. Literature review.

4.1. Climate change affecting marine resources.

Marine environments are affected by climate variability. All the creatures that live in the oceans are affected directly in a strong or low degree by climate variability (Hoegh-Guldberg and Bruno, 2010). It can then be safely assumed that changes in climate will impact all the biological marine communities to a higher or smaller degree. A *regime shift* will also have a major impact in all marine communities and could determine the collapse of a fishery (Folke *et al.,* 2004; Deyoung *et al*., 2008).

Now-a-days, most of the scientific community agrees that planet Earth is going through a warm period and that human activity is accelerating the natural cycle (IPCC, 2014; Cook *et al.*, 2016). Global warming is a major problem for most countries, especially those where their production systems depend on natural resources. This occurs because one of the main impacts of global warming is on ecosystems and their services, particularly on marine ones (Köster *et al*., 2003; Drinkwater *et al*., 2009; Drinkwater *et al*., 2010

The impacts of human activities over marine environments can be direct (by affecting fisheries, generating contamination, and impacting coastal infrastructures and buildings) or indirect -by contributing to the global warming- (Barbier, 2017). Both ocean warming and over-fishing act with synergetic effects in marine ecosystems (Möllmann and Diekmann, 2012). Therefore, in order to introduce adaptation actions to cope with unfolding climatic changes in fisheries, it is crucial to both examine the likely impacts and identify how fishing activities can be sustainable managed to reduce the risks.

The global increase of temperature in the atmosphere can impact directly in the oceans around the Earth by increasing their temperatures (Dufresne and Bony, 2008). Beside this impact, the increase in temperatures can create multiple cascade effects that can substantially change marine conditions. The changes can have a worldwide effect as well as local ones (Genner *et al*., 2017).

In their report, Genner *et al*. (2017) discuss different modifications in global climatic conditions, which have an impact over the biotic component of marine structures. These modifications are thermal change on sea water, ocean circulation changes, ocean acidification, dissolved oxygen changes, sea ice and sea level changes. Two major factors impacting the structure of marine communities are the type of fishing and climate variability (Hiddink and Ter HofStede, 2008). This means that to properly assess and manage a fishery both factors must be considered (Brander, 2003). A key point drawn from this is to predict, and be prepared for, the likely scenarios in which climate change could unfold in the future.

Understanding how climatic factors affect fisheries, in general, and their impacts on those species that suffer most pressure, in particular, is thus a fundamental knowledge for analysts, planners and decision-takers both in Governments and private industry. It is also a key knowledge for the millions whose livelihood substantially depends on fishing, especially for people in fishing villages in developing countries.

4.1.1. Sea Surface Temperatures in Uruguay.

The Uruguayan cost is an area that has the peculiarity of having the occurrence of three masses of water in a dynamic mixing. These water masses are subtropical waters of Brazilian current, cold waters of the Malvinas/Falkland current, and freshwater from the "Río de la Plata". This water structure creates high spatial and temporal variability in hydrographic parameters and primary productivity (Acha *et al*., 2004; Ortega and Martínez, 2007). This variability thus generates a mixed ecosystem that is characterized by high nutrient, rich waters, and high salinity changes over time. It is characterized also by the fact that the "Río de la Plata" is one of the biggest estuaries of the world and hence its impacts on the environment are significant (Acha *et al.,* 2008).

The patterns of sea surface temperature (SST) variability on seasonal and longer timescales result from a combination of atmospheric and oceanic processes (Deser *et al*., 2009). SST of the Uruguayan coastal zone have suffered a change moving from a cold climatic regime into a warm one in 1997 (Barros *et al*., 2005; Paesch *et al*., 2014; Martínez *et al*., 2017; Figure 1). Moreover, a time analysis of sea surface temperature anomalies (SSTA) (ranging from 1982 to 2013) shows a tendency of an increase of the positive anomalies (Martínez *et al*., 2017) - Figure 1. A significant increase has been also documented of the sea temperature on the Uruguayan coast, associated with the migration of the warm water front (20°C isotherm) that showed a progressively long-term poleward shift with a rate of ca. 9 km.yr−1 (Ortega, *et al*., 2016).

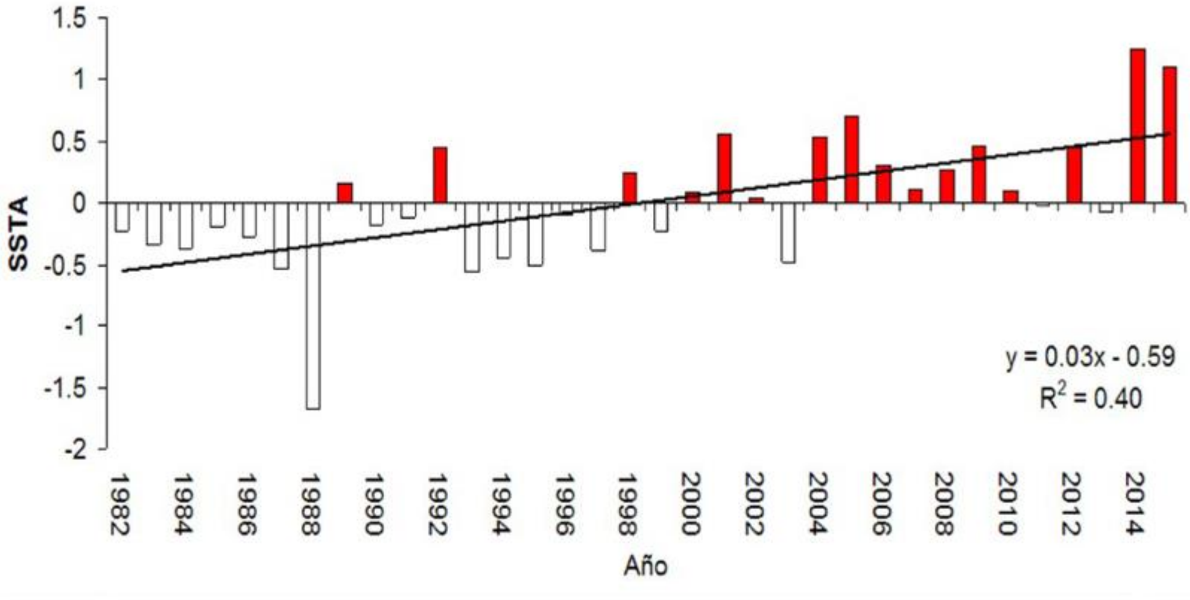


Figure 1. Sea Surface Temperature Anomalies (SSTA), showing the prevalence of positive anomalies since 1998. SSTA proceed from the region 31 S to 49 S of latitude and 40 W to 60 W of longitude.

Source of Figure and text: Martínez *et al*. (2017)

The effects of the increase of SST combined with the intensification of Brazilian current in the region have caused changes in the presence, distribution and abundance of many species of fish and invertebrates (Segura *et al*., 2008; Izzo *et al*., 2010; Milessi *et al*., 2013; Ortega, 2013; Milessi, 2018). Most extreme changes in SST in the coastal region of Uruguay are often accompanied by subsequent phenomena of mortality events, of different magnitude, of different species (Fabiano *et al*., 2013). In this manner SST changes that conditions the marine life in general (Pörtner and Peck, 2010), also conditions Uruguayan region marine life.

Another significant fact is that the predictions of SST for the Uruguayan coastal region shows that the tendency of increase in water temperature will continue (Tommasi *et al*., 2017). Under this scenario, it can be safely assumed that the fish communities of Uruguay will continue being affected as temperature is one of the main factors that regulate biological process (Pörtner *et al*., 2001). Many studies have shown that the population change of various fish species in different parts of the world are related to temperature changes (e.g. Jiao, 2009; Alheit, 2009; Deyoung *et al*., 2008).

4.1.2. Climatic indexes.

Fisheries activities and stocks of fish variability are strongly linked to climate and weather dynamics. Fish populations fluctuate at different time scales, from seasonal to centennial and longer (Lehodey *et al*., 2006). Many of these time scales are forced by atmospheric and climatic processes, consequently climate variability is a driver of changes in fisheries (Knights, 2003; Lehodey *et al*., 2006). For this reason, the understanding of oceanographic processes driven by low-frequency signals is important when analysing fisheries dynamics (Lehodey *et al*., 2006). Low-frequency signals, as reflected by indices tracking large-scale climate patterns.

A Climatic index is a value that can be used to describe the state and changes of a climatic system. The clime of a place is the average state of the atmosphere during a long period of time (Jiménez Quiroz,2011; Universität Hamburg, 2017). Climatic indexes allow us to perform statistical analysis like real time comparisons, thus getting means and identifying extreme values and tendencies (Jiménez Quiroz,2011; Hartmann, 2015; Universität Hamburg, 2017).
There is a wide variety of indicators which describes certain aspects of climate. Each of them is defined by an equation which include variables that have strong influence in the climate system. These variables can be atmospheric, such as temperature, pressure, solar radiation, and precipitation; or not atmospheric, such as SST or ice cover (Jiménez Quiroz,2011).

4.1.2.1. ONI index

The Oceanic Niño Index (ONI) is one of the most renown climatic indexes. This index is the main indicator for monitoring El Niño Southern Oscillation (ENSO) that is compound of two opposite phases called El Niño and La Niña (Philander, 1983).

The ONI index is a time series of SST anomalies calculated out measurements made in El Niño 3.4 region (5 ° N-5 ° S, 120-170 ° W). Data is obtained using mobile means method applied to periods of three months. There is a base period that covers data from 1986 to 2015. The temperature measures used to calculate the index belongs to the Extended Reconstructed Sea Surface Temperature database from the NOAA National Climatic Data Centre. The hot and cold episodes ("El Niño" and "La Niña") are defined when the anomaly is found above or below a threshold value (±0.5 ° C) for at least five consecutive periods (NOAA, 2020).

4.1.2.2. AMO index

The Atlantic Multidecadal Oscillation (AMO) describes the medium-term cycles in SST present in the North Atlantic Ocean. It depicts an oscillation where each warm and cold phase last from 20 to 40 years approximately (NOAA, 2020). AMO index oscillates into positive and negative phases during the last 150 years. The oscillation can be described as follows, an initial mainly positive phase from 1860 to 1900, continued by a negative phase until 1925, then a positive phase up to 1965, which is followed by a negative phase until 1995. Finally, a positive phase until today (Deser *et al*., 2010; Alheit *et al*., 2014). This oscillation influences precipitation and air temperature of almost all North America and Europe. For this reason, it has been associated with most of the intense hurricanes, droughts occurrence and changes in fish populations (Goldenberg *et al*., 2001; Jiménez Quiroz, 2011; Frajka-Williams *et al*., 2017). In some of the phases, it is also considered that it masks or exacerbates increase in temperature induced by global warming of anthropic origin (Trenberth, 2007).

4.1.2.3. AAO index

The Antarctic Oscillation (AAO) is represented by the mean sea-level pressure of the southern hemisphere, and is also associated to regression patterns of zonal wind, temperature, and geopotential height from the surface to the stratosphere (Fyfe *et al*., 1999). It is characterized mainly as a wind belt and low-pressure surrounding Antarctic which moves south or north (Australian Bureau of Meteorology, 2020). In its positive phase, the wind belt pushes the

Antarctic Circumpolar Current to get stronger and contracts towards the south (Thompson *et al*., 2011), while in its negative phase the belt moves toward the north. Winds associated with the positive AAO generally cause upwelling of deep circumpolar warm water along the continental shelf of the Antarctic (Hayakawa*et al*., 2012). This phenomenon has been linked to the melting of the basal ice shelf (Greene *et al*., 2017).

4.2. The Resource: Fisheries of *Micropogonias furnieri* and *Cynoscion guatucupa*.

The fish communities of the Uruguayan coast comprise at least 360 permanent or occasional species (Cousseau *et al*., 1998). Among these species, the sciaenids, whitemouth croaker (*Micropogonias furnieri*), striped weakfish (*Cynoscion guatucupa*) and argentine croaker (*Umbrina canosai)* are the most significant and abundant species (Norbis *et al*., 2006). The first two (Figure 2) are target species of the Uruguayan bottom trawls coastal fleet that operate in the "Río de la Plata" and Uruguayan coastal area (Norbis and Galli, 2013). They represent the major volume of fish landed by that fleet (Lorenzo, 2016; CTMFM, 2020). These species are not only important for the industrial fleet, but also for local self-employed fishermen (that use traditional fishing methods) because they are one of its main sources. (Norbis, 1995; Vasconcellos and Haimovici, 2006; Norbis and Galli, 2013).

Figure 2. The two principal fish sciaenid species whitemouth croaker (on the top), and striped weakfish on the bottom for Uruguayan bottom trawls coastal fleet (Source: Pescadores da Pedra do Ponta, 2018; INIDEP, 2018)

4.2.1. Micropogonias furnieri

The whitemouth croaker is a demersal benthic marine species that is widely distributed along the western Atlantic coast from Mexico (20ºN) to Argentina (41ºS) (Isaac, 1988). This wide distribution is due to the fact that this species is eurythermal, euryhaline and can adapt its habits in order to be reproductive fit (technique file in CTMFM, 2020). It is a multiple spawner that spawn in the inner zone of the "Río de la Plata" estuary, Uruguayan Atlantic coast and Coastal lagoons from October to March (Austral spring-summer) (Macchi *et al*., 1996; Vizziano, 2002; Macchi *et al*., 2003; Norbis and Verocai, 2005; Puig and Mesones, 2005; Jaureguizar *et al*., 2008). The young of the year (YOY) use as nursery ground the coastal areas, coastal lagoons and low areas of rivers that feed the estuary (Braverman, 2011; Haimovici and Cardoso, 2017; Santana *et al*., 2018).

The length of first maturity of this species for the period 1998-2013 was 30.7 cm for males, 34.7 cm for females and 32.2 cm for the total of individuals (Militelli and Macchi, 2016). During this period, the extractive pressure on the resource was increased steadily. The age of first maturity for the same period (1998-2013) was: 2.58 years for males, 3.2 for females and 2.86 for the total of individuals (Militelli and Macchi, 2016; CTMFM, 2020). *M. furnieri* partial fertility in December 2013 presented an average value of 201,666 (± 70,440) hydrated oocytes, corresponding to a range of sizes of individuals between 32 and 76 cm of total length. Partial fertility showed a potential relationship with height and linear with the weight and age of the individuals (Militelli and Macchi, 2016). Relative fecundity for *M. furnieri* in that period varied between 63 and 415 oocytes per gram of female (free of ovaries). Partial and relative fecundity present significant differences with the estimates made by Macchi *et al*. (2003) for the years 1995 and 1997 (Militelli and Macchi, 2016).

This is a longevous species; specimens of 45 years old have been found. In the first 4 years of life, specimens show an exponential growing face in which they reach 60% of their maximum size. The females tent to be bigger than the males (technique file in CTMFM, 2020). Whitemouth croker have generalist and opportunistic feeding habits that vary through its life period based on the size of the fish. Its diet is mostly based on benthonic invertebrates, crustaceans, and occasionally small fishes (Puig, 1986; Sardiña and Cazorla, 2005; Olsson *et al*., 2013; technique file in CTMFM, 2020).

In the study area of "Río de la Plata" between Argentina and Uruguay and its maritime front, two demographic units are identified, which are managed as a single population stock shared between Uruguay and Argentina. However, genetic and morphometric studies have found those two different population groups - one group associated with the "Río de la Plata" and the seafront and the other group would be located on the Atlantic coast of Uruguay (Márquez *et al*., 2012; D'Anatro *et al*., 2011; Galli and Norbis, 2013). The last group is also common in the southeast of Brazil (Haimovici *et al*., 2016).

M. furnieri is the most important demersal species in the Southwestern Atlantic fisheries (Haimovici and Cardoso, 2017) and is a resource exploited by Brazil, Uruguay, and Argentina. According to these authors, the catches of the southern and southeast regions of Brazil in some years (2011-2012) exceeded 30,000 tons. These volumes are similar to those landed annually by Argentina and Uruguay between 2004 to 2013 (DINARA, 2020).

The extraction in the three countries is carried out by industrial and artisanal vessels. In Uruguay, the fishing gear used by the industrial fleet is exclusively the bottom trawl operated by single boats or in pairs, while the artisanal fleet uses longline and gillnets (Norbis *et al*., 2006). The catches thus obtained make *M. furnieri* the second most important species in the landings of Uruguay, and in some years the most one (CTMFM, 2020).

4.2.2. Cynoscion guatucupa

The striped weakfish is a demersal bentho-pelagic fish found wide spreads in South American Atlantic waters. Its distribution starts in Río de Janeiro (22º54´S), Brazil, and extends to the northern Patagonia, Argentina (43ºS) (Menezes *et al*., 2003; Cousseau and Perrotta, 2004). The striped weakfish is a partial spawning species (Cassia, 1986; Macchi, 1998) that spawns in spring-summer in the oceanic and coastal area in front of Punta del Este (35º15’S – 54º50’W), Uruguay (Macchi, 1998; Militelli and Macchi, 2006).

The estimated length of first maturity of this species is 29.4 cm for males, 32 cm for females and 30.7 cm for the total of individuals (Lorenzo, 2009). Similar values were found by Militelli and Macchi (2006). The age of first maturity is: 2.5 years for males, 3.1 for females and 3 for the total of individuals (Lorenzo, 2009). Males presents a higher growth rate than females (11.9 and 10.7 cm / year respectively) indicated by the L50 / t50 ratio (Lorenzo, 2009; CTMFM, 2020).

This species presented an estimated partial fertility values for March 2000, and an average value of 78977 (± 15616) hydrated oocytes, corresponding to a size range between 33 and 47 cm LT (CTMFM, 2020). These values showed a potential relationship with height and linear with the weight of the individuals (CTMFM, 2020). The estimated relative fecundity varied between 37 and 276 oocytes per gram of female (free of ovaries). This variable does not show any trend in relation to the size of the spawners (CTMFM, 2020).

The recruitment of small juveniles happens in Spring and Summer in coastal waters shallower than 25 meters depth, moving in Autumn to deeper waters when they reach bigger sizes (Haimovici *et al*., 1996; de Miranda and Haimovici, 2007). When the Juveniles are between 2 and 3 years old, the main nursery ground that they frequent are the inner shelf of Uruguay and Southern Brazil (Haimovici *et al*., 1996; Haimovici and Cardoso, 2017).

In the Argentinian - Uruguayan Common Fishing Zone (AUCFZ) this species reaches a maximum age of 14 year old based on its otoliths analysis; however, 23 year old individuals have been found (Ruarte *et al*., 2000; Ruarte and Sáez, 2006; Lorenzo, 2009; CTMFM, 2018).

Young fishes of this species feed of zooplankton in the water column, shifting gradually the juveniles to a diet that includes fish and shrimp (Cordo, 1986; Martins, 2000; de Miranda and Haimovici, 2007; technique file in CTMFM, 2020). This species feeds mostly of fishes when it is an adult and it shows occasional cannibalism (Cordo, 1986; technique file in CTMFM, 2020).

C. guatucupa is a resource exploited by Brazil, Uruguay and Argentina. According to different authors (de Miranda and Haimovici, 2007; Sabadin *et al*., 2010; Haimovici and Cardoso, 2017) constitutes a single population that extends from Bahía Blanca in Argentina to Cabo de Santa

Marta (29 ° S) in southern Brazil. The striped weakfish has been fished in this area since the 1950s (de Miranda and Haimovici, 2007). In the early 1970s the annual commercial landings of it were under 5,000 tons. Then, after a rapid increase, landings oscillate between 20,000 and 48,000 tons. These catches come from gill-net and coastal bottom trawl fisheries in Southern Brazil and the coastal trawl fishery of Argentina and Uruguay (de Miranda and Haimovici, 2007).

In Uruguay, the landings of this species occupy the third place and it is considered the second most important species among the coastal demersal resources of the AUCFZ, after the whitemouth croaker. It is mostly captured by the industrial fleet through bottom trawls in the couple mode (Cordo, 1986; Nion, 1998). The area with the highest concentration of catches by the Uruguayan fleet is in the "Río de la Plata" region. Since 2014, it has been observed that Uruguayan Atlantic coastal region also represents more than a quarter of the catches (CTMFM, 2020).

4.2.1. Temperature Effects on habitat preferences and Natural Mortality of *M. furnieri* and *C. guatucupa*

M. furnieri and *C. guatucupa* have distinct spatial preferences for environmental factors and these preferences are the most important to determine its habitat differentiation (Jaureguizar *et al*., 2008, Norbis and Galli, 2013). The higher density of whitemouth croaker occurred at temperatures of 16 to 20ºC and salinity between 13.5 and 22.5 and striped weakfish typically displayed high density with a temperature between 12 and 18 ºC and salinity ranging from 28.9 and 33.1 (Lorenzo *et al.*, 2011). Also, there is an estimation of how the population of these two fishes are distributed based on the time that the trawler boats that target this species spend fishing in different areas (Horta and Defeo, 2012; Galli and Norbis 2016; Figure 3).

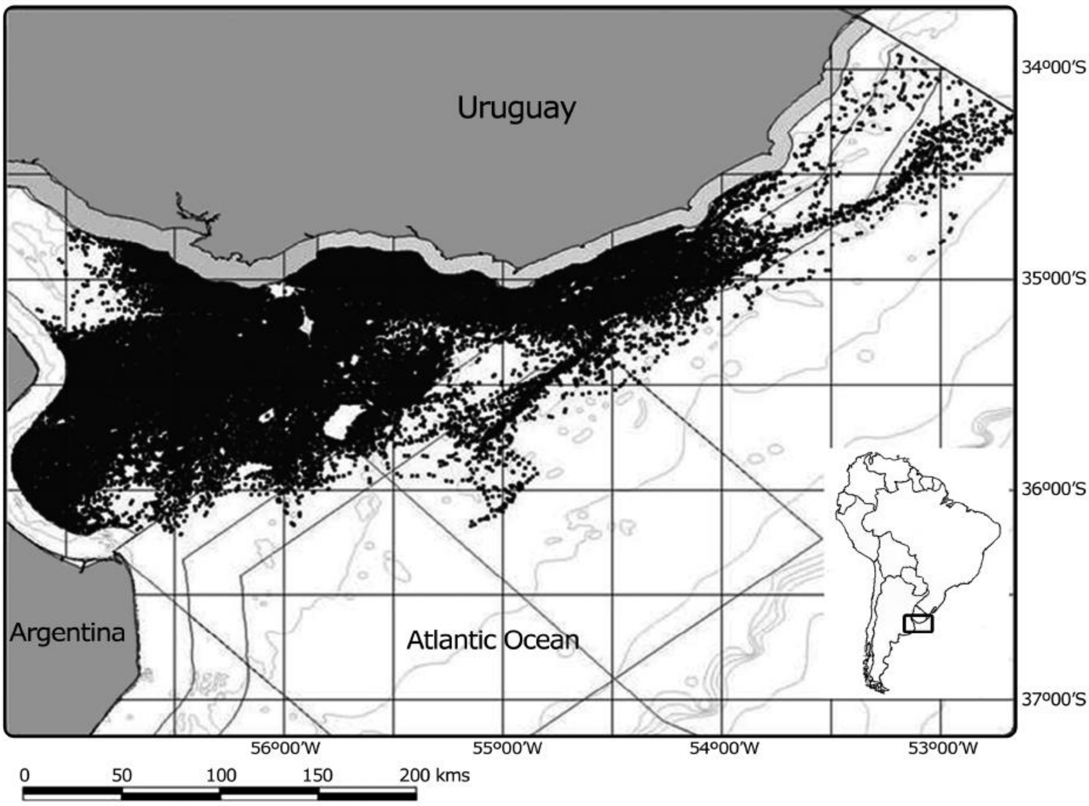


Figure 3. Spatial distribution of the Uruguayan coastal fleet activity along of the year.

Source of Figure and text: Galli and Norbis (2016)

Thermic regime in costal are fundamental to fish because most are ectotherms with physiologic process directly controlled by temperature of the ambient environment. (Isaak *et al*., 2012). The temperature strongly conditionate the distribution and abundance of individual species across many spatial and temporal scales (Pörtner and Peck, 2010). Temperature affects many physiological and development characteristics of fish (Pörtner and Peck, 2010; Griffiths and Harrod, 2007), being one of them natural mortality (Pauly, 1982). Natural mortality of fishes depends directly of sea temperature. The empirical equation of Pauly (1982) relates both parameters especially for fishes. The increase of SST by climate change can affect the natural mortality of different species including the focus species and the stock as presented by Griffiths and Harrod (2007).

4.3.Runoff: Rainfall in the region and its impact on the fish resources.

The spring-summer rainfall in the South American Atlantic is correlated with ENSO variability (Diaz *et al*., 1998; Montecinos *et al*., 2000). A positive trend in high rainfall levels and high river run-offs of the Paraná and Uruguay Rivers has been reported for the region (García and Vargas, 1998; Genta *et al*., 1998) correlated with negative South Oscillation Index years (El Niño). Increases in river discharge related to ENSO strongly influence salinity, turbidity, volume, and temperature of the "Río de la Plata" (Mechoso and Irivarren, 1992; Pisciottano *et al*., 1994; Nagy *et al*., 2002). In this sense, the increase of the flow rates (effect of "El Niño") and the decrease (effect of "La Niña"), displaces the turbidity front of the "Río de la Plata" and affects the distribution of the whitemouth croaker (Acha *et al*., 1999; Macchi *et al*., 2003; Puig and Mesones, 2005). Striped weakfish spawn inshore (depth <10 m) in marine Atlantic coastal waters of high bottom salinity (33-34 ups) and low temperatures (Militelli and Macchi, 2006; Jaureguizar *et al*., 2006; Jaureguizar and Guerrero, 2009).

The greater flows of Uruguay and Parana rivers generated by "El Niño" effect tend to unload along of the Uruguayan coast (Mechoso and Iribarren, 1992; Pisciottano *et al*., 1994; Nagy *et al*., 2002) affecting the distribution and availability of the analysed species. This relation has already been mentioned when *M. furnieri* and *C. guatucupa* biological aspects were presented. One of the remarkable life history aspects of this species is that their spawning of is strongly related with "Río de la Plata" runoff, being *M. furnieri* one in the convergence of salty and fresh water in the inner "Río de la Plata" and *C. guatucupa* at the strictly end of Rio the la Plata (Macchi *et al*., 1996; Macchi, 1998; Vizziano, 2002; Macchi *et al*., 2003; Norbis and Verocai, 2005; Puig and Mesones, 2005; Militelli and Macchi, 2006; Jaureguizar *et al*., 2008).

4.4. Uruguayan reality in fisheries

4.4.1. – Uruguayan fishery fleet composition, laws and regulations.

Fisheries in Uruguay are a traditional resource that has started covered in legislation in 1900 (Marín, 2016). Uruguayan licenses for the industrial fishing fleet are divided in four categories according the target species. These are category A = *Merluccius hubbsi* (Argentinian hake) and accompanying fauna, category B = *M. furnieri* and *C. guatucupa* and accompanying fauna, category C = other target species called "non-traditional" species and category D = vessels operating outside of national waters (law 19.175 of Uruguayan law, 2013). The Uruguayan industrial fishing fleet Category B is composed of 32 ships that work with the couple's trawl mode and 1 ship that works with a trawler network with doors. They are vessels with averages of 23 metres in total length, 129 gross register tonnage (GRT) and 415 horsepower (HP) (DINARA, 2020; CTMFM, 2020).

The fish stock of *Micropogonias furnieri* and *Cynoscion guatucupa* is a shared resource between Uruguay and Argentina, as these two countries share the "Río de la Plata" estuary and the so called AUCFZ – see Figure 4. The second one is a maritime area where Argentinian and Uruguayan fleet with the flag of any of these countries can fish ("Tratado del "Río de la Plata" y su Frente Marítimo" Uruguayan and Argentina collateral agreement – Vieira *et al*., 1973). For this reason, collateral commissions (CARP-from Spanish "Comisión Administradora del Río de la Plata", and CTMFM- from Spanish "Comisión Técnica Mixta de Frente Marítimo") work together joining work forces and interest of both countries to manage the resource (CTMFM, 2020). The amount of tones that each country can fish of each specie is fixed by CTMFM each year (CTMFM, 2020). The allowed fishing amount is calculated by applying Schaffer-Fox models (Lorenzo, 2016; CTMFM, 2020). Is important to consider that as the interdependency on both countries legislations of the resource, the measurements that aim to improve the resource must be taken in a long term frame, with compromise of both countries. This is the way of a measurement to be effective. Both species have been declared fully exploited (that is, the fishery remains closed to new vessels) and the management of the annual catch quotas is carried out jointly by both countries within the framework of the CTMFM (CTMFM, 2020). As well the fishing nets size are regulated, a minimum landing size for different species and zone of trawling exclusion are implemented, plus seasonal zone of exclusion depending mostly of spawning seasons (CTMFM, 2020).

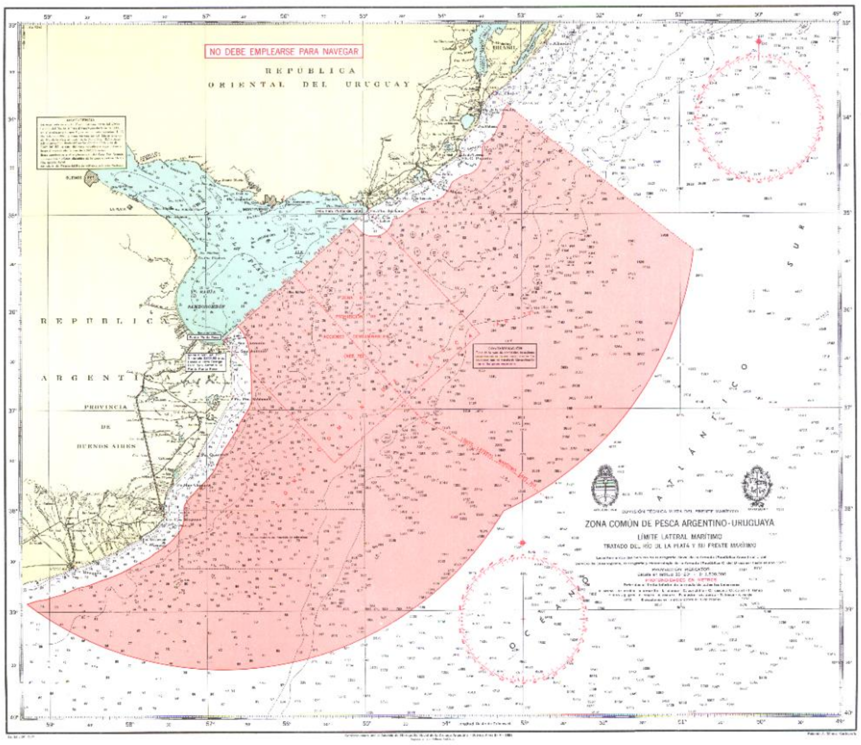


Figure 4. “Argentinian - Uruguayan Common Fishing Zone” AUCFZ Source of Figure: CTMFM – Comisión Técnica Mixta del Frente Marítimo

The consideration of an ecosystemic approach in fisheries began in the late 20 years and incorporated in the Uruguayan fisheries legislation in 2013 (law 19.175 of Uruguayan law, 2013). The ecosystem approach, which was finally included in the Fisheries Law, had as its initial framework in Uruguay, a project formulated and executed by DINARA-MGAP, which worked with different pilot sites (with "communities" or groups of artisanal fishermen from those sites) on the coast of the “Río de la Plata” and the Atlantic Ocean and in a reservoir of the Río Negro (e.g. Horta *et al*., 2013). The project design involved participatory co-management mechanisms for fishermen in proposing and making decisions. The project was called: “GEF-DINARA-FAOGCP / URU / 030 / GFF Pilot trial of an ecosystem approach to coastal fishing in Uruguay”. Since 2012 projects focused on helping in the mitigation of threatens that affect especially small-scale fisheries caused by Climatic Changes. Thought the Climate change have not been incorporated in the fishing law yet.

4.4.1. - Uruguayan fish market.

Uruguayan market is characterized by being small, because the population of the country is 3.449.299 habitants (Pellegrino and Calvo, 2020). This characteristic combined with the attribute that Uruguay is mainly sustained by primary production exportation makes the country economy dependent on international prices of commodities (Estrades and Terra, 2012). Fisheries in Uruguay do not escape to this reality agreed with the fact that internal market of fish is small. Fishes products for consumption are not a preferred item for Uruguayans, presenting small index of 6.5 kg/capita per year of fish consumption, compared with 77 kg/capita per year of meat (Bertullo, 1965; Etchebehere *et al*., 2018). These facts make the Uruguayan fishery dependent on international markets and international prices if the intervention of the government does not occur (Etchebehere *et al*., 2018).

The dependency of fisheries on market price can push the fishery towards the collapse as the increase of prices push the boundaries of resilience of the stocks (Roughgarden and Smith, 1996; Pascoe, 2006; Baeta *et al*., 2009; Tsikliras and Polymeros, 2014). On the other side the decrease of prices can lead to the diminish of fishing effort and landings (Pascoe, 2006). To analyse a fishery landing deeply is important to consider both the economic aspects and biological factors to get a holistic comprehension of it.

4.5. Global and Uruguayan context of fisheries.

Global fish stocks are under high pressure by fisheries (Bodiguel *et al*., 2009; FAO, 2018; Pauly and Zeller, 2019). In 2000, FAO estimated that 20 % of the global stocks are moderately exploited, 47 % are fully exploited, 18 % are over exploited and 10 % are under recuperation. (Payne and Bannister, 2003; Bodiguel *et al*., 2009). Currently, about 7.0 % of the total assessed stocks are underfished, 59.9 % of the stocks are maximally sustainably fished and 33.1 % of the stocks are over exploited (FAO, 2018). A remarkable fact is that climate change has been presented as a major threat for fisheries in FAO 2018 report (Pauly and Zeller, 2019). In this turbulent and delicate global context special attention must be given to the fisheries of *Micropogonias furnieri* and *Cynoscion guatucupa.* The risk of “the tragedy of commons” -

where the common resources are exploited to get self-benefit instead of plural and eco-systemic benefit (Lloyd, 1980; Hardin, 1998) - is clearly possible. The idea of self-benefit when exploding a resource must hence be considered carefully.

The exploitation status of fishery resources in Uruguay does not escape to the reality of global fisheries. When the history and current situation of industrial fisheries in Uruguay is analysed, three phases can be identified in the period 1975 and 2018. These phases correspond to the development or *expansion*, *maturity* and *decline* of the activity, according to the description of Etchebehere *et al*. (2018). Although the origin of industrial fishing dates back to 1940 (Etchebehere *et al*., 2018; Marín, 2016), the development phase for other authors (e.g., Gianelli and Defeo 2017), begins in 1975 with the implementation of the national fisheries plan. This phase extends until approximately 1981 where a maximum peak of catches and landings (147,000 tons) was reached. The maturity phase extends approximately until the year 1998 (17 years) and in this phase the total landings fluctuated between 90,000 and 144,000 tons. From 1999, the decay phase that remains until today is installed, registering a sustained and important decrease in industrial landings, which in 2015 were around 46,196 tons (Fishery Statistical Bulletin 2015 in DINARA, 2020). The last years of this phase of industrial fisheries were accompanied by further development of marine-coastal and inland artisanal fisheries. Other authors (Marin 2016, Gianelli and Defeo 2017) consider instead 4 phases that basically correspond to the previous ones, but introduce another phase separate an initial phase of slow growth from catches, from the next phase of accelerated growth.

Since its beginning, the industrial Uruguayan fishing fleet grew in number and size and in 2005 the maximum of 110 vessels was reached. This number includes all categories of fishing licenses present in Uruguay (A, B, C and D). Since then, there has been a constant decrease in numbers (Marín 2016). Between 1997 and 2013, the industrial sector registered only 65 vessels. In the fishery of *M. hubbsi*, this led to fishing effort reduction (Lorenzo and Defeo, 2015; Gianelli and Defeo, 2017). During the global financial crisis in 2009, there was a reduction in the demand of *M. hubbsi* from the European Union and the United States, which impacted the fleet that had the study species as targets (Lorenzo and Defeo, 2015; Gianelli and Defeo, 2017). Category B, on the other hand, remains stable throughout the period with around 30 vessels. Furthermore, since 1990 the coastal fishery has been closed with no more than 33 licenses approved (Decree No 115/018 of law 19.175 of Uruguayan law, 2013).

Given the decline in catches of global species and particularly the Argentinean hake (*M. hubbsi*), together with the closure in 2015 of one of the most important companies in the sector (FRIPUR SA), Marín (2016) locates the Uruguayan fishing system current in a collapse phase.In this context, the landings of *M. furnieri* and *C. guatucupa* - the dominant species in the industrial and artisanal coastal marine landings and analysed in this thesis - followed a similar evolution.

5. Justification.

Climatic factors are proven to affect fishes and fisheries (Lehodey et al., 2006). Observed and projected changes in climate, especially global warming, are considered major threats for fisheries all over the world (Tommasi *et al*., 2017). As mentioned, fisheries of *Micropogonias furnieri* and *Cynoscion guatucupa* are extremely important to Uruguay and the region (CTMFM, 2020). Moreover, these fisheries are completely exploited (or over exploited depending on authors) what make them extensively vulnerable to unfolding climatic changes (Vasconcellos and Haimovici, 2006; de Miranda and Haimovici, 2007; CTMFM, 2020).

Understanding the environmental socio-economic context is crucial to analyse how the fisheries of the two most important fish species for Uruguay - *Micropogonias furnieri* and *Cynoscion guatucupa* - could be affected by climate variability in order to manage them properly now and in the likely future. The generated knowledge about the environmental effects and their relationship with the two more important coastal species could assist in establishing suitable management measures. These will be mainly related to the regulation of fisheries based on likely climatic variations and focused on the vulnerability of the species to climate changes. The sustainable and resilient approach thus generated would enable the fisheries to cope with unfolding climatic pressures.

6. Hypothesis.

Climate variability is generating a change in the fishery captures of *Micropogonias furnieri* and *Cynoscion guatucupa* for the period of 1982 to 2018.

7. Research Aim.

Analyse how climate variability affects the fisheries of two Sciaenid species: whitemouth croaker (*Micropogonias furnieri*) and striped weakfish (*Cynoscion guatucupa*) in the “Río de la Plata” and Uruguayan ocean coast.

8. Specific objectives.

1) Analyse how the SST variability affect the fishery capture of the two targets coastal fishes species (*M. furnieri* and *C. guatucupa*) applying statistical models.
2) Analyse how the phenomenon of “El Niño” and “La Niña affect the availability of the two species using ONI index and runoff of “Río de la Plata”.
3) Analyse how other climatic indexes, such as AMO and AAO, affect the availability of the two focus species.
4) Analyse how SST variability affect the natural mortality of the two species.
5) Analyse if the fishery captures are driven by market prices of fish changes or by the climate variability.

9. Methodology.

9.1. Study Area.

The study area selected for the study extends from 34° S to 39° S, in the inner continental shelf (depth < 50 metres) of Uruguay and Argentina, covering approximately 160000 km^2 as shown in Figure 5. This area covers the middle and outer "Río de la Plata" and the coastal zone of the AUCFZ, area in which the Bottom Trawler Fleet can fish excepting the exclusive coastal zone of each country (CTMFM, 2020). To understand how the resource grows and develops in this coastal region, year time data of different variables and indexes were analysed.

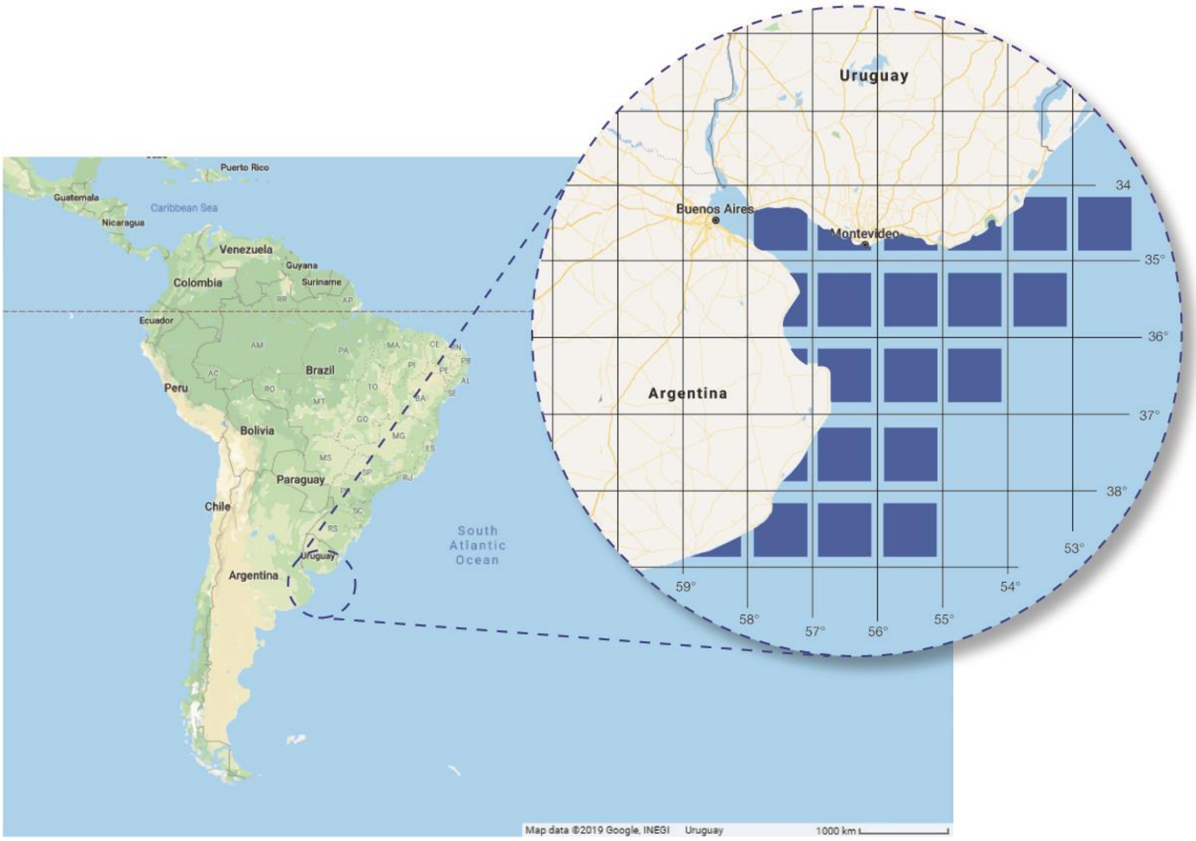


Figure 5. Selected study area, quadrangles of latitude and longitude are marked in blue. Base map extracted from Google Maps.

9.2. Climate.

9.2.1. Sea Surface Temperatures (SST).

SST from different quadrangles was downloaded from Columbia University wave page (https://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc/.Reyn_SmithOIv2/weekly/sst/datas-election .html) with an spatial resolution of 1 degree of latitude (~ 111 km) and longitude (~90 km varying a bit with the longitude). The area selected was from latitude 33.5 S to 39.5 S and longitude 52.5W to 60.5W in the web page. To cover all the AUCFZ. Then from this range the marine cost region that embedded the coastline of AUCFZ (share area for fishing between Argentina and Uruguay) to 50 meters depth was selected specifically. This area is related with the distribution of a stock of *M. furnieri* for fishery regulations (technique file in CTMFM, 2020). It includes the area of operation of the bottom trawling fleet, excepting the 7 miles where there is a restriction for the fleet. This distance varies from 5 miles to the east of "Isla de Flores" to the border of the country (Decree No 115/018 of law 19.175 of Uruguayan law, 2013 - Article 122).

Year time data was created from weekly SST data. Year averages and standard deviation from the weakly data for the period from 1982 to 2018 for each quadrangle were calculated. The minimum and maximum SST for each quadrangle for every year was also extracted and an annual average of minimum for all the area and the maximum for each year and quadrangle were calculated.

The annual sea surface temperature anomaly (SSTA) was calculated as the difference between the total mean temperature for the period (1982-2018) and the annual mean SST for each year. SSTA present the same spatial resolution of annual average SST as the data used to calculate it comes from the same area of study.

9.2.2. Climatic indexes.

ONI index was downloaded (https://ggweather.com/enso/oni.htm). ONI index is a 3-month index that encompass previous and following month of the month presented. To obtain an annual index an average was calculated that include twelve-month index starting from January of one year to January of the next, and called index ES-ONI. This was calculated for the time period between 1982 to 2018.

AMO and AAO index were downloaded from NOAA webpage (http://www.esrl.noaa.gov/psd/data/climateindices/list/). To obtain an annual index an average that included twelve-month index was made following the same procedure used in ONI index. When AAO index was over ±0.4 it was considered as a remarkable event.

9.3. Runoff Data.

The runoff from "Río de la Plata" was requested from INA- "Instituto Nacional del Agua" of Argentina. The data acquired was the daily average flow of three corridors of the basin that discharge to the estuary of "Río de la Plata". These corridors are Palmas, Guazú and Uruguay. The three corridors daily average was added to get the daily flow of the whole estuary of "Río de la Plata". This addition does not contemplate some small flows of tributary rivers (e.g. Rio Santa Lucia), but considering Berbery and Barros (2003) this is not significant compared the input of the ones already considered. The average daily flow of "Río de la Plata" was calculated in m^3/s per for each year.

9.4. Fisheries.

9.4.1. Captures Data

Captures of *Micropogonias furnieri* an *Cynoscion guatucupa* data were obtained from multiple sources. Captures of this species by the Uruguayan fishing fleet were mined from "INAPE Statistic Fishing Compendia 1992" for the period from 1982 to 1992. For the period 1993 to 1997, data was extracted from "INAPE Fishing Sectorial Inform 1997". For the period of 1998 to 2015, data of captures was extracted from different DINARA Statistic Bulletins (DINARA from Spanish, National Directorate of Aquatic Resources, ex INAPE). For the period of 2016 to 2018, data of captures was extracted from the webpage of CTMFM (2020).

The number of trips performed by the fleet and the amount of boats were obtained by personal communication from Miguel Rey (Sub-director of DINARA). As for this work, only the number of trips of the category B fleet that operated during the years analysed was available. Therefore, an index of catches per trip per year called Captures Per Trip (CPT Index) was built.

9.4.2. Fish market-price

Fish price of exports of *M. furnieri* and *C. guatucupa* were obtained for the period of 1981 to 1997 from the Statistic Bulletins published by DINARA (previously called INAPE) for each year. The market price taken for this period was an average of the average price of export to each country of the frozen full fish. For the period of 2002 and 2008, the price of the fish was extracted from the "Statistic Bulletin" published by DINARA using the medium Fob price. Same price was used for the time period of 1998, 2000 to 2001 and 2008 to 2019, but the data was provided by Carlos Maza, in charge of statistic area of DINARA. For the specific year of 1999 fish market prices were extracted from "Infopesca" Monthly Bulleting (the available months), and annual average from export prices to each country of the frozen full fish was created.

Fish market-prices were analysed to verify that changes in the captures were not caused by economic factors if not by populational factors (Tsikliras and Polymeros, 2014). Even market prices are not the only factors that drive a fishery they are important drivers and give a good idea of the demand of fish and also affect the stock and population dinamis of the resourse (Tsikliras and Polymeros, 2014).

9.4.3. Natural mortality of fishes

The estimation of natural mortality M is made through the Pauly`s (1982, fide at FISAT II program) empirical equation:

$$\log(M) = -0.0066 - 0.279 \log(L\infty) + 0.6543 \log(K) + 0.4634 \log(T)$$

where:

L∞(cm) = asymptotic length of the species measured in total length of the fish.

K (1/year) = the Von Bertalanffy growth constant.

T (ºC) = Mean annual habitat temperature.

Mean annual SST as the habitat temperature as bottom temperatures are not available.

L∞ and K for *Micropogonias furnieri* are taken from CTMFM (2020) that present the formula $Lt= L\infty e^{-k(t-to)}$ from Gulland (1969). The values obtained in that formula does not show statistical difference with the ones presented in Argentina by Salvador *et al*. (2015). L∞ and K for *Cynoscion guatucupa* were extracted from de Miranda and Haimovici (2007).

These values are L∞=56.25 and K=0.15 for *M. furnieri* and L∞=52.5 and K=0.28 for *C. guatucupa*.

9.5. Statistical analyses.

Multiple statistical analyses were undertaken to build a comprehensive picture of the situation of the two species in the study region and the functions of the relevant variables. All statistical analyses were performed in R (R, 2020).

First, there were performed different exploratory analysis, creating graphs and scatterplots of data. Z index (Zar, 1999) was calculated for the variables of SST, Runoff, Capture and price of both species using the following formula:

Z = (measurement – mean of the data series) / standard deviation of the data series.

This index has the advantage of being centred and standardized (non-scalar) giving us the possibility of compare tendencies between different variables measures at different scales.

9.5.1. Correlation of variables

To explore the relationships between the data, all the variables where correlated between each other, using Pearson correlation coefficient (Benesty *et al*., 2009). This graphic is presented in and appendix as the size of it made it not legible in A4 format. This analysis was made mainly for exploratory purpose.

9.5.2. Runs Test

For analysed if the data following a random trend or not, the runs test (Agin and Godbole, 1992; Koutras and Alexandrou, 1997) was carried. The variables analysed were average annual SST, SSTA, runoff of “Río de la Plata”, Number of trips, Number of trips from 1990 capture of *M. furnieri* and *C. guatucupa* and the standardized data of these last two variables, CPT index of *M. furnieri* and *C. guatucupa* and the standardized data of these last two variables and the Price of *M. furnieri* and *C. guatucupa.*

9.5.3. Autocorrelation and Partial Autocorrelation Analysis

An autocorrelation analysis and partial autocorrelation analysis (Bowerman and O'Connell, 1993; Dürre *et al*., 2015) for all the different variables: annual mean SST, SSTA, runoff of “Río de la Plata”, capture of *M. furnieri*, Capture of *C. guatucupa,* CPT of *M. furnieri* and CPT *C. guatucupa,* was carried out. This test was preformed to find if each measurement is dependant with the other years measurements or if they are independent.

9.5.4. Cross-correlation Analysis

Cross-correlation analysis (Olden and Neff, 2001) between the variables: capture of *M. furnieri* vs annual mean SST, capture of *C. guatucupa* vs annual mean SST, *M. furnieri* capture vs SSTA, *C. guatucupa* capture vs SSTA, SSTA vs ES-ONI, Runoff vs ES-ONI, *M. furnieri* capture vs runoff, *C. guatucupa* capture vs runoff, *M. furnieri* capture vs ES-ONI and *C. guatucupa* capture vs ES-ONI was carried out.

9.5.5. Wavelets

Wavelets are useful for the analysis of two time series. In this study wavelets were carried out to test and determinate the frequencies in which covariance between the time series is significant and the time persistence of this relationship (Torrence and Compo, 1998; Grinsted *et al*., 2004). This was done for the variables capture of *M. furnieri,* Z of capture of *M. furnieri,* CPT index of *M. furnieri,* Z of CPT index of *M. furnieri,* capture of *C. guatucupa,* Z of capture of *C. guatucupa,* CPT index of *C. guatucupa,* Z of CPT index of *C. guatucupa,* SST and Z of SST. In the wavelet analysis the area that is inside the cone of confidence is the only one that have statistical significance. Inside this cone, the areas that confidence can be analysed.

9.5.6. Statistical Models

A Linear model (LM) was performed to correlate the SST with the years to see if this was a tendency of increase. LM, General Linear Models (GLM) and General Additive Models (GAM) (Hastie and Tibshirani, 1987; Guisan *et al*., 2002; Venables and Dichmont, 2004; Zuur *et al*., 2009; Durbán, 2009) were run to find which variables had better description of the variables capture of *M. furnieri*, capture of *C. guatucupa,* CPT of *M. furnieri* and CPT *C. guatucupa.* Although a lot of models were run, only the ones that better fitted the variables were present, for this reason there is not a single GLM as the AIC of these models were not better than the GAM ones with the same variables (Zuur *et al*., 2009; Durbán, 2009). All statistical analysis were performed in R (R, 2020).

10. Results.

10.1. Climate.

10.1.1. Sea Surface Temperatures.

The SST of the selected study area of ZCPAU show an increase of the mean annual temperature for the period 1982-2018 (Figure 6). This linear tendency (y = 0,0474x-78.2438) was significant (p=1.116e-07 < 0.05) (Table 1) and the 58,2% of the increased of temperature was explained during the period of study. The run test based on the mean of this samples showed that the change on the tendency is not random (Table 2). There is also a tendency of increase of the mean maximum and mean minimum SST (Figures 7 and 8, table 2).

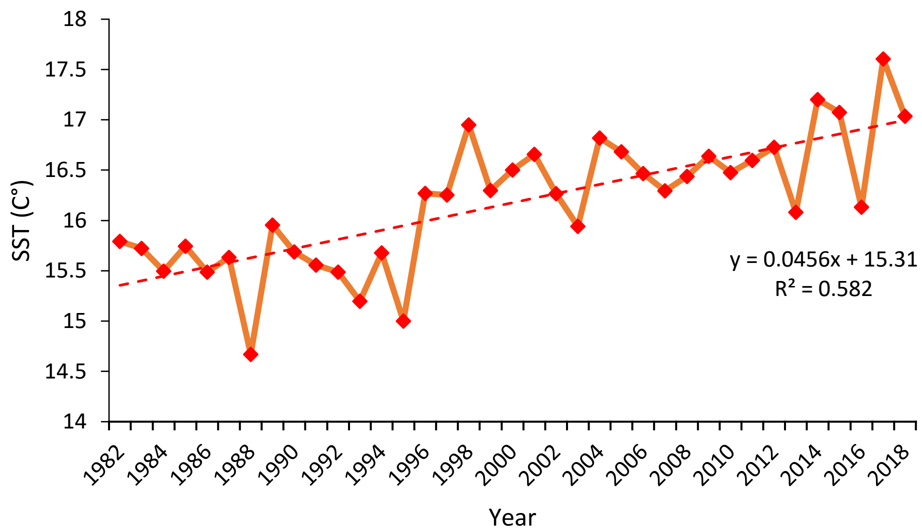


Figure 6. Annual mean Surface Temperature variation between 1982 to 2018 for the studied area.

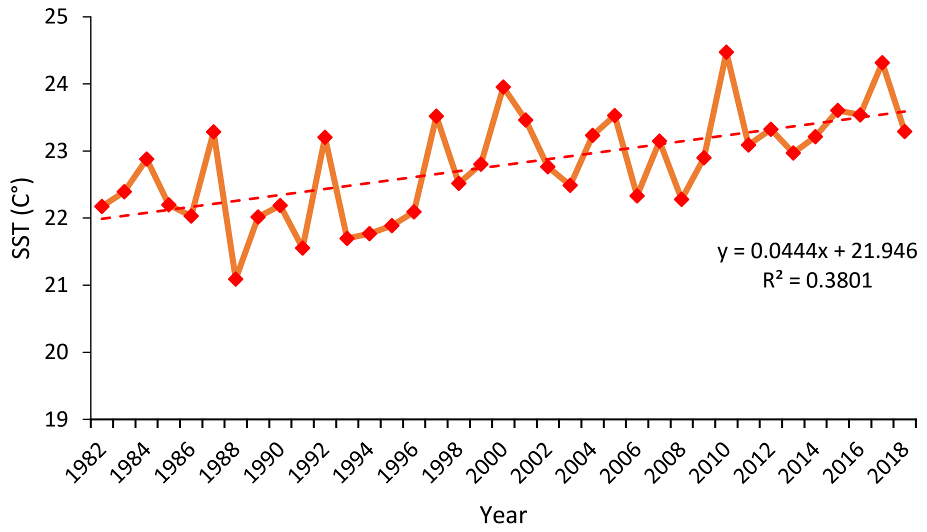


Figure 7. Annual mean maximum Surface Temperature variation between 1982 to 2018 for the studied area.

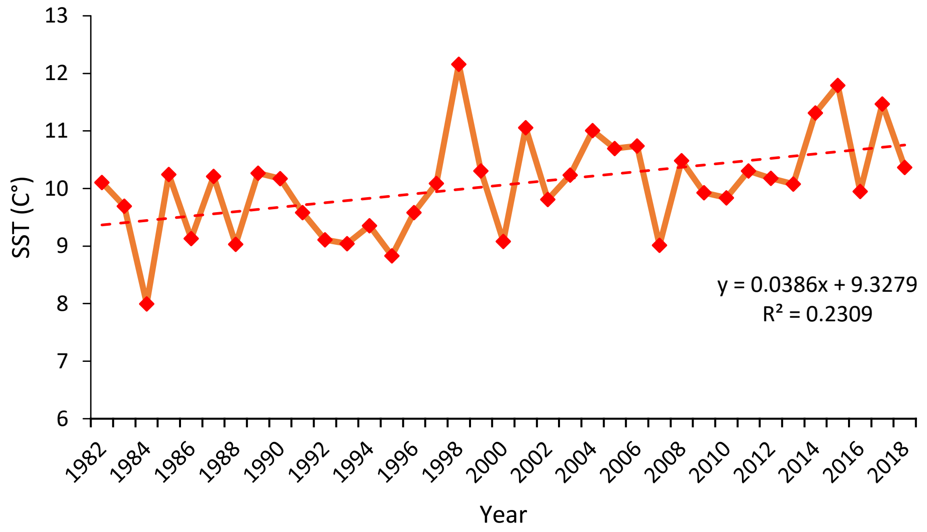


Figure 8. Annual mean minimum Surface Temperature variation between 1982 to 2018 for the studied area.

Table 1. Linear model that adjust Annual mean SST between 1982 to 2018 for the study area. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residuals:				
Min	1Q	Median	3Q	Max
-0.95918	-0.19923	0.03849	0.27934	0.86355

Residual standard error: 0.4242 on 35 degrees of freedom
Multiple R-squared: 0.582
F-statistic:

Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-75.0033	13.0621	-5.742	1.69E-06
Slope	0.0456	0.0065	6.981	4.05E-08 ***

48.73 on 1 and 35 DF
Adjusted R-squared: 0.57
p-value: 4.05E-08

The SSTA showed a prevalence of positive anomalies since 1996 and was found a regimen shift of the anomalies from that year (Figure 9). The run test for SSTA show that this tendency is not random (Table2).

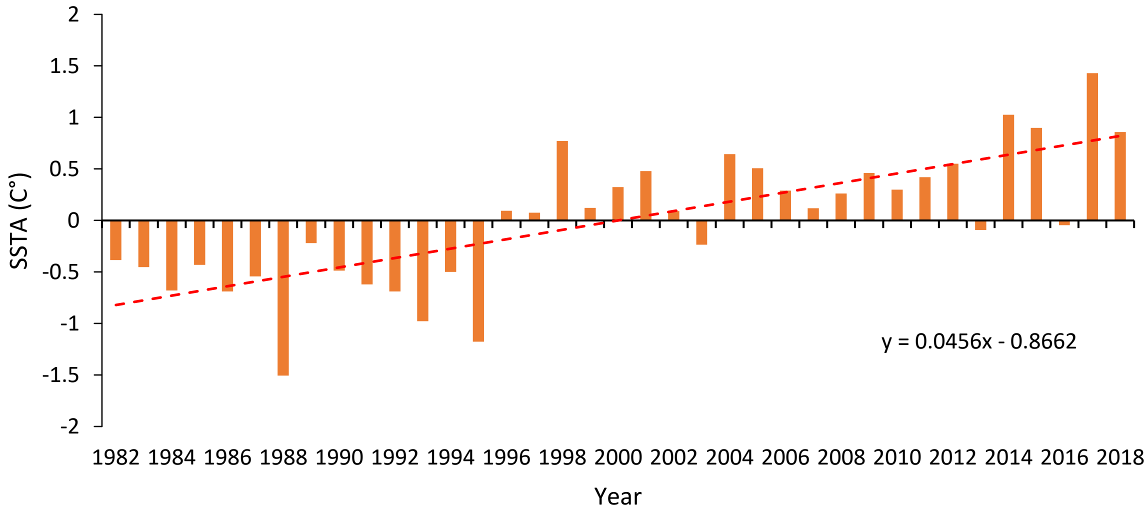


Figure 9. Standardized Surface Temperature Anomalies (SSTA) between 1982 to 2018 for the studied area, showed a prevalence of positive anomalies since 1996.

10.1.2.Climatic indexes.

The ES-ONI is shown in figure 10. When the value is superior to 0.5, a prevalence of "El Niño" can be appreciated during the year, while when the value is inferior to -0.5, a prevalence of "La Niña" can be appreciated. Values between 0 and 0.5 show some influence of "El Niño" and values between 0 and -0.5 are vice-versa for la "La Niña". The years when the ONI index presented positive values are 1982, 1983, 1987, 1991, 1992, 1997, 2002, 2015 and 2016. The negative years are 1985, 1988, 1989, 1996, 1999, 2000, 2008 and 2011.

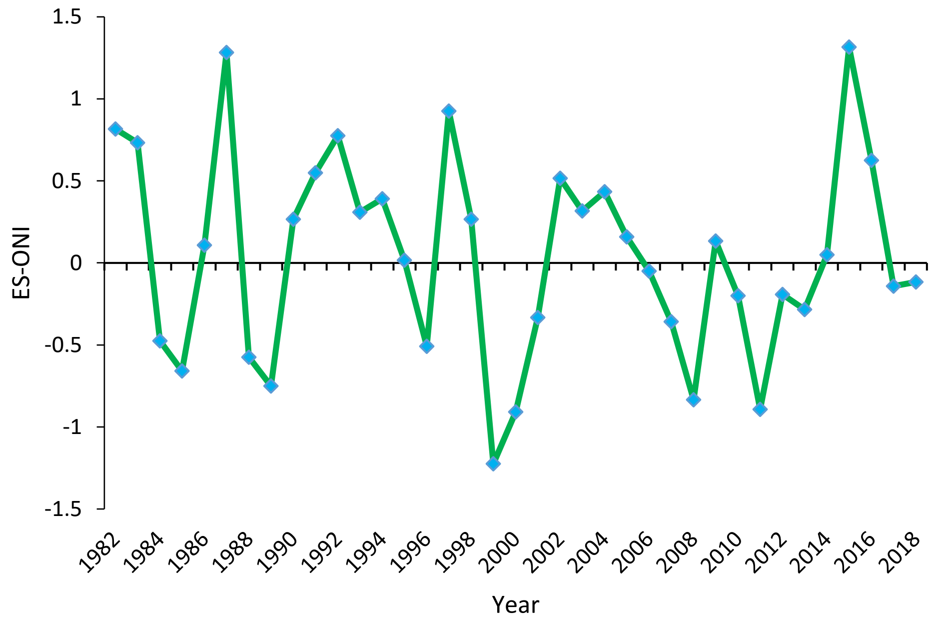


Figure 10. Annual estimator created from ONI index (ES-ONI) for that year. Period shown from 1981 to 2018.

The ES-AMO is presented in Figure 11. This index shows a mainly negative phase between 1982 and 1996 (excluding two events on 1987 and 1995). After this period, it changes abruptly into positive periods. The start of this positive phase can vary between 1995 and 1997; although what appear to be clear is the regime change after that period to the date. This positive phase is characterized by 3 peaks (bigger than 0.3) present on 1998, 2010 and the last one that last two year from 2016 and 2017. There is a fourth peak not as strong as the others in 2005, occurring in a period of relatively high years compared with the media (Figure 11).

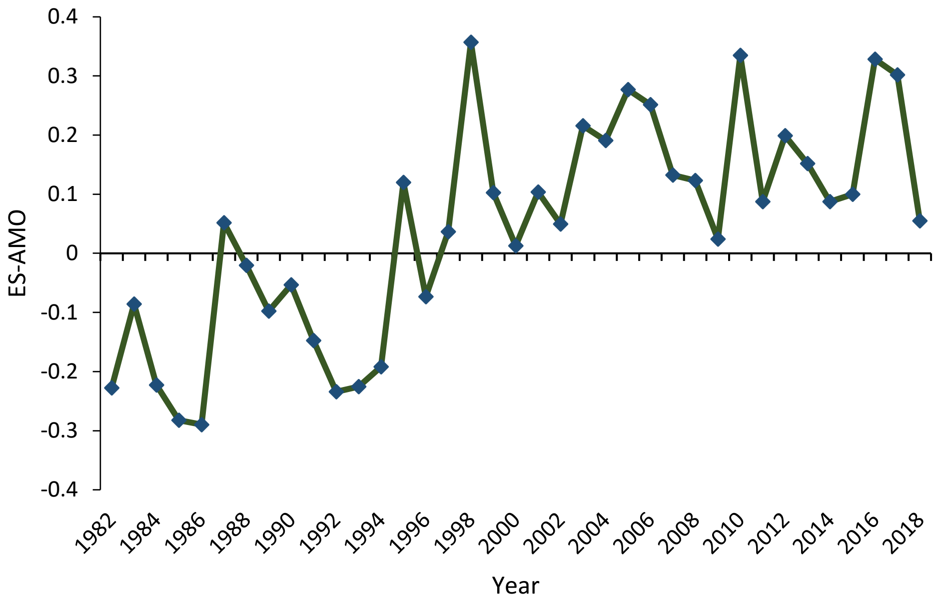


Figure 11. Annual estimator created from AMO index (ES-AMO) for the period of 1981 to 2018.

The ES-AAO (also called SAM, Southern Hemisphere Annular Mode) in shown in Figure 12. The year in which the AAO index presented positive values (superiors to 0.40) are 1985, 1989, 1993, 1998, 1999, 2008, 2010, 2015, 2016, 2017 and 2018. And the negative ones (inferior to -0.40) are 1991, 1992, 2002 and 2007.

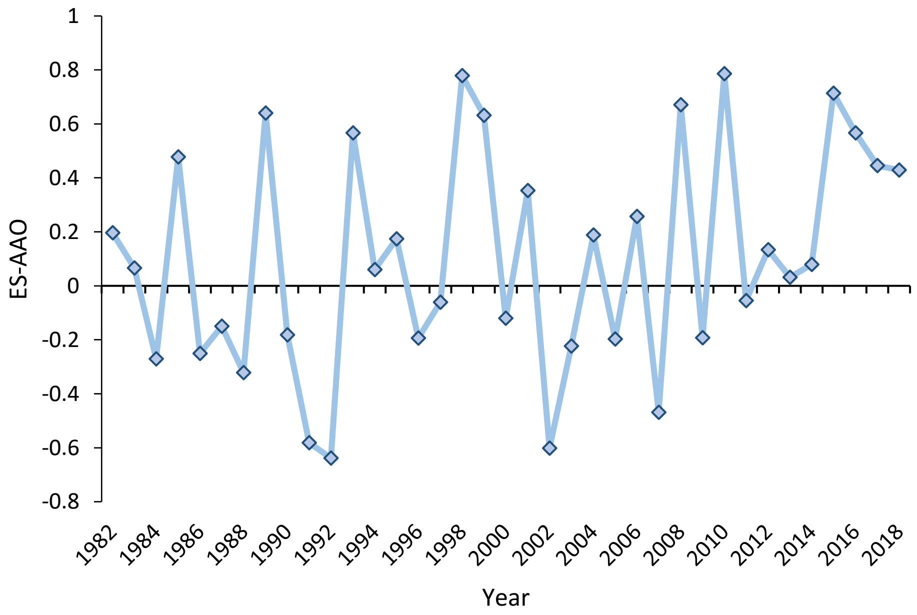


Figure 12. Annual estimator created from AAO index (ES-AAO) for the period of 1981 to 2018.

10.2. Runoff data.

The runoff of "Río de la Plata" during 1982 to 2018 is ranged from a Min = 16433 to Max = 57432 m^3/s (Figure 13). There are four marked events of high runoff, the two biggest ones on the years 1983 and 1998, follow other two 2016 and 1992. The average runoff for this period is 26744 m^3/s; whilst the Annual Runoff is correlated with ES-ONI.

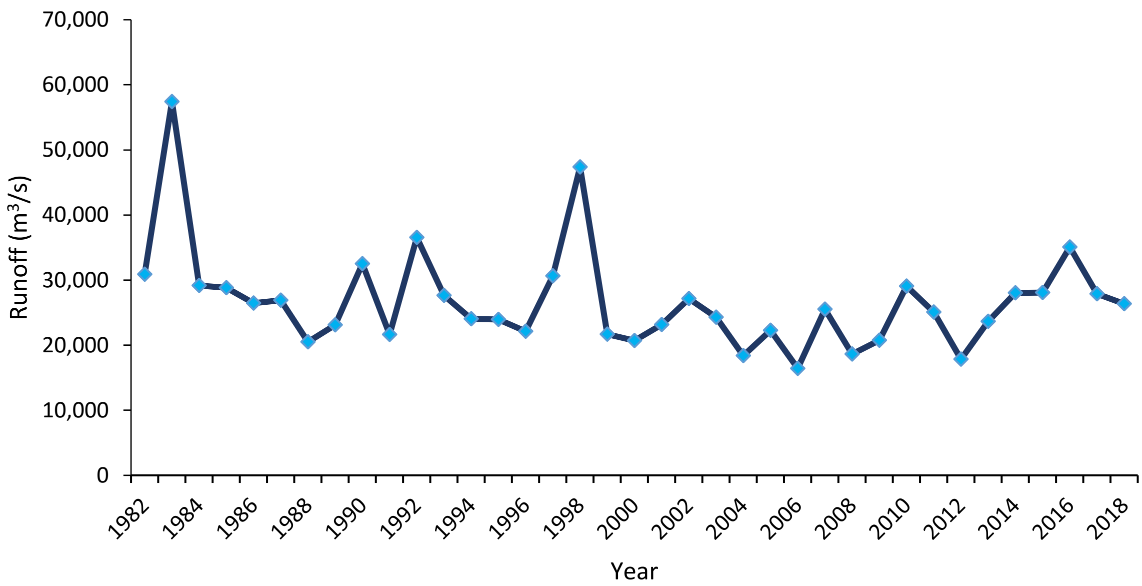


Figure 13. Annual Runoff of "Río de la Plata" for the period of 1981 to 2018.

10.3. Fisheries.

10.3.1.Captures Data

Captures of *M. furnieri* during the period of study presented a minimum of 11177 tons in 2013 and a maximum of 29928 tons in 2006 (Figure 14). This variable showed a non-random tendency (Table 1) and was found that there is a tendency of decrease compared to the mean from 2006 to the date.

The CPT index of *M. furnieri* during the period of study presented a minimum of 13.944 tons/trip in 2010 and a maximum of 29.661 tons/trip in 2006 (figure 14 This variable showed a non-random tendency (Table 1) and was found that there is a tendency of decrease compared to the mean from 2006 to the date. It can be appreciated that CPT and captures of *M. furnieri* varies in a similar way during the period of study excepting some punctual years.

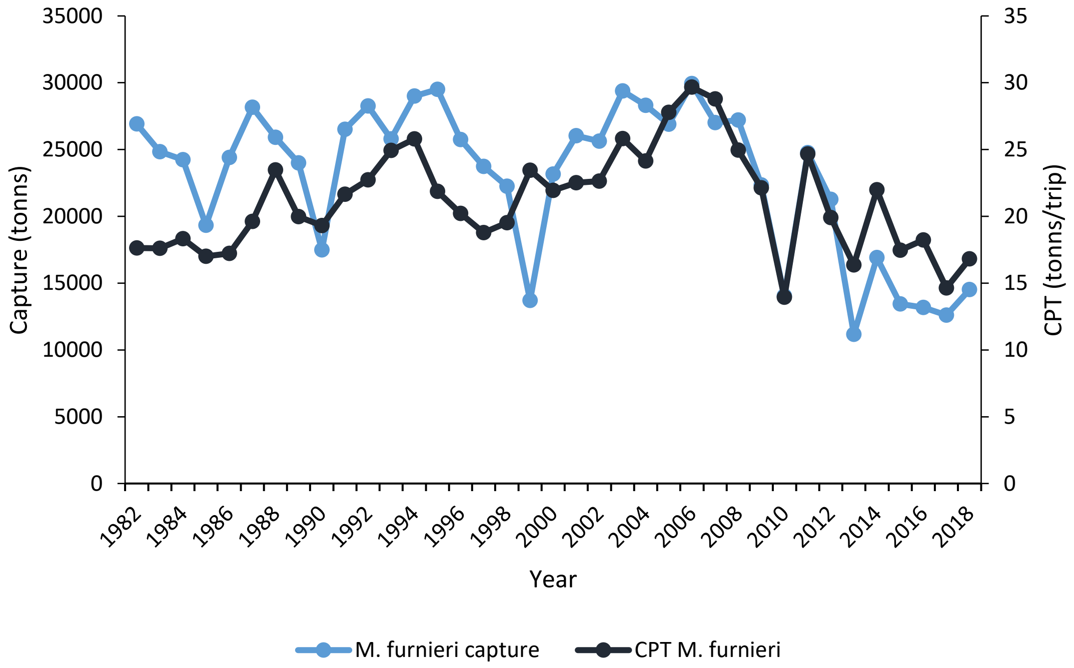


Figure 14. Captures and CPT index of *M. furnieri* for the period 1982 to 2018.

Captures of *C. guatucupa* during the period of study presented a minimum of 3187 tons in 2015 and maximum of 15285 tons in 1998 (figure 15). The tendency is random distributed along the period however you can see that from 1998 or 2001 values tend to decrease, excluding a rise between 2004 and 2009, and continue decreasing to the date (figure 15).

The CPT index of *C. guatucupa* during the period of study presented a minimum of 4.139 tons/trip in 2015 and a maximum of 14.522 tons/trip in 1999 (figure 15). The tendency is not random distributed (Table 1) and you can see that from 1998 values tend to decrease, excluding a rise between 2004 and 2009, and continue decreasing to the date. It can be appreciated that CPT and captures of *C. guatucupa* varies in a similar way during the period of study excepting some punctual years.

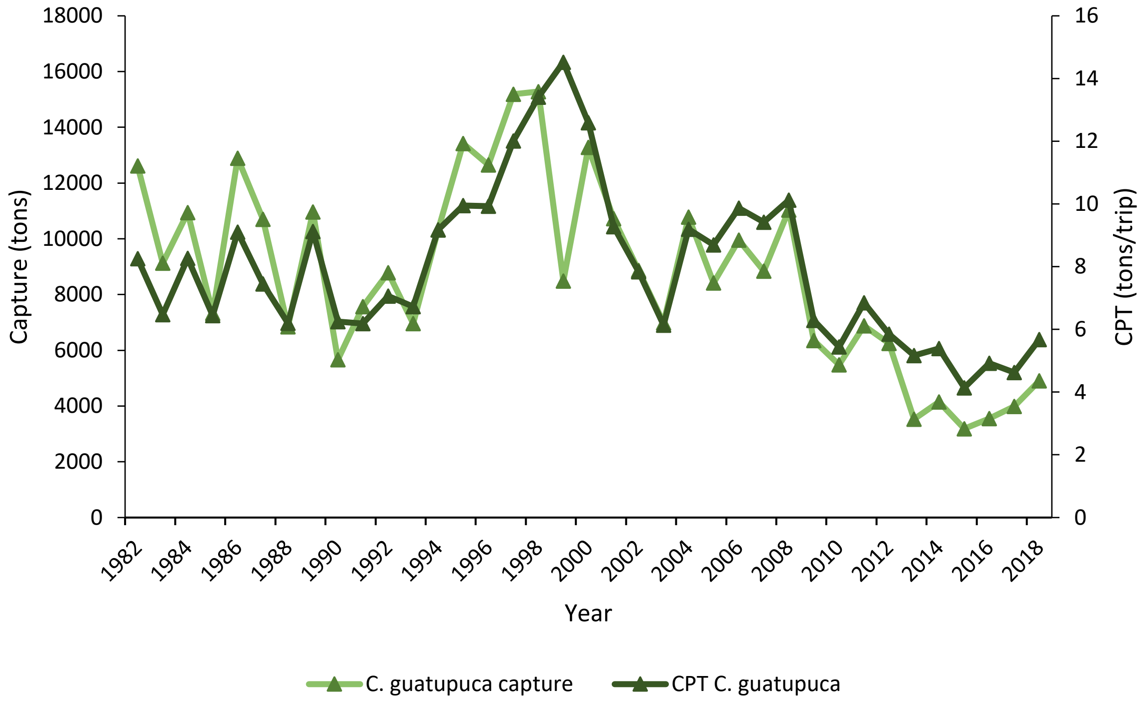


Figure 15. Captures and CPT index *C. guatucupa* for the period 1982 to 2018.

10.3.2.Fish price

The analysis of the fish export price of *M. furnieri* and *C. guatucupa* does not show a random tendency over time (Table 2). Prices also show a tendency of increase during the period of 1982 to 2018 (Figure 16). Prices of *M. furnieri* are negatively correlated with the captures of *M. furnieri* (Figure 17, Appendix 1). Prices of *C. guatucupa* are negatively correlated with the captures of *C. guatucupa* (Figure 18, Appendix 1).

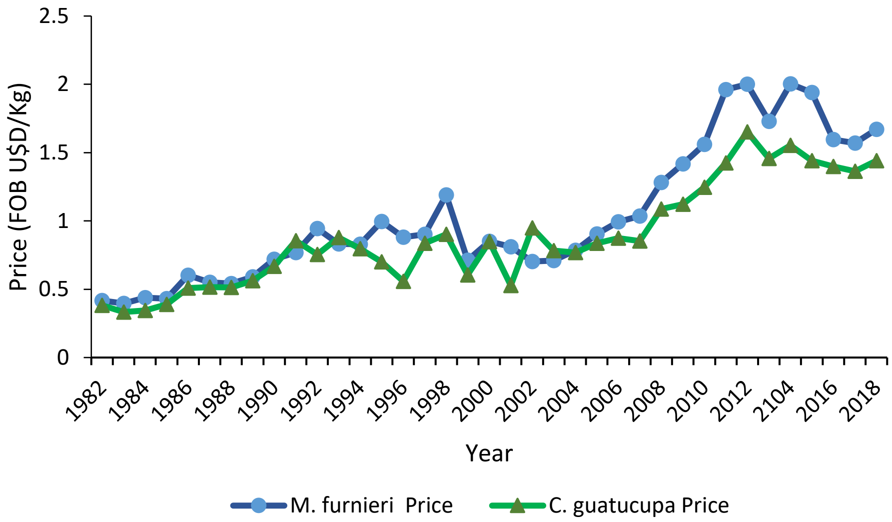


Figure 16. Prices variation of *M. furnieri* and *C. guatucupa* Uruguayan exports for the period of 1982 to 2018.

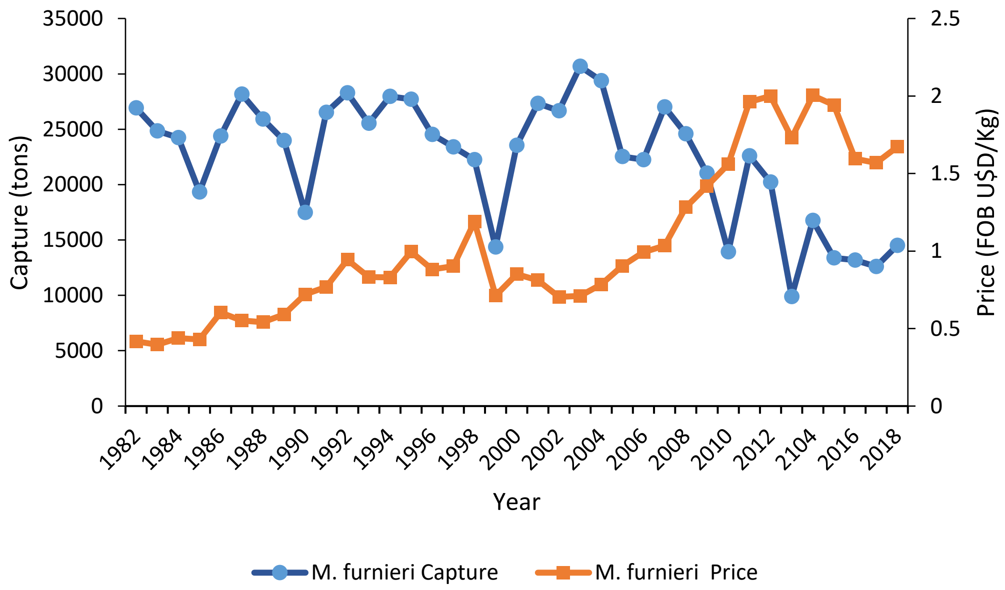


Figure 17. *M. furnieri* captures and price variation of Uruguayan exports for the period of 1982 to 2018.

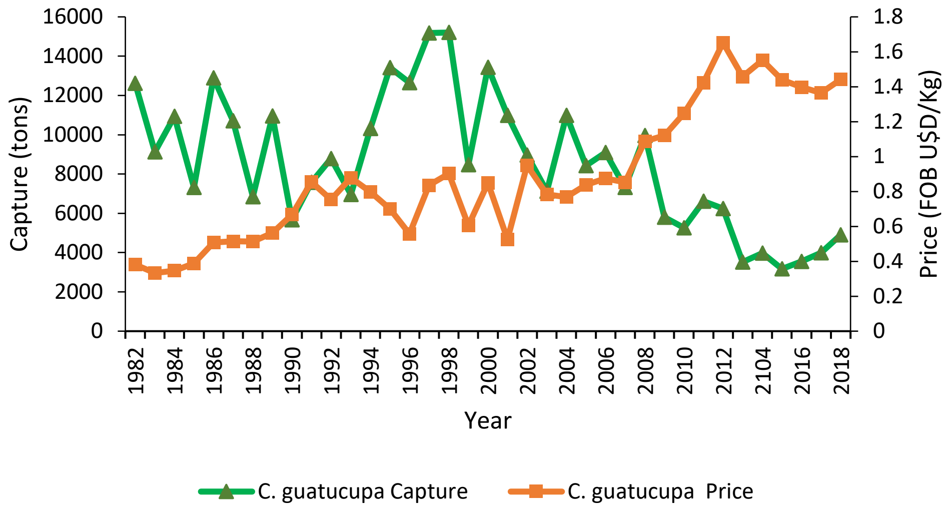


Figure 18. *C. guatucupa* captures and price variation of Uruguayan exports for the period of 1982 to 2018.

10.3.3.Characteristics of the fleet

The number of trips performed by the fleet that target species *C. guatucupa* and *M. furnieri* varies from a maximum of 1527 in 1982 and a minimum of 584 in 1999 (Figure 19). Number of vessels of the fleet that target species *C. guatucupa* and *M. furnieri* varies from a maximum of 36 in 1997 and 2000; and a minimum of 29 in 1984, 1990 and 1994 (Figure 19).

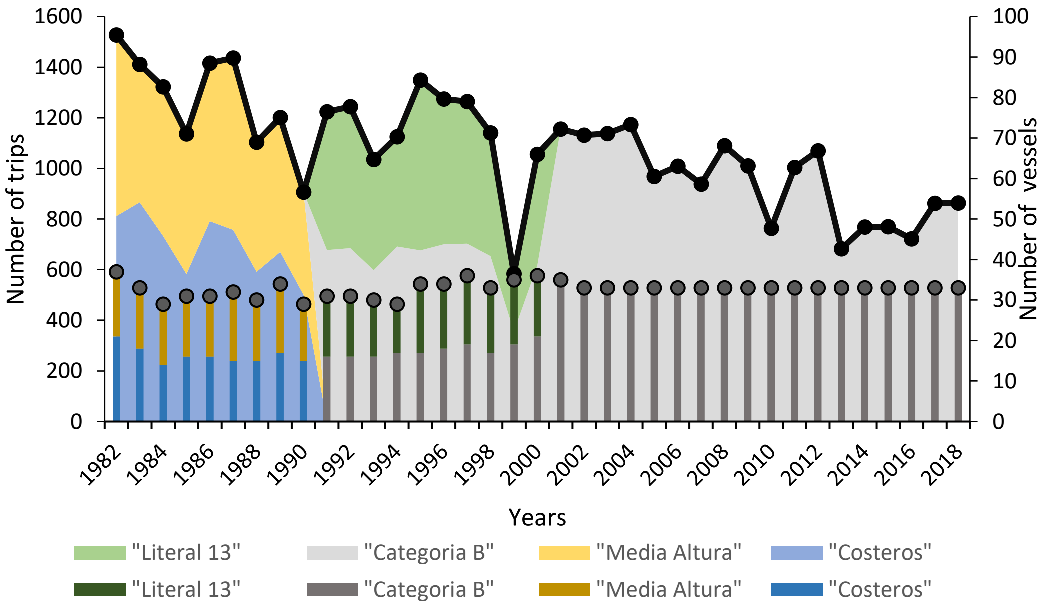


Figure 19. Number of trips (primary x axis, presented with lines) and number of vessels (secondary x axis presented with bars) of the different category of fleet for the time period of 1982 to 2018. Totals are made from the categories presented.

10.4. Fisheries and Climate.

A negative correlation between the captures of *M. furnieri* and the mean annual SST in the study area was found (Figure 20). This correlation is not only significant for Lag= 0, also for Lag= -2, Lag= -1, Lag= 1, Lag= 9, and Lag= 12 (Figure 26). It can also be appreciated a correlation between Z of SST and Z of captures of *M. furnieri* (Figure 21). Furthermore, since 2007, the anomalies of Z of SST tend to increase, meanwhile the anomalies of *M. furnieri* and *C. guatucupa* tend to decrease.

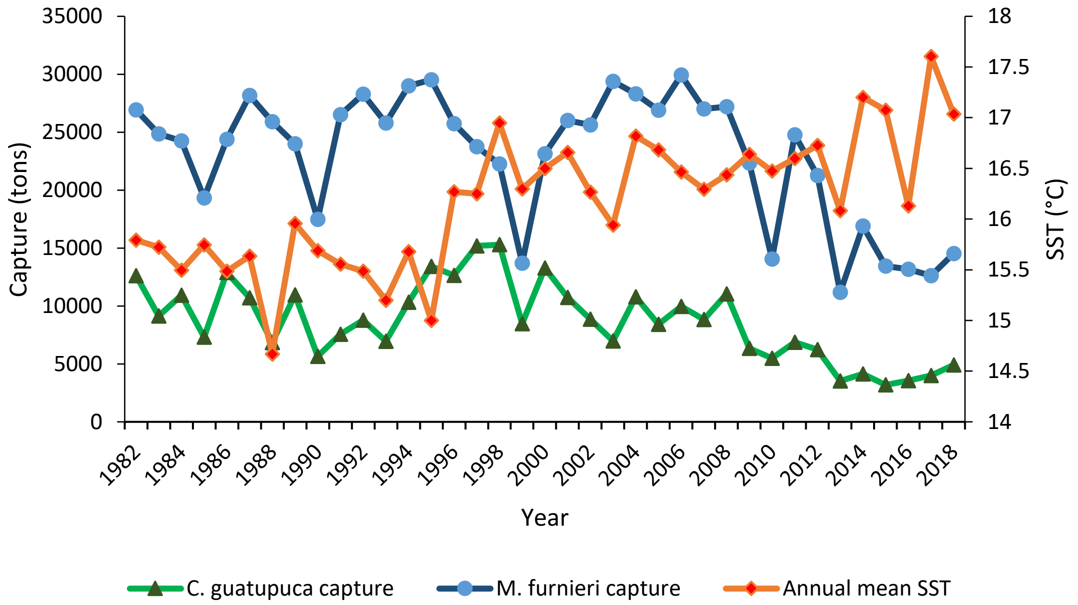


Figure 20. Capture of *M. furnieri* and *C. guatucupa* (both by the Uruguayan industrial costal fleet) and Mean Annual SST between 1982 to 2018 for the studied area.

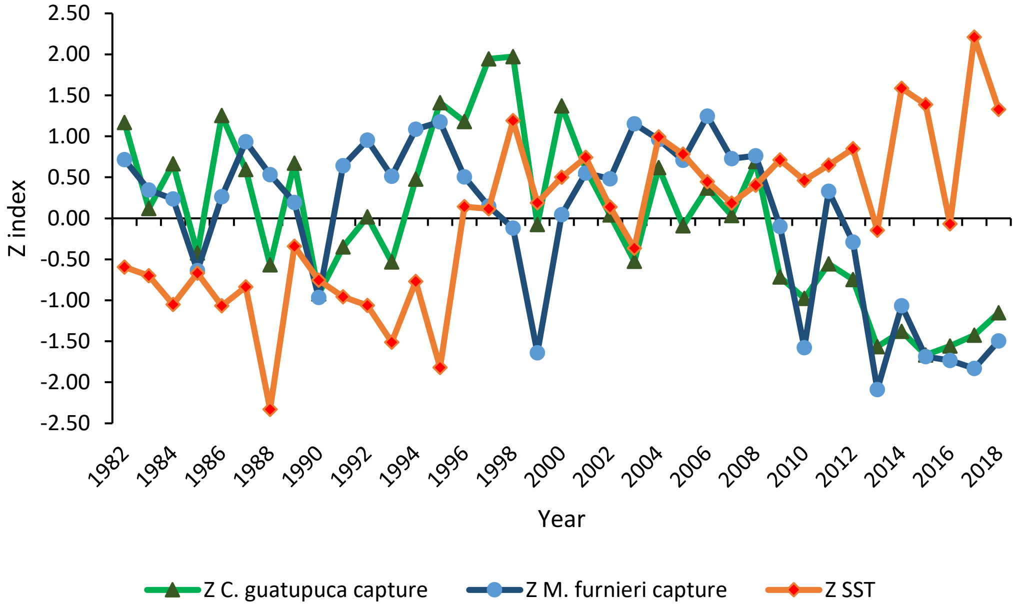


Figure 21. Z index of Capture of *M. furnieri*, *C. guatucupa* (by the Uruguayan industrial costal fleet) and Mean Annual SST between 1982 to 2018 for the studied area.

There is not a significative correlation between the CPT index of *M. furnieri* and the mean annual SST in the selected area of study (Appendix 1, Figure 22). Also, there is no significative correlation between Z SST and Z of CPT index of *M. furnieri* (Appendix 1, Figure 23).

It was also found that there is not a significative correlation between the CPT index of *C. guatucupa* and the mean annual SST in the selected area of study (Appendix 1, Figure 22). Moreover, there is not a significative correlation between Z SST and Z of CPT index of *C. guatucupa* (Appendix 1, Figure 23).

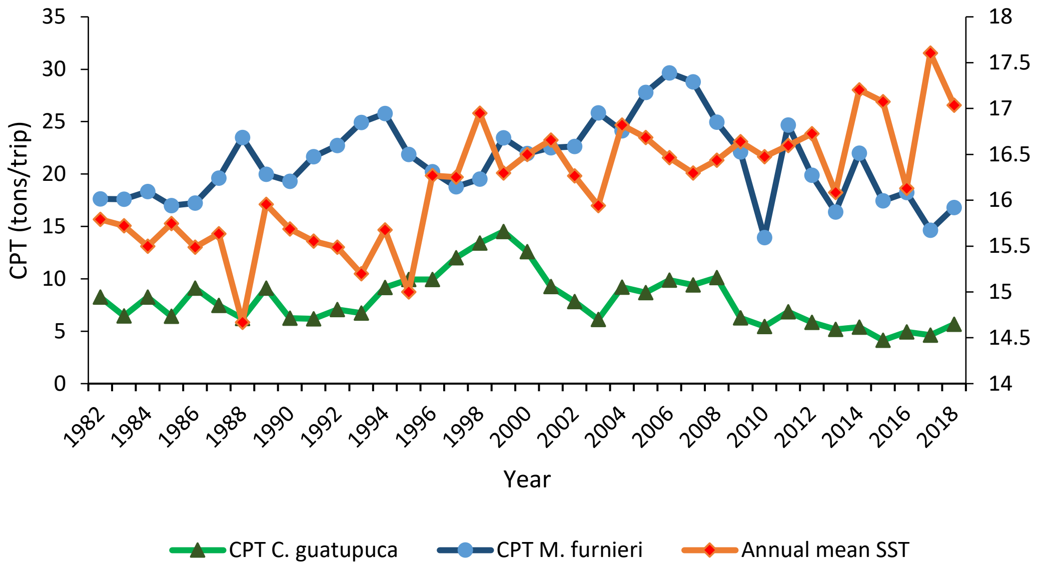


Figure 22. CPT index of *M. furnieri*, CPT index of *C. guatucupa* (both Uruguayan industrial costal fleet) and Mean annual SST variation between 1982 to 2018 for the studied area.

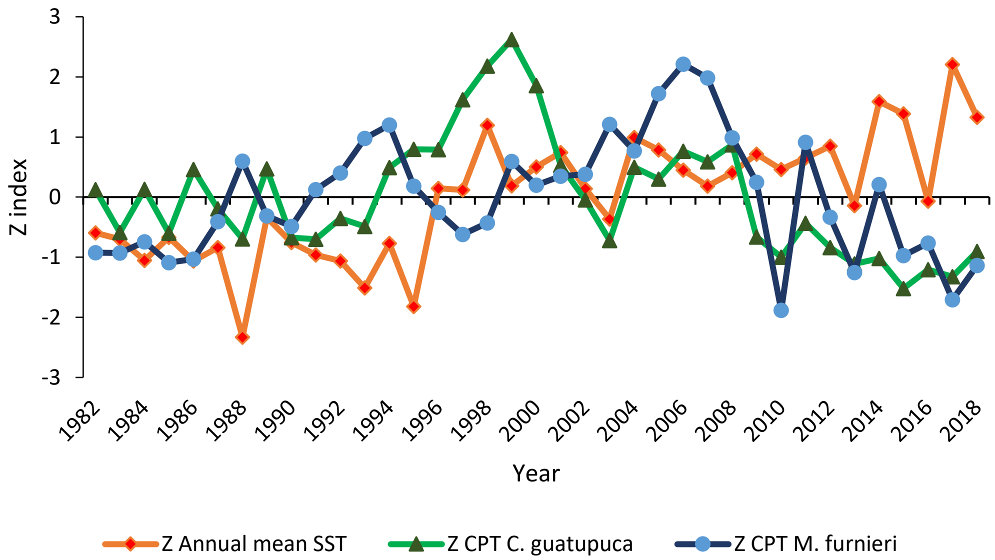


Figure 23. Z index of CPT index of *M. furnieri*, CPT index of *C. guatucupa* (by the Uruguayan industrial costal fleet) and Z index of Mean annual SST variation between 1982 to 2018 for the studied area.

10.4.1.Natural mortality of fishes

A gradual and significant increase of natural mortality of *M. furnieri* and *C. guatucupa* over the period studied (Figure 24) was found. Also exist a direct relationship between the variation in mean sea temperature and the natural mortality.

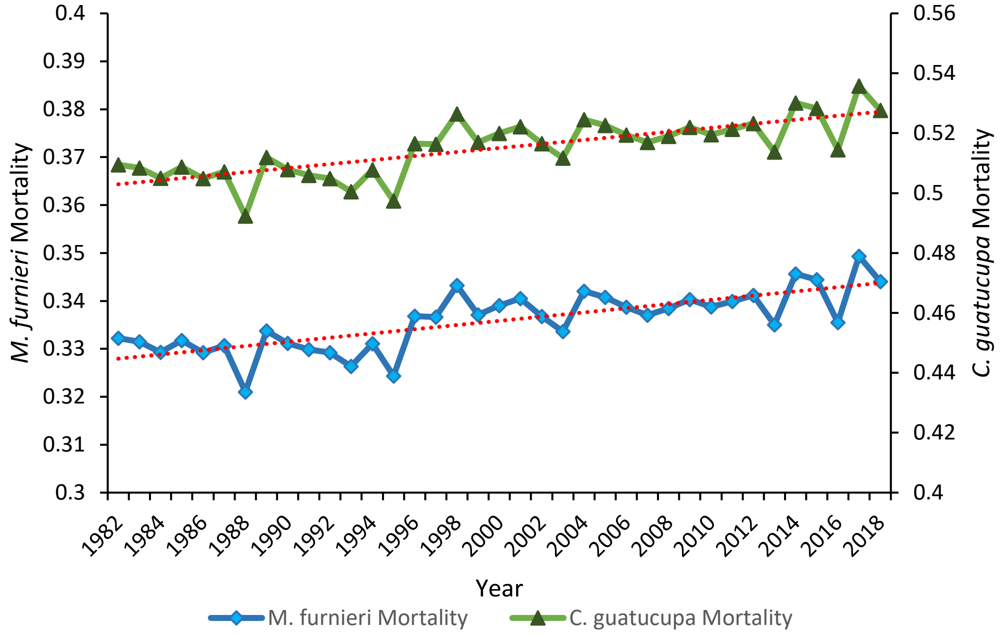


Figure 24. Natural mortality of *M. furnieri* and natural mortality of *C. guatucupa* between 1982 to 2018 for the studied area. Trendlines are plotted, and for both species the equation is $y = 0.0007x + 0.5352$ and an $R^2 = 0.5796$ and $p=4.81E^{-05}$.

10.5. Statistical analysis.

10.5.1. Runs test

The existence of a random distribution was rejected by the runs test for the variables SSTA, Z of Mean Annual SST, Runoff, Number of trips, *M. furnieri* Capture, Z *M. furnieri* Capture, CPT *M. furnieri*, CPT *C. guatucupa*, Z CPT *M. furnieri*, Z CPT *C. guatucupa*, *M. furnieri* Price and *C. guatucupa* Price (Table 2). Random distribution could not be rejected for the variables Mean Annual Maximum SST, Mean Annual Minimum SST, Number of trips from 1990, *C. guatucupa* Capture and Z *C. guatucupa* Capture (Table 2).

Table 2. Runs test for different variables

Variable	Statistic	Runs	n1	n2	n	p-value	result
Mean Annual SST	-3.044	10	18	18	36	0.0023	Reject random trend
SSTA	-3.044	10	18	18	36	0.0023	Reject random trend
Z of Mean Annual SST	-3.044	10	18	18	36	0.0023	Reject random trend
Mean Annual Maximum SST	-1.691	14	18	18	36	0.0908	
Mean Annual Minimum SST	0.338	20	18	18	36	0.7352	
Runoff	-2.029	13	18	18	36	0.0424	Reject random trend
Number of trips	-3.7202	8	18	18	36	0.0001	Reject random trend
Number of trips from 1990	-1.5407	11	14	14	28	0.1234	
M. furnieri Capture	-3.72	8	18	18	36	0.0002	Reject random trend
C. guatucupa Capture	-1.691	14	18	18	36	0.0908	
Z M. furnieri Capture	-3.72	8	18	18	36	0.0002	Reject random trend
Z C. guatucupa Capture	-1.691	14	18	18	36	0.0908	
CPT M. furnieri	-2.706	11	18	18	36	0.0068	Reject random trend
CPT C. guatucupa	-2.367	14	18	18	36	0.0179	Reject random trend
Z CPT M. furnieri	-2.706	11	18	18	36	0.0068	Reject random trend
Z CPT C. guatucupa	-2.367	14	18	18	36	0.0179	Reject random trend
M. furnieri Price	-4.397	6	18	18	36	0	Reject random trend
C. guatucupa Price	-2.367	12	18	18	36	0.0179	Reject random trend

10.5.2.Autocorrelation and Partial Autocorrelation analyses.

The annual mean SST time series data show autocorrelation for lags equal to 1, 2, 3, 4 and 5, being 4 and 5 closes to confidence limit (Figure 25). This series also present partial autocorrelation for lag equal 1 and "less significant" for lag equal 2(Figure 25). The SSTA time series data shows an autocorrelation for lags equal to 1, 2, 3, 4 and 5, being 4 and 5 closes to confidence limit (Figure 25). This series also present partial autocorrelation for lag equal 1 and "less significant" for lag equal 2(Figure 25).

M. furnieri capture time series data shows autocorrelation for lags equal to 1, 2 and 3 being 2 and 3 closes to confidence limit (Figure 25). This series also present partial autocorrelation for lag equal 1. *C. guatucupa* capture time series data shows autocorrelation for lags equal to 1, 2 and 3 (Figure 25). This series also present partial autocorrelation for lag equal 1 and close to confidence limit for lag equal 2(Figure 25). The Runoff of Rio the la Plata time series data does not present autocorrelation neither partial autocorrelation.

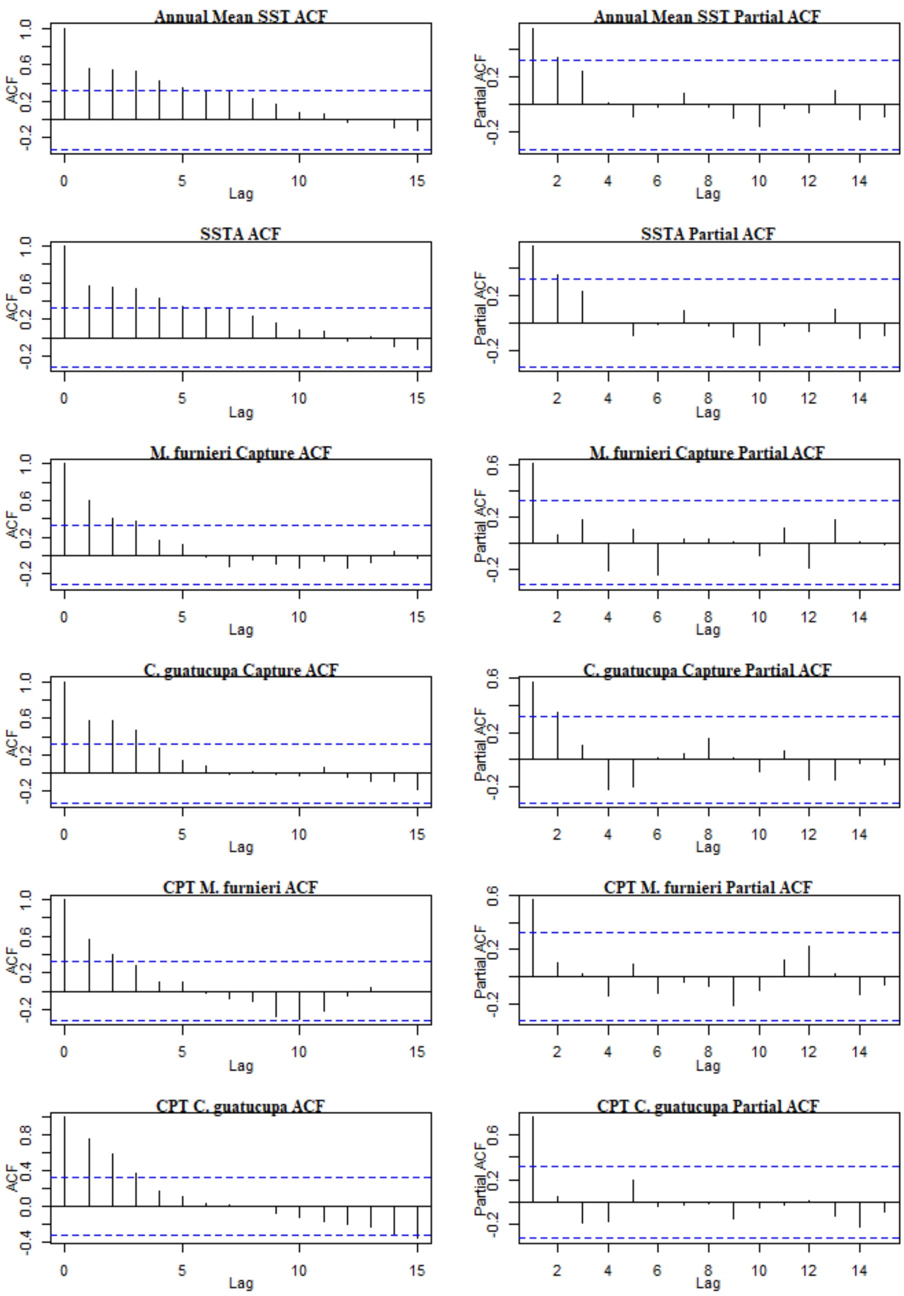


Figure 25. Auto correlation and partial autocorrelation tested on data of Annual mean SST, SSTA, *M. furnieri* capture, *C. guatucupa* capture, CPT index of *M. furnieri* and CPT index of *C. guatucupa*. The series of time used was comprehended between 1982 and 2018.

10.5.3.Correlation of variables

The correlation of the main variables is exhibited in Appendix 1. A significant correlation is shown in green or red colour depending if it is a positive or negative one. The correlation is also graduated by stars, having more stars mean more significance of the correlation.

10.5.4.Cross-correlation analyses

M. furnieri capture time series and annual mean SST time series show significant cross-correlation for lags -2, -1, 0, 1,9 and 12 (figure 26A). *M. furnieri* capture time series and SSTA time series show significant cross-correlation for lags -2, -1, 0, 1,9 and 12 (figure 26A). *M. furnieri* capture time series and Runoff of "Río de la Plata" time series show significant cross-correlation for lags 9, 10 and 12 (figure 26A). *M. furnieri* and *C. guatucupa* capture time series does not show significant cross-correlation with ES-ONI time series for any lag in between -15 and 15 (figure 26A and 26B).

C. guatucupa capture time series and annual mean SST time series show significant cross-correlation for lags 1,3,4, 5,6,7,9,10,11,12 and 13 (figure 26B). *C. guatucupa* capture time series and SSTA time series show significant cross-correlation for lags 1,3,4, 5,6,7,9,10,11,12 and 13 (figure 26B). *C. guatucupa* capture time series and Runoff of "Río de la Plata" time series show significant cross-correlation only for lag 14 (figure 26B).

SSTA time series and ES-ONI time series does not show significant cross-correlation for any lag in between -15 and 15 (figure 26C). Runoff of "Río de la Plata" time series and ES-ONI time series show significant cross-correlation only for lag 0 (figure 26C).

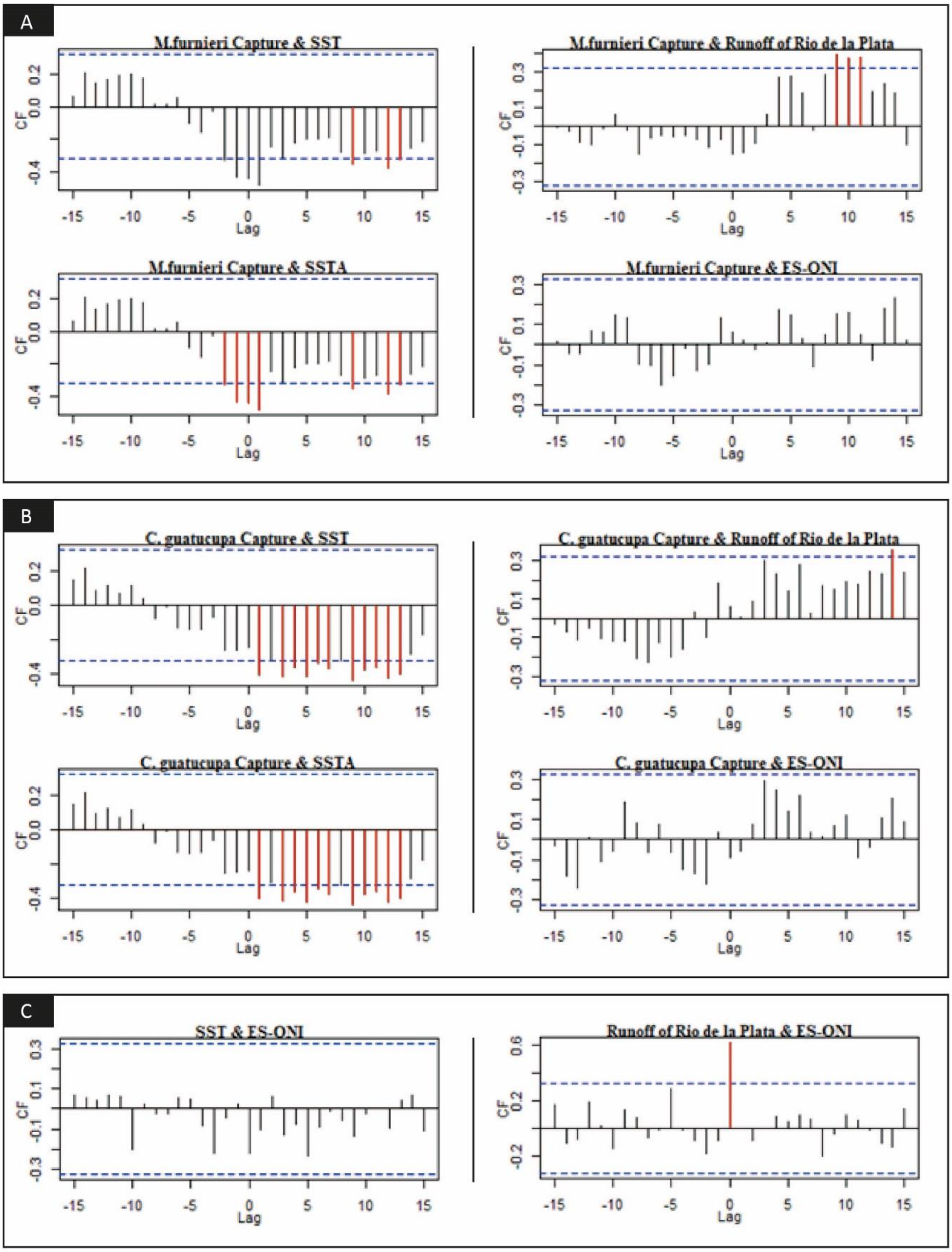


Figure 26. Cross correlation for lag 15. The variables correlated I f **part A** were *M. furnieri* with Annual mean SST*,* Annual mean SSTA, runoff of "Río de la Plata" and ES-ONI index. In **part B**, *C. guatucupa* capture is correlated with Annual mean SST*,* Annual mean SSTA, runoff of "Río de la Plata" and ES-ONI index. Finally, in **part C**, ES-ONI index is correlated also with Annual mean SST and runoff of "Río de la Plata".

10.5.5.Wavelets analyses

The analysis *M. furnieri* capture time series and annual mean SST time series in the wavelet analysis (Figure 29) present covariation in all times, being stronger for the period of 1985 - 1993, 1998-2002 and 2007-2013 at a scale equal to 0. Two small covariation areas in the confidence interval are found, one between 1987-1990 at the scale of 5 and the second at scale of 6 in the period of 2007 to 2010. At a higher scale comprehended between 7 and 10 strongest confidences were found between the years 1992 and 2006.

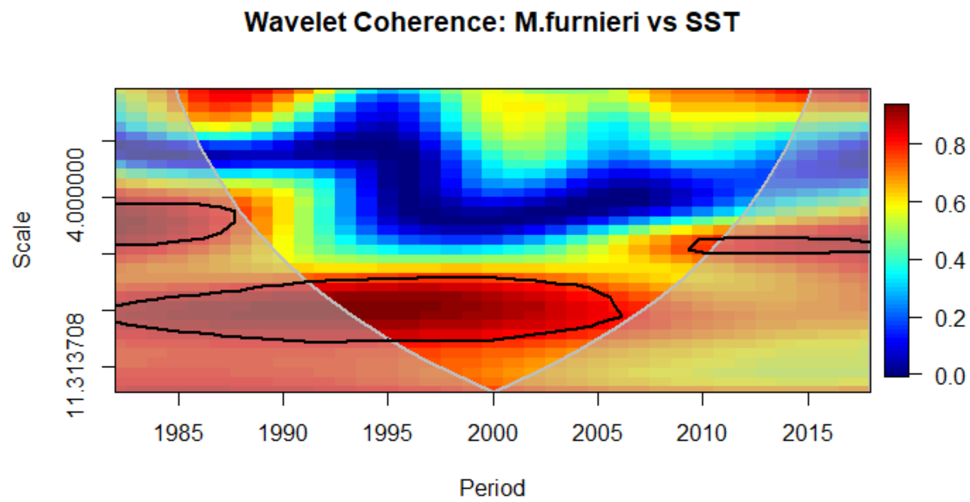


Figure 27. Wavelet analysis that correlate captures of *M. furnieri* time series and SST time series for the period between 1982 to 2018 for the studied area.

The analysis of *M. furnieri* capture time series and SSTA time series shows covariation in the wavelet analysis (Figure 28) for all the period being stronger between the years 1985 -1990, 1998-2002 and 2007-2013 at a scale equal to 0. Two small covariation areas in the confidence interval are found, one between 1987-1990 at the scale of 5 and the second at scale of 6 in the period of 2007 to 2010. At a higher scale comprehended between 7 and 10 the strongest confidences were found between the years 1992 and 2006.

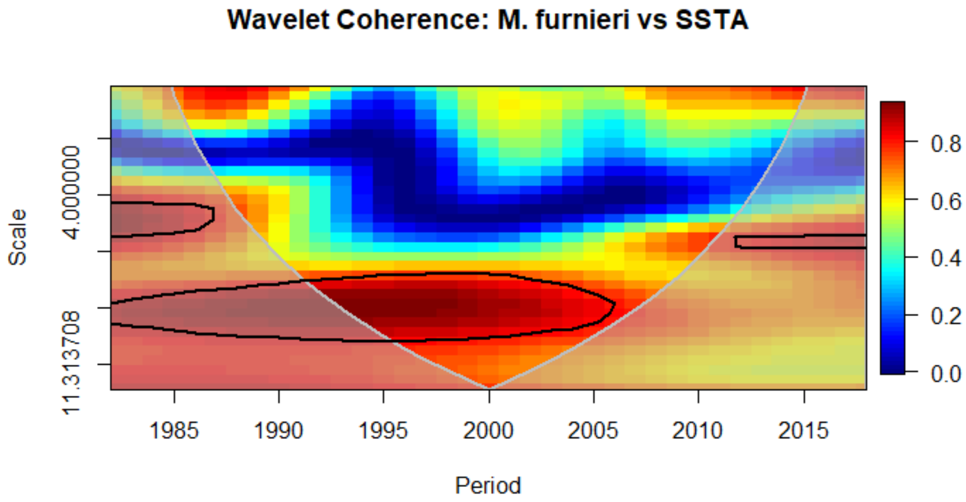


Figure 28. Wavelet analysis that correlate captures of *M. furnieri* time series and SSTA time series for the period between 1982 to 2018 for the studied area.

The analysis of Z of *M. furnieri* capture time series and Z of annual mean SST time series covariation (Figure 29) shows in the wavelet analysis for all the period being stronger between the years 1985 -1990, 1998-2002 and 2007-2013 at a scale equal to 0. Two small covariation areas in the confidence interval are found, one between 1987-1990 at the scale of 5 and the second at scale of 6 in the period of 2007 to 2010. At a higher scale comprehended between 7 and 10 the strongest confidences were found between the years 1992 and 2006.

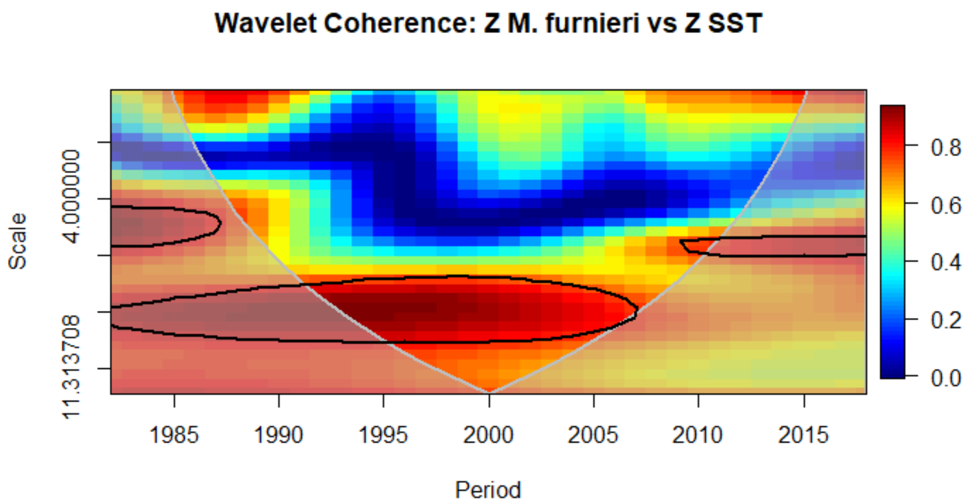


Figure 29. Wavelet analysis that correlate Z of captures of *M. furnieri* time series and Z of SST time series for the period between 1982 to 2018 for the studied area.

The analysis CPT index of *M. furnieri* time series and annual mean SST time series shows covariation in the wavelet analysis (Figure 30) for the period of 1985 -1990, 1996-1999 and 2008-2013 at a scale equal to 0. Two small covariation areas in the confidence interval are found at the scale of 4 for the periods of 1987-1990 and 1997-2002. At a higher scale comprehended between 7 and 10 the strongest confidences were found for all the confidence interval at that scale comprehended between the years 1990 and 2010.

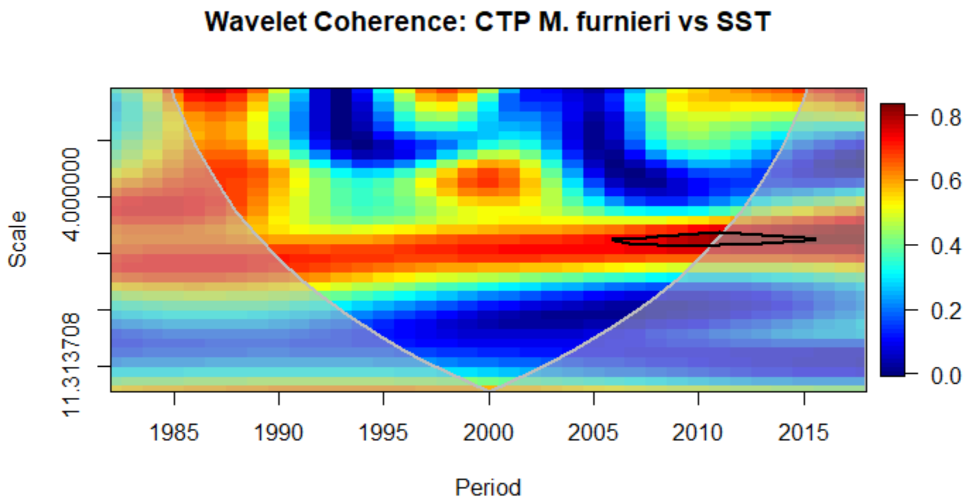


Figure 30. Wavelet analysis that correlate CPT of *M. furnieri* time series and SST time series for the period between 1982 to 2018 for the studied area.

The analysis of Z CPT index of *M. furnieri* time series and Z annual mean SST time series shows covariation in the wavelet analysis (Figure 31) for the period of 1985 -1990, 1996-1999 and 2008-2013 at a scale equal to 0. Two small covariation areas in the confidence interval are found at the scale of 4 for the periods of 1987-1990 and 1997-2002. At a higher scale comprehended between 6 and 7 the strongest confidences were found for all the confidence interval at that scale comprehended between the years 1990 and 2010.

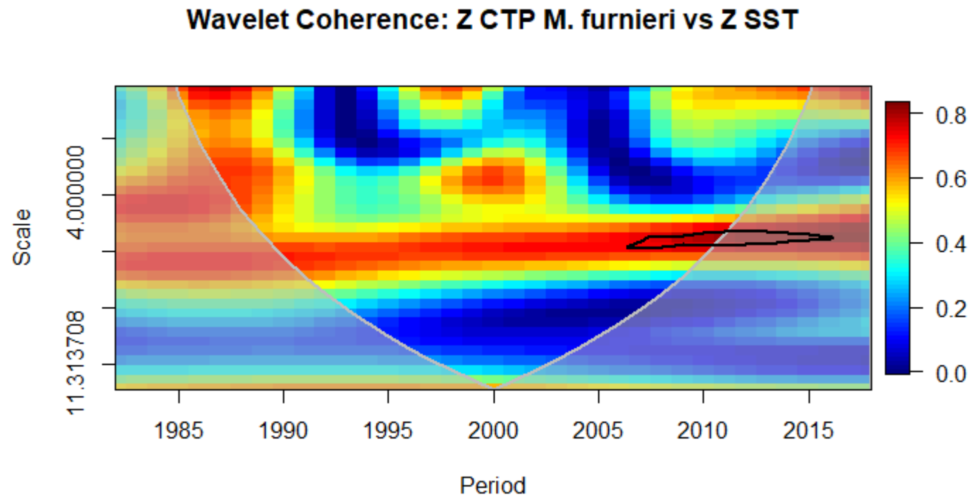


Figure 31. Wavelet analysis that correlate Z CPT index of *M. furnieri* time series and Z SST time series for the period between 1982 to 2018 for the studied area.

The analysis of *C. guatucupa* capture time series and annual mean SST time series in the wavelet analysis (Figure 32) present covariation for the period of 1985 -1993, 1998-2003 and 2013-2014 at a scale equal to 0. Covariation in the confidence interval between the scale of 2 and 4 was found for the periods of 1997-2007. At a higher scale comprehended between 7 and 10 covariation was found between the years 1992 and 2003.

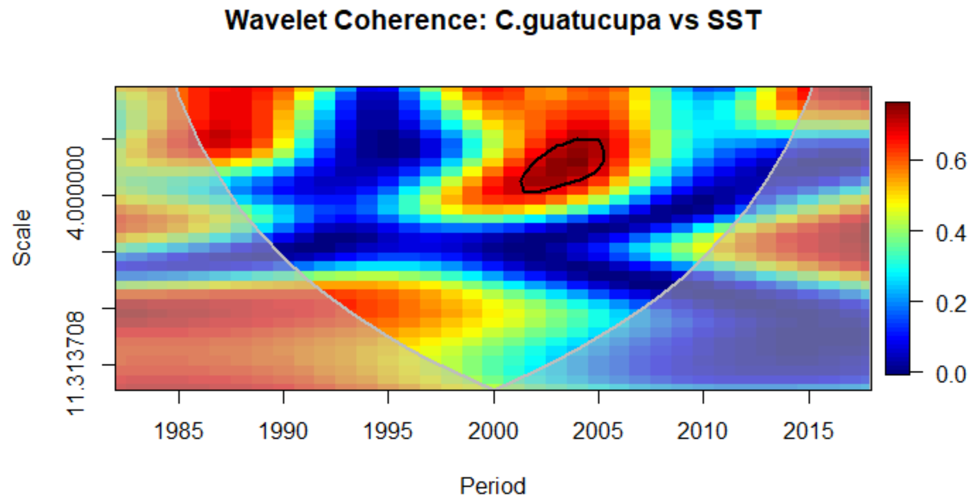


Figure 32. Wavelet analysis that correlate captures of *C. guatucupa* time series and SST time series for the time period between 1982 to 2018 for the studied area.

The analysis of *C. guatucupa* capture time series and SSTA time series (Figure 33) shows covariation in the wavelet analysis for the period of 1985 -1993, 1998-2003 and 2013-2014 at a scale equal to 0. Also, covariation in the confidence interval between the scale of 2 and 4 was found for the periods of 1997-2007. At a higher scale comprehended between 7 and 10 covariation was found between the years 1992 and 2003.

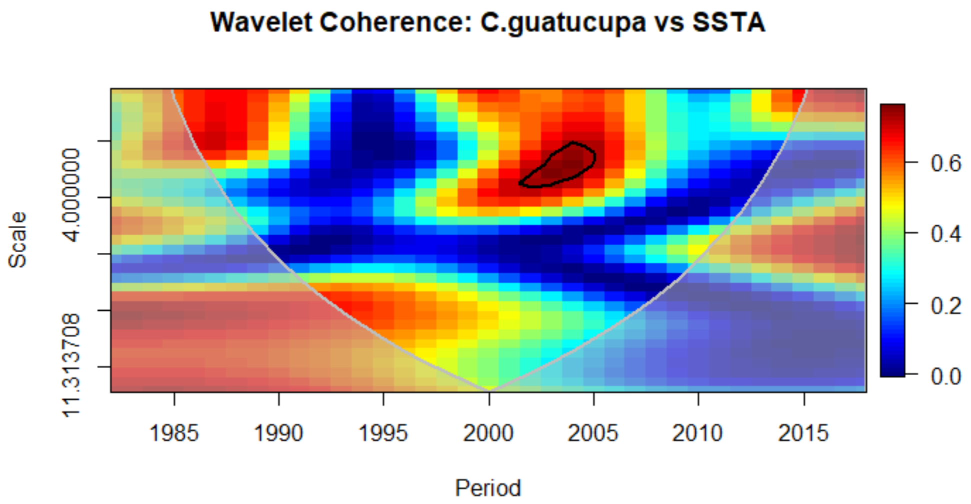


Figure 33. Wavelet analysis that correlate captures of *C. guatucupa* time series and SSTA time series for the period between 1982 to 2018 for the studied area.

The analysis of Z of *C. guatucupa* capture time series and Z of annual mean SST time series (Figure 34) shows covariation in the wavelet analysis for the period of 1985 -1993, 1998-2003 and 2013-2014 at a scale equal to 0. Also, covariation in the confidence interval between the scale of 2 and 4 was found for the periods of 1997-2007. At a higher scale comprehended between 7 and 10 covariation was found between the years 1992 and 2003.

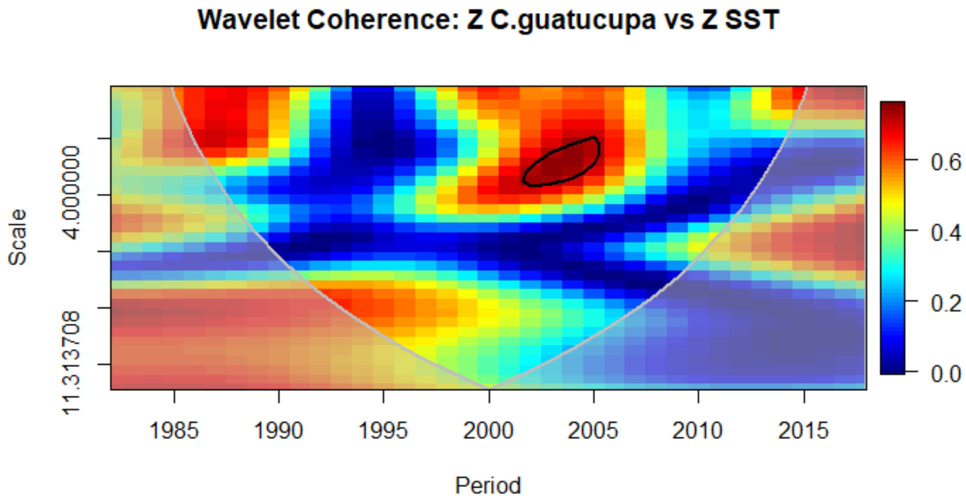


Figure 34. Wavelet analysis that correlate Z of captures of *C. guatucupa* time series and Z of SST time series for the time period between 1982 to 2018 for the studied area.

The analysis CPT index of *C. guatucupa* time series and annual mean SST time series (Figure 35) shows covariation in the wavelet analysis for the period of 2012-2014 and a lower one for the period 1985-1990 at a scale equal to 0. Covariation in the confidence interval between the scale of 2 and 3 was found for the period of 1987-1990. At a higher scale comprehended between 10 and 11 low confidence covariation was found between the years 1994 and 2006.

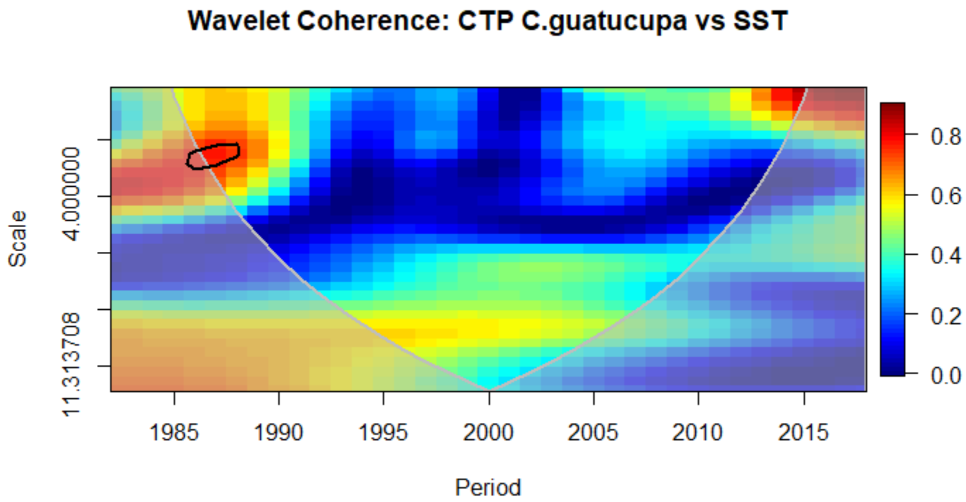


Figure 35. Wavelet analysis that correlate CPT index of *C. guatucupa* time series and SST time series for the period between 1982 to 2018 for the studied area.

The analysis of Z CPT index of *C. guatucupa* time series and Z of annual mean SST time series (Figure 36) shows covariation in the wavelet analysis for the period of 2012-2014 and a lower one for the period 1985-1990 at a scale equal to 0. Also, covariation in the confidence interval between the scale of 2 and 3 was found for the period of 1987-1990. At a higher scale comprehended between 10 and 11 low confidence covariation was found between the years 1994 and 2006.

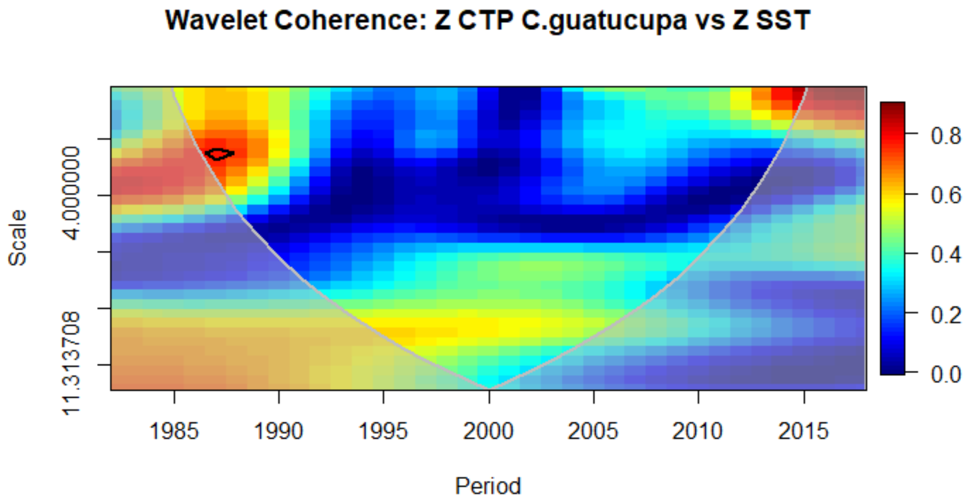


Figure 36. Wavelet analysis that correlate Z CPT index of *C. guatucupa* time series and Z SST time series for the period between 1982 to 2018 for the studied area.

10.6. Statistical linear and General Additive Models.

Even other type of models were run trying to explain capture and CPT index of both species GAM models were chosen as they were the ones that presented lower AIC. Although to explain the capture of *M. furnieri* a LM presented an AIC not much bigger than the GAM with other variables. The model was also significant. Thought the r square was low, being the same only 0.19. For this reason, both models the LM and the GAM are presented (Table3).

Table 3. AIC, GCV and Deviance explained from different models

Model	Variables	AIC	GCV	Deviance explained
Lm 1	Capture *M. furnieri* ~ Annual mean SST	741.1		r^2=0.19
Gam 2	Capture *M. furnieri* ~ Annual mean SST + AAO index	737.6	$2.54E^{+07}$	29.10%
Gam 3	CPT *M. furnieri* ~ Annual mean SST + AMO index + ONI index + AAO index	149.1	9.8993	94.90%
Gam 4	CPT *C. guatucupa* ~ Annual mean SST + Runoff	164.1	5.7477	64.10%

Model 1 is a LM that relate Capture of *M. furnieri* with Annual mean temperature, Annual estimator of ONI index and Annual maximum mean temperature (Figure 37). The theoretical quantiles versus the standardized ones do not show a pattern and the follow the theoretical line distribution. The residuals are mostly randomly distributed not showing any odd pattern of distribution. These mentioned things give robustness to the model.

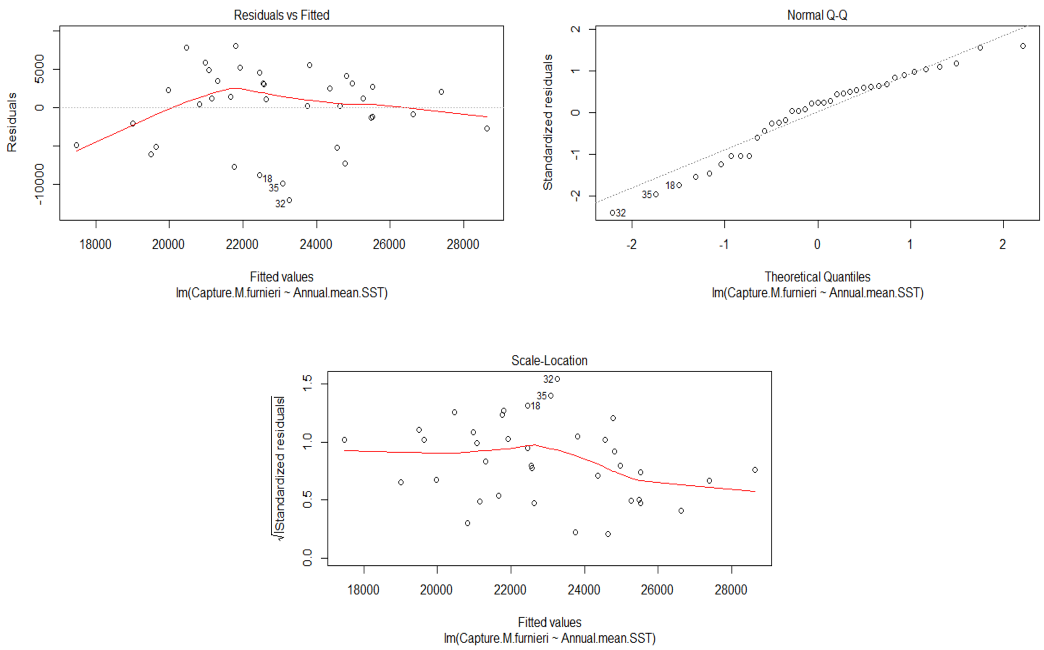
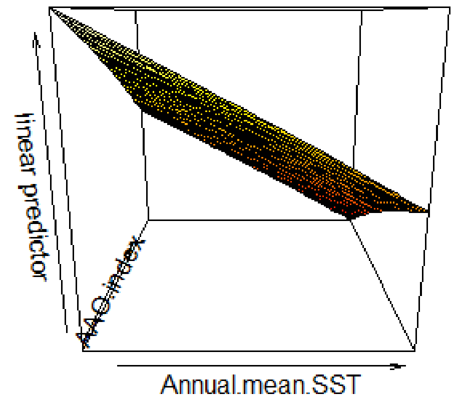


Figure 37. Plot of model 1, it is a LM that relates of the variable annual mean SST with Capture of *M. furnieri.*

Model 2 is a GAM that relate Capture of *M. furnieri* with Annual mean temperature and Annual estimator of AAO index (Figure 38). The spine lines adjust inside the confidence area. Linear correlation can be appreciated between the SST and AAO with the variable.



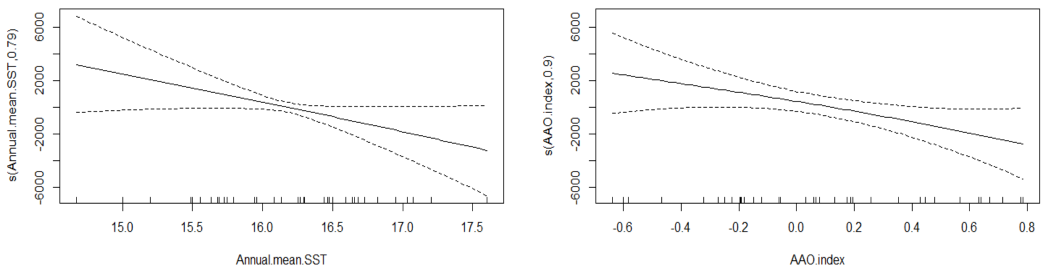


Figure 38. Plot of model 2, it is a GAM that relate the variables annual mean SST and AAO index with Capture of *M. furnieri*

Model 3 is a GAM that relate CPT index of *M. furnieri* with Annual mean temperature, Annual estimator of AMO index, Annual estimator of ONI index and Annual estimator of AAO index (Figure 39). The spine lines adjust inside the confidence area.

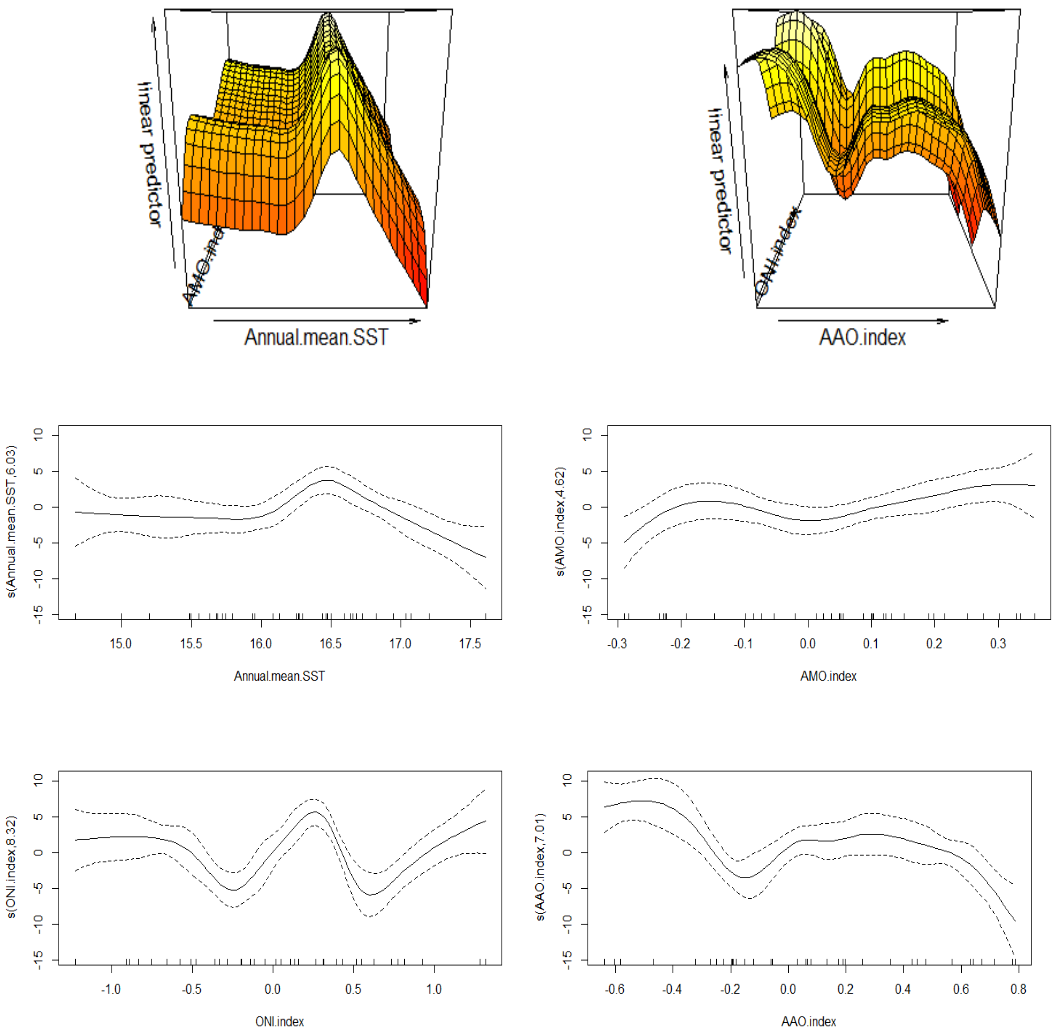


Figure 39. Plot of Gam 3 model, showing the relation of the variables annual mean SST, AMO index, ONI index and AAO index with CPT index of *M. furnieri*

Model 4 is a GAM that correlate CPT index of *C. guatucupa* with Annual mean temperature, Runoff, Annual estimator of ONI index and Annual estimator of AAO index (Figure 40). The spine lines adjust inside the confidence area. A consistent correlation cannot be appreciated between the Runoff and the variable, though taking it away reduces considerably the deviance explained.

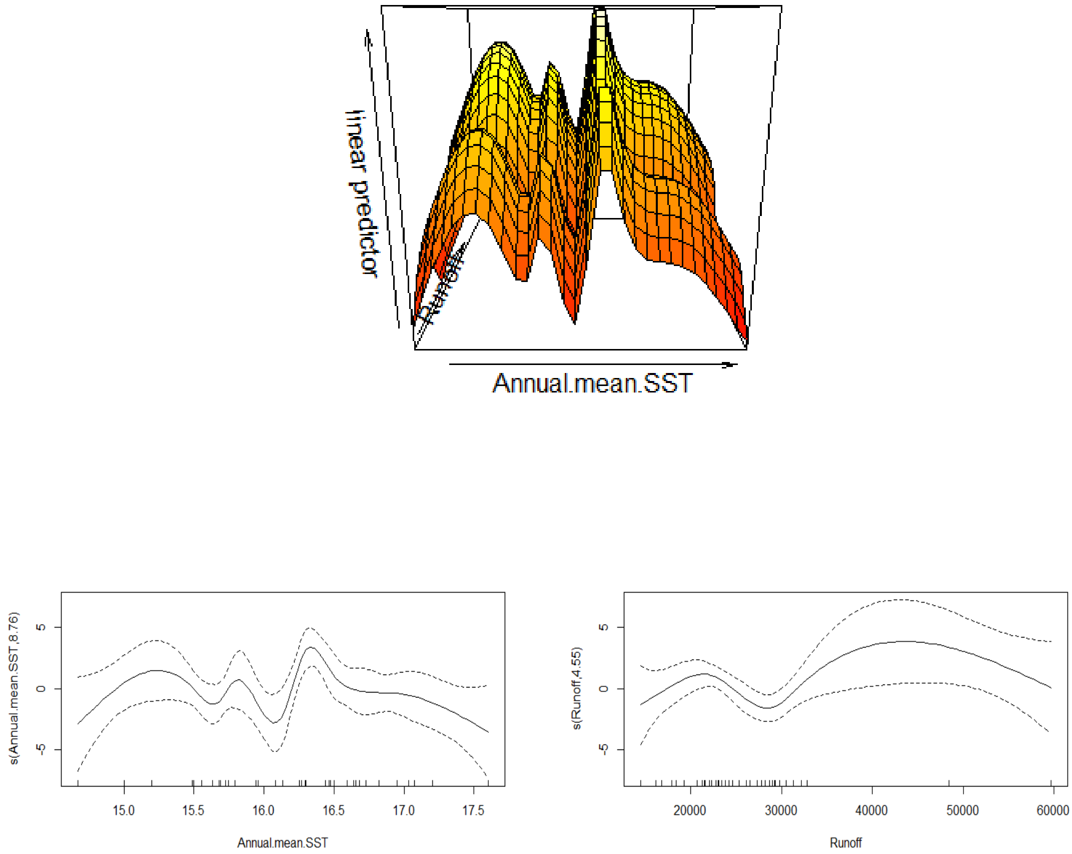


Figure 40. Plot of Gam 4 model, showing the relation of the variables annual mean SST and Runoff with CPT of *C. guatucupa*

11. Discussion.

11.1. Climate.

11.1.1.Sea Surface Temperature

There is a tendency of increase of the SST in the study area during the period 1982 to 2018. Also, increase of the positive anomalies in the in the last two decades can be appreciated. This tendency is coherent with the information provided by the IPCC5 (2014) and other works (Barros *et al*., 2005; Solomon, 2007; Paesch *et al*., 2014; Stocker, 2014; Martínez *et al*., 2017). Not only the average annual SST increase, also the annual maximums and the annual minimums. This two can have major impacts on the biota (Pörtner and Peck, 2010) and in the studied species as it will analyse further in the text. This increment can be due because the increment of the SST perse or because the movement of the Brazilian current further south (Ortega *et al*., 2016).

Even that the increment of temperature is being measured by the satellite on the surface, an increment in the bottom temperature (at least in the area of “Río de la Plata”) can be assume. This interpretation can be made as mixing processes are significant in “Río de la Plata” as the waters are shallow, for this reason the column of water can easily mix even with week winds (Norbis, 1995; Guerrero *et al.*, 1997; Nagy *et al*., 1998; Framiñan *et al*., 1999; Barros *et al*., 2005). The impressive fact detected with the analysis of SST was the trend of increase of SST. Assuming this trend continues in 10 years the average SST would have increase 0.456 Celsius degrease. This increase would have major impacts that will be analyse further in the text.

11.1.2.Climatic indexes

There is a positive correlation between AMO index and mean annual SST, anomaly of SST and Z of SST. Same correlation happens with AAO index and SST, anomaly of SST and Z of SST. This does not happen with the ONI index, as no relation with SST was found. The correlation of AMO and AAO index with SST can be due to teleconnection in atmospheric or oceanic process impacting on the region of study. AMO index covariates with the Atlantic meridional overturning circulation (Wei and Lohmann, 2012). For this reason, it is suggested that changes in ocean circulation could determine the observed trend in SSTA in the South Atlantic Ocean (SAO)(Seager *et al*., 2010; Ortega, 2013).

AAO index embody changes in atmospheric mass of large-scale between medium and high latitude surface pressures in the Southern Hemisphere (Gong and Wang, 1999). It also produces changes in precipitation, wind, sea ice, and SST variability (Silvestri and Vera, 2003; Turner *et al*., 2007; Justino and Peltier, 2008; Vasconcellos and Cavalcanti, 2010; Chang *et al*. 2015), this is the main reason that this index is correlated with the SST of the study area. On the other hand, ONI index is correlated with the runoff of “Río de la Plata”. This has been already mentioned in the literature by Nagy *et al*. (1998) and Robertson and Mechoso (1998).

11.2. Runoff data.

Runoff of “Río de la Plata” data is not autocorrelated neither is partially autocorrelated. This means that the runoff of a single year does not impact in the runoff of the next year. As mentioned before the runoff is correlated with the ONI index and with the CPT index of *M. furnieri*, and with the Z CPT index of *M. furnieri*. This can be due that *M. furnieri* search the interaction of the fresh water of “Río de la Plata” and salty water from the ocean to spawn (Isaac, 1988; Macchi *et al*., 1996; Acha *et al*., 1999; Vizziano, 2002; Macchi *et al*., 2003; Norbis and Verocai, 2005; Puig and Mesones, 2005; Jaureguizar *et al*., 2008). The increases of the runoff make less retention of the ichthyoplankton, affecting *M. furnieri* recruitment (Acha *el at*., 2012).

The fact that *C. guatucupa* is not being affected by the Runoff can be explained as this species inhabit more oceanic area than the estuary and spawns in the oceanic environment (Macchi, 1998; Militelli and Macchi, 2006), where is not affected by the Runoff of Rio the la Plata variability. Thought interaction cannot be discarded as GAM models found interactions between these variables.

11.3. Fisheries.

11.3.1. Captures Data

11.3.1.1. M. furnieri

Captures of *M. furnieri* fluctuate around 20000-25000 tons of fish. This would be expected as this amount is normally the top up amount imposed by CTMFM for Uruguayan fishing fleet (CTMFM, 2020). Thought in the last years starting on 2009-2010 there is a long-term decrease of this number as can be seen in the last years. Or focus is how the temperature and other climatic variables affect the captures, but there can be other factors affecting them. These factors can be completely not related to the temperature or climate, indirectly or directly caused by the temperature increase caused by climate change.

It is important to understand that in the past this fishery has been over exploited or maximum exploited (Arena and Rey, 1999; Rey, 2001; Defeo *et al*., 2011). This could be one of the main reasons that causes the decrease in the las years captures. On the other hand, from 1990 the species is considered fully exploited (CTMFM, 2020) and the coastal fishery has been closed, this implies that no more than 33 licenses are created (Decree No 115/018 of law 19.175 of Uruguayan law, 2013). Moreover, the fishing effort measured as the number of trips remained relatively constant with a slight tendency to decent (Lorenzo, 2016, Figure 19). Furthermore, there is no statistic variation since 1990 in the number of trips (Table 2). Since 2006, catches of *M. furnieri* decrease as does the CPT index. The change in SST and SSTA related scenario in 1996-97 (ten years before), which can be explained in the wavelet relationship between SST and SSTA at a scale of 9 to 11. In other words, the increase in SST and SSTA could be producing a decrease in the availability of the resource in the analyzed area, which is reflected in a tendency to decrease of *M. furnieri* captures and the CPT index, despite the fact that the fishing effort has remained relatively constant. This effect of temperature becomes relevant from the year 1996 where a scenario change can be appreciated in annual mean SST and SSTA and could be explaining the decline in *M. furnieri* catches.

11.3.1.2. C. guatucupa

Captures of *C. guatucupa* do not show a significant statistical tendency but the last years present lower captures than the mean. This pattern is a similar to *M. furnieri* but did not showed a significant tendency. Even that *C. guatucupa* is also toped up by legislation the variation of the catch of this species is not as regular as the catch of *M. furnieri*. This happens because *M. furnieri* is more quoted in the market. For this reason, the fishing fleet try to catch more *M. furnieri* and *C. guatucupa* tend to be second catch species. Currently there is no industrial fleet whose target species is the catch of *C. guatucupa*, a situation that was registered until 2001 (CTMFM, 2020).

The low landing volume recorded in 2013 corresponds to total activity stoppage of coastal fleet in the months of May to June. From 2010, the catch of *C. guatucupa* declined systematically until 2015 to recover later in 2016 (CTMFM, 2020). The exploitation status of this species is not considered at risk since there is no fishery that aims at its capture and is only caught as a bycatch species of *M. furnieri* (Norbis and Galli, 2013). Also, the decrease in fishing pressure on hake, due to the breakage of a principal fishery industry (FRIPUR) and the decrease in the activity of the Uruguayan hake fleet, may have favored its recovery.

11.3.2.Fish Price

As an overall, captures and the CPT index of both species do not relay on prices of the market of this species. This indicates us that changes in these two variables depend more on populational changes either that market changes. Thought this asseveration is convincing with the results, there is a lack in the analysis of cost of managing a boat, crew pay and or other economic factors that where not analyzed.

M. furnieri and *C. guatucupa* have an increasing of their international prices for the analysed period. It accelerates after the maximum of the captures, 2003 for *M. furnieri*. For *C. guatucupa* the maximum is 1997 (and later “small maximums” on 2000 and 2004). From 2006 on, prices go up and captures go down, to a stabilization plateau after 2014. The crossing of tendencies in price increase and capture descent occurs during the world economic crisis of

2008-2009 (Jacquet *et al*., 2010). Even if prices go up, the capture still goes down after 2009 what would show a collapse in this coastal fishery of Uruguay. That explains why the feasibility of this fishery is in doubt in the marine economic sector of this country.

For *M. furnieri* and *C. guatucupa* there is no positive relation between the increase of prices and the increase of the capture during analysed period, completely the opposite. There is a negative correlation between the increase of prices and the capture. There are two possible explanations for this fact. The first is that there is less resource, making less catch of it. And the second is that the resource is less rentable for the catchers, for example high crew cost. Both hypothesis work under the idea that prices are internationally regulated, and do not depend on the catch, which is mostly the case, as the production is not so big to regulate the international price as Uruguayan fish market is a small market (Bertullo, 1965; Etchebehere *et al*., 2018). The first hypothesis is the most plausible one as these resources are completely exploited. The idea that it arises is that the resource is probably decreasing as it is what this study tries to analyse the reasons behind and suggesting it is climate-based cause.

11.4. Fisheries and Climate.

The study area clearly presents a trend of temperature (means, minimums and maximums) increase over the studied period. The effects of this increase have caused changes in the presence, distribution and abundance of many species of fish and invertebrates and were discussed in the regional literature (Segura *et al*., 2008; Izzo *et al*., 2010; Milessi *et al*., 2013; Ortega, 2013; Milessi, 2018). Species of tropical and subtropical distribution and sporadically present in the region of study waters are currently more frequently reported in Uruguay (Segura *et al*., 2008; Izzo *et al*., 2010; Milessi *et al*., 2013; Ortega, 2013; Milessi, 2018). Most extreme changes in sea temperatures are often accompanied by subsequent phenomena of mortality events, of different magnitude, of different species (Fabiano *et al*., 2013).

In this study statistical correlation between the fisheries of *M. furnieri* and *C. guatucupa* with climatic variables are present. There are strong correlations and some others are diffuse, but still evidence some interaction.

Statistically significant relation with captures of *M. furnieri* and SST, SSTA and the standardized variables have been found. This is coherent with studies of Rolim and Ávila-da-Silva (2018) that also found relations between captures of *M. furnieri* and SST, as they analysed during 2003 and 2011. There is a dependency of the capture of *M. furnieri* and SST but not the same dependency of CPT index of *M. furnieri* and SST. This can mean that there is no correlation of the population of *M. furnieri* and SST or that the effort measure that were used in the study is not the best one. Especially considering that the number of trips does not have necessarily the same efficiency. Efficiency increase can be assumed over the years as the fishermen's get more experienced and the technologies increase during that period (Thorpe *et al*., 2000, Pascoe and Coglan, 2002). Under this assumption the first years in the time series would have less fishing effort, what would change the relation with the temperature, making the correlation of the CPT index of *M. furnieri* with SST significant. There is a third option, in which the population of *M. furnieri* does not depend linearly of SST if not in a complex function with more variables involved. This relation can be described by a GAM, and it will be analysed it further in the text.

There is a correlation of *M. furnieri* and SST in lag =0 detected by Pearson correlation function also by CCF. The second function also find correlation for lag -2, -1,1,4 and 9. This means that the effect of temperature of a year is not impacting only the captures of that year if not the next year capture. It is also creating a diffuse effect in the future 4 and 9 years. This diffuse process distant in the time is difficult to understand (thought is analysed in the wavelet), while the one-year process can be explained by recruitment processes. This recruitment process would be the reproduction, and growth of juveniles as this fish tend to reproduce once a year.

M. furnieri fisheries in Brazil are catalogued as least concern (Chao *et al*., 2015) a catalogued as a Medium resilience species with lower to moderate vulnerability based on fishery models (Froese and Pauly, 2019; Cheung *et al.*, 2005). Thought as Pörtner & Peck (2010) presents, there can be stages in its growing cycle where it can be more susceptible to climatic variables forces by climate change. Especially when it is an egg or a larva (Acha *el at*., 2012). In response to climate change species modify their geographical distribution. These changes are generally most evident near the southern or northern boundaries of the species geographic range, where cooling or warming is theoretically assumed to drive marine fishes to lower and higher latitudes, respectively (Pörtner and Peck, 2010). Consequently, these changes are less evident in the medium latitude distribution range of the species. Simultaneously, the effects of warming act on different levels of fish stocks (at the level of organism, population and community and ecosystem), so it is usually very difficult to distinguish and separate the synergistic effect of global warming from the effect of fishing. Particularly this is the case in species that live in mid-latitudes where seasonal differences in temperature and tolerance ranges of species to these variations are wide (Pörtner and Peck, 2010). These processes could be masking the effects of temperature over *M. furnieri* and specially *C. guatucupa* where no correlation is founded. The CCF showed significant statistical relation for *C. guatucupa* and SST *C. guatucupa* capture time series and annual mean SST time series show significant cross-correlation for lags 1,3,4, 5,6,7,9,10,11,12 and 13, that could be explained by variation in the population, specially recruitment affectation by SST.

The relation of AAO with *M. furnieri* can be explained by teleconnection processes, specially the movement circumpolar winds in which AAO index affect the study region (Thompson *et al*., 2011). Also, Chang *et al*. (2015) found relations in the variation of CPUE index of Illex *argentines* and AAO index. This relation shows how AAO index affect SAO conditions that ultimately affects the biota that lives on it. Same relation with AAO index can be happening with whitemouth croaker, specially by the fact that AAO index have shown correlations with interannual rainfall in the SAO (Aravena and Luckman, 2009), which would affect retention and recruitment of larvae of this specie (Acha *et al*., 2012).

11.4.1.Natural mortality of fishes

Natural mortality of *M. furnieri* and *C. guatucupa* increase over the studied period and are completely dependent with the SST as it is the variable in the equation that change. The increase of the empirical Mortality can be even underestimated as K that represent the constant of grow taken from literature can increase when the temperature increase. Even if it is difficult to disclosure exactly the proportion of the increment of natural mortality and SST over the years, the influence seems to be evident. The influence of temperature over fish mortality has been reported by other authors (Pörtner & Peck, 2010). Moreover, mortality can continue increasing if the SST continue rising due to climate change.

The theoretical natural mortality related to temperature calculated in *M. furnieri* and *C. guatucupa*, indicate that the increase in sea temperature would determine the increase in natural mortality of both species. In the North-western Atlantic, different authors show, by different methods, the involvement of the sciaenid's *M. undulatus* and *C. nebulosus* (Miller *et al*., 2011; Diamond *et al*., 2013; Hare *et al*., 2016) due to climate variability and change. It is possible to assume that SAO species may have affectations in close future if the observed trend of increase of SST is maintained. The observed variation range in large-scale in SST the SAO are within the ranges of expected variation for the different phases of the vital cycles of the species under study (CTMFM, 2020; Jaureguizar, 2008; Norbis and Galli, 2013; Froese and Pauly, 2019 and references herein).The study area can be considerate of Meso-scale in which the reproduction and nursery area of both species occur(Macchi *et al*., 1996; Macchi, 1998; Vizziano, 2002; Macchi *et al*., 2003; Norbis and Verocai, 2005; Puig and Mesones, 2005; Militelli and Macchi, 2006; Jaureguizar *et al*., 2008). Furthermore, on a smaller scale, different phases of life cycles may be affected.

There is growing affectation of worldwide coastal environments as it happens in Uruguay. Natural habitats and especially the breeding areas in shallow environments of the water courses that drain to the middle and outer "Río de la Plata" and the Atlantic coast (brackish coastal lagoons), are being degraded by anthropic uses including fishing. Also, the increasingly frequent intense flood and drought events. All these mentioned impacts determine the decrease in the contribution of recruits to the fishery of *M. furnieri* (Fabiano *et al*., 2016), as was also found in the southern Brazil (Vieira *et al*., 1996).

Another population stress indicator in Uruguay cause by the increase of temperature has been the diagnosis of a virus in wild white croaker that affected juveniles and early adults. In 2015, coinciding with the period of one of the positive thermal anomalies of greater magnitude (Martínez *et al*., 2017, present work), Lymphocystis disease caused by a virus of the Iridoviridae family. This was the first diagnosed of virus decease in wild fish populations in Uruguay and in a South American sciaenid (Fabiano *et al*., 2015). The authors propose that environmental stress and in particular high temperatures explain its presence and high prevalence in some environments.

Extra factor that can be impacting over the populations of *M. furnieri* and *C. guatucupa* caused by SST is the increase and persistence of cyanobacteria, dinoflagellates and other bloom forming organisms. This appearance and persistence of blooms of cyanobacteria, dinoflagellates and other bloom forming organisms in the region has been related to SST (Andrinolo *et al*., 2007; Martínez *et al.,* 2017), were the increase would be beneficiating them. The occurrence of this organisms can affect more to *M. furnieri* and *C. guatucupa* young of the year individuals directly or either affect them indirectly by changes in the trophic chain.

11.4.2.Autocorrelation and Partial Autocorrelation analyses

The autocorrelation analyses show significant autocorrelation for the variables Annual mean SST, SSTA, *M. furnieri* capture, *C. guatucupa* capture, CPT index of *M. furnieri* and CPT index of *C. guatucupa*, to a lag of even 5 in the case of SST and SSTA. Although when in the partial autocorrelation analysis only SST, SSTA and Capture of *C. guatucupa* have a significant partial autocorrelation for lag equal to 1. This means that these three variables have a strong effect that condition the value presented in one year based on previous year data.

Partial autocorrelation of SSt shows that the SST of the previous year has an impact on the ones of the next. Being the probable cause climate change, as the tendency is an increment, it is expected that if the previous year increase, the next one will have an increment as well (Dyson, 2005; IPCC5, 2014). In *C. guatucupa* the reason of the autocorrelation of data is that the population respond on dynamics that impact next generation, either by the fact that is an internal population process or being affected by fishery.

11.4.3.Cross correlation analyses

These analyses results have already been discussed in previous parts of the thesis when each variable was tackled down individually. What is important to enhance is that is has been found correlation in different lags between climatic variables and fishery ones, what shows the dependency of the second ones over the first ones. This process has also been found in other fish and mollusc species (Waluda *et al*., 1999; Poloczanska *et al*., 2013; Chang *et al*., 2015; Pranovi *et al*.,2016; Genner *et al*., 2017; Rolim and Ávila-da-Silva, 2018).

11.4.4. Wavelet analyses

The already mentioned correlation of Captures of *M. furnieri* an SST can be appreciated as covariation of these time series when wavelet analysis are presented. What it is even more remarkable is that this covariation also occurs for captures of *M. furnieri* and SSTA and for Z of captures of *M. furnieri* and Z of SST. This gives more statistical significance in the covariation between captures of *M. furnieri* and SST. Also, wavelets analysis of *M. furnieri* shown a similar pattern of coherence when CPT index and standardized CPT index were analysed towards SST, SSTA and Z of SST. These wavelets (captures and CPT index of *M. furnieri*) also show that at a scale equal to 0 the covariation is almost present all the time, with higher values between the periods of 1985 -1990, 1998-2002 and 2007-2013.

These higher values are characterized by presenting embed a strong “Niña” event (Negative face superior to -0.5 in our ONI index). The years that “Niña” event occurs are 1985, 1988 and 1989 in the first area of correlation; 1999 and 2000 in the second area of correlation; and 2008 and 2011 in the third area of correlation. The process working behind could be that events of la “Niña” dramatically decreases rainfall in the “Río de la Plata” basin and consequently decrease the runoff of “Río de la Plata” (Nagy *et al*., 1998; Robertson and Mechoso, 1998) and this would be promoting mechanisms of retention of larvae of *M. furnieri* that is traduced in increase of recruitment of the specie (Acha *et al*., 2012).

El “Niño” process appears to be related in appearance to higher scale (4,6 and 7 to 11) in the wavelets. This suggest that there is an effect of el “Niño” that generate dependency with the temperature after that period. The mechanism behind could be that ONI index increase the rainfall over the basin which increase the runoff of “Río de la Plata” (Nagy *et al*., 1998; Robertson and Mechoso, 1998). As mentioned before, the runoff affects the mechanisms of larvae retention and recruitment (Acha *et al*., 2012), thing that would affect after the grow of the individuals, and it populational dynamic (period of 4 to 7 years) the captures and CPT index of *M. furnieri*. Also, the cohorts of *M. furnieri* present a cyclic distribution with peaks occurring in a period that round 6.5 years related to the ONI index (Acha *et al*., 2012).

Something remarkable that allow to predict changes in the fishery, specially of *M. furnieri* is that when a very strong ONI index is present in the Pacific Ocean (magnitude 3.5 or 4), It is related to a greater increase in runoff in the Rio the la Plata (Nagy *et al*., 1998; Robertson and Mechoso, 1998) and fishery in a period after 6 years will be affected as shown in the wavelets. For *M. furnieri* and *C. guatucupa* (captures and CPT index) analysed towards SST, SSTA and Z of SST, at scale 0 shows that the "tails" of the data have strong influence when correlating them. Explanation for this process would be the fact presented by Pörtner and Peck (2010). They say that nektonic species have an optimum range of temperature, and out of it they are affected. This optimum range would be in the period of 1990 to 2007, taking out the period of 1998 to 2002 where rice of temperature occurs in 1999. On the period that there is no correlation is because the temperature is in the optimum range and is not playing part, and the population is being regulated by other factors.

11.4.5.Statistical Models.

Different climatic variables explain in LM and GAM models the behaviour of *M. furnieri* and *C. guatucupa* captures and CPT indexes. The relation between captures *M. furnieri* and SST explained by LM 1 has been deeply analysed previously in the text. A GAM that can explain the captures of *M. furnieri* based on the variables of Annual mean SST and AAO index was adjusted (GAM 2). This model is suggesting that the capture of *M. furnieri* is corelated into these variables. The interactions happening behind can be explained by process mentioned before. The role of SST has been explained previously. The produced changes by AAO index in precipitation, wind, and SST variability (Silvestri and Vera, 2003; Turner *et al*., 2007; Justino and Peltier, 2008; Vasconcellos and Cavalcanti, 2010; Chang *et al*., 2015) it is novel for the species and can be playing a role over the distribution, abundance and biology of the species, that should be studied more deeply.

A GAM that can explain the CPT index of *M. furnieri* based on the variables of Annual mean SST, AMO index, ONI index and AAO index was adjusted (GAM 3). This model is suggesting that the CPT index of *M. furnieri* is corelated into these variables. The interaction happening behind can be explained by process mentioned before, and the same can be done for GAM 2. Adding ONI index that affects the runoff of "Rio the la Plata" (Nagy *et al*., 1998; Robertson and Mechoso, 1998) which ultimately affects the recruitment of this species (Acha *et al*., 2012). AMO index can be showing influence over the study area as presented by Seager *et al*. (2010) and Ortega (2013).

A GAM that can explain the CPT index of *C. guatucupa* based on the variables of Annual mean SST and runoff of "Río de la Plata" was adjusted (GAM 4). This model is suggesting that the CPT of *C. guatucupa* is corelated into these variables. The SST and Runoff are the main variables that affect primary production (Garcia and Garcia, 2008; Vögler *et al*., 2015). Changes on primary production can be creating a trophic cascade that ultimately affects *C. guatucupa*. Also, this species tends to aggregate close the end of the discharge plume of "Río de la Plata" (Acha *et al*., 2004; Norbis and Galli, 2013). This effect is not direct and would be affecting the spatial distribution of the species.

The problem is that complex models are not so easy to understand and some time they only reflect numerical relationships missing the point of real biological process. Thought as an analysis, is important to take out which variables can be influencing in the behaviour of the population and so on the CPT and the catches of this specie. Furthermore, this model can be used to predict the behaviour of the captures and the CPT index of both species in a future time.

12. Species considerations.

M. furnieri and *C. guatucupa* are considered Resilience and medium vulnerability species (Froese and Pauly, 2019). The distinction between the two species is that *M. furnieri* depends mostly of shallow estuarine waters for its reproduction while *C. guatucupa* is a marine reproducer. Estuarine environment and specially “Rio de la Plata” is more variable (specially in temperature and salinity) than the oceanic environment (Nagy *et al*. 1998). This make the first species (even that is more resistant than the second) more susceptible to SST. This would explain why relationships between the capture and the CPT index of *M. furnieri* have been found while this relation has not been found with the capture of *C. guatucupa* and the relation with SST and CPT index of *C. guatucupa* is less robust. The mentioned effects of clime over the species is crucial, not only to the species itself, if not to the whole fish community as this species has been identified by Lorenzo *et al*. (2011) as main components of some of the fish assemblage of the region.

The effect of temperature changes that leads to a warmer change of scenery from the years 1996-1998 (Barros *et al*., 2005; Paesch *et al*., 2014; Martínez *et al*., 2017; present study), which continues with a growing trend (Martínez *et al*., 2017, actual study) the effect of the phenomena the “Niño” (increases in the flow of the “Río de la Plata”) and the “Niña” and the decrease in catches and capture by effort (Lorenzo, 2016) from 2006, with a fishery that remains closed since 1990, seems to indicate that the decent of *M. furnieri* catches would be affected by the new warming scenario in the region.

For *C. guatucupa* it is observed a decrease in catches since 1997, as well as the significant CPT index, an effect of the “Niño” on the spatial distribution of the resource related to its stenohaline preference (Lorenzo *et al*., 2011), which would indicate that SST increase in the region translates into a decrease in catches, since the relationship with the annual mean SST in the GAM 3 were significant.

13. Main Conclusions of the Research

The main aim of this thesis was the investigation of the potential effects of unfolding climatic conditions in two of the most important commercial fish species for the fishery of Uruguay, the species are *M. furnieri* (whitemouth croaker) and *C. guatucupa* (stripped weakfish). The study area for the investigation was the current, suitable habitat for these species in the shared fishing waters of Argentina and Uruguay. This is a coastal region extending from the boundary of Uruguay with Brazil (approximately 34 Latitude South) to the huge estuary of the "Río de la Plata" and the coast of Argentina (approximately 39 Latitude South). A comprehensive research was undertaken, and the results obtained were explained.

Long-term data from 1982 to 2018 was compiled (when available), developed (when not available or not existing in an appropriate form) and then analysed. The climatic variables analysed included SST, SSTA; as well as different climatic indexes such ONI, AMO, AAO; and the runoff of "Río de la Plata". The fisheries variables were landing, natural mortality, and the number of vessels and their fishing trips. The economic variable analysed was fish market-price. To examine relationships between climatic variables and fishery landings, several methods were applied including trend analysis, autocorrelation and partial autocorrelation analysis, Wavelets Analysis and GAMs.

Based on the results of the research, it can be unambiguously stated that climate variability affects the captures and CPT index of *M. furnieri* and *C. guatucupa*. The climatic effects are stronger in *M. furnieri* than in *C. guatucupa*. It is infer that this situation is a consequence of *M. furnieri* spawning in nursery areas are in shallower waters in the estuary of "Río de la Plata" and coastal lagoons, which are mostly affected by climate variation (primary impacts by temperature and runoff of the "Río de la Plata"). While *C. guatucupa* spawns in the oceanic coastal area close to the river-mouth of the estuary, where waters are deeper.

In the study area, temperature tend to increase over time, during the same period where captures and CPT index of *M. furnieri* and *C. guatucupa* tend to decrease. This fact is supported by the result of wavelets analysis and GAM models that allow me to conclude that

SST and SSTA have a major impact in the population of these two focus species. Although it cannot be fully proven that temperature is the primary cause for the decrease in population of the species (to do that further research would be needed), there are many relevant results from my research that indicate that temperature is undoubtedly having a significant effect in the population of both species, especially in *M. furnieri*. Furthermore, a CPT index relationship with the runoff of the “Río de la Plata” were found, which further supports the conclusion that the populations of both species are clearly affected by climate variation. Another remarkable point is that the CPT indexes of both species are linked by GAMs to climatic factors.

The methods and models applied are certainly very useful to analyse the behaviour of the CPT index of *M. furnieri* based on SST, ONI index AMO index and AAO index and *C. guatucupa* based on SST and the river runoff during the study period.

The knowledge generated in the present study can be the cornerstone for an important research path leading to the incorporation of climatic variability and climatic change effects in the fishery management and legislation focused on the two of the most important commercial species for Uruguay, Argentina and Brazil.

14. Foresight.

As the research shows, *M. furnieri* and *C. guatucupa* are being impacted by the SST increase, and the impacts are likely to be much more severe in the future. This is also the case for many marine ecosystems and multiple fisheries around the world (Tommasi *et al*., 2017). For instance, the mean temperature effect has been demonstrated for the species in the catch category class B (Gianelli *et al*., 2019) – category in which both studied species are included. The observed trends of the last ten years for the captures of *M. furnieri* and *C. guatucupa* have decreased while SST trends show that they will continue rising.

These remarks can be placed within the scope of a dangerous plausible future where the fishery of both species will be strongly affected by climate change and, as a local expression, the increase in SST. Taking this into account, it is essential that the conditions for the fishery of concern are rethought to ensure their adaption and, become more resilient, to unfolding climatic changes and other drivers. As mentioned, major drivers of change in the fishery include overfishing, pest, and illnesses, change of prices in the international markets.

In particular, the trend in the increase of prices for fish products and the predicted continuation of this trend by FAO (2018) are similar to the prices registered in this thesis of *M. furnieri* and *C. guatucupa*. This tendency must be managed carefully by stakeholders as it can easily drive to overexploitation of the resource due to an increase in demand, if strong management measures are not put in place (Roughgarden and Smith, 1996; Pascoe, 2006; Baeta *et al*., 2009; Tsikliras and Polymeros, 2014).

As an alternative to industrial fisheries - which in most cases over the world over-exploit the stocks of fishes if they are not properly regulated (Peterson *et al*., 2018) - there is the possibility of promoting small scale and regional/local fleets fisheries. This type of artisanal fishing already exists in Uruguay, and could be promoted to better compete with industrials and encourage the emergence of local entrepreneurs and the creation of local jobs. This possibility does not imply, however, that industrial fisheries cannot continue, but that they should be re-constituted based on the idea of B-Corporations (as discussed by Haymore, 2011) by having both a profit aim and eco-systemic aim as well. This kind of business balances purpose and profit. B-Corporations are legally required to consider how their decisions impact on their workers, suppliers, customers, community, and, importantly, the environment (Reiser, 2011).

Nevertheless, in any plausible future, both industrial and artisanal fishery must consider climate change as a major threat to their survival. This thesis demonstrated how industrial fishery is affected by climate whilst the effects on artisanal fishery has also been proven by various authors (Norbis, 1995; Nagy *et al*., 2008). These facts clearly indicate that climatic variation and change must be a primary concern when formulating management regulations to achieve sustainable fisheries, in particular, for *M. furnieri* and *C. guatucupa*. Figure 41 provides a conceptual signpost for this fishery becoming resilient and robust to changes.

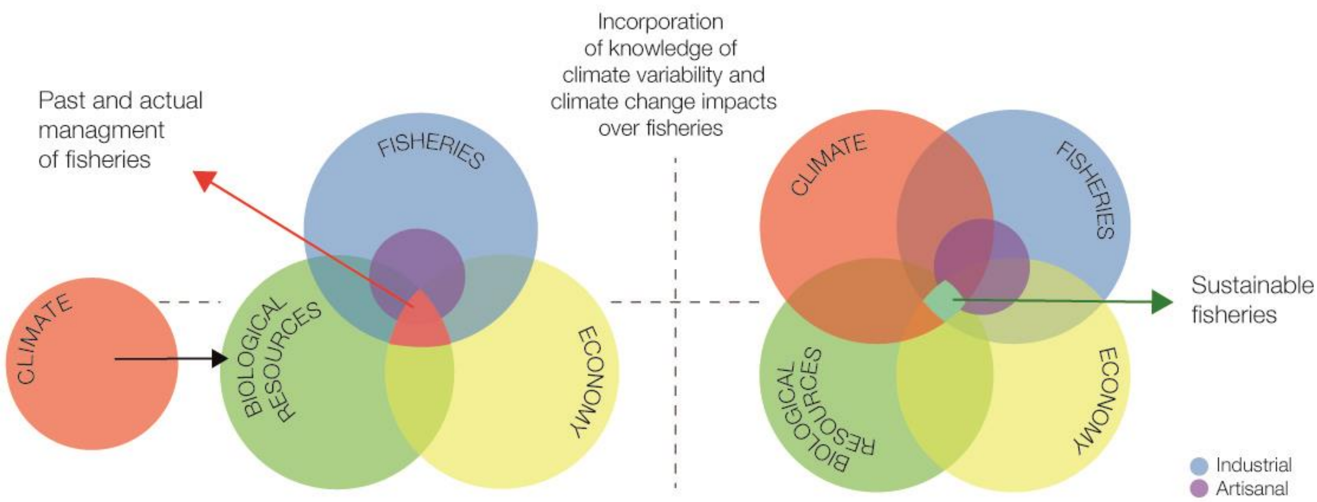


Figure 41. Scheme representing the incorporation of climate change and climate variability into fishery management to achieve sustainable fisheries, that are robust to change and adapt to climate change threatens. Inside the fishery, artisanal and industrial fleet can be distinguished.

15. Further Research

To further analyse the population dynamics of the focus fisheries, it would be necessary to have data on the ‘effort of fishing’, to achieve the Capture per unity of effort (CPUE). In this research, it was not possible to obtain these data from DINARA and for this reason the CPT was used, which, is nevertheless, a good indicator of effort. Also, if the fishing institute would provide more detailed data, it would be convenient to focus the analysis on smaller geographic areas instead of using the whole coastal region gaining more resolution in the study.

A climatic parameter that would enrich the investigation if included in the analysis would be the salinity in the study area. The possibility of investigating this indicator is hampered because there is not a complete timeline data of salinity and the ones available are not accurate and depend on river water make measurements generally obtained via satellites. Bottom temperature would be another interesting climatic parameter to include in the future, though this variable has not been recorded in a continuous series of time, neither in the whole space of the study area.

Chlorophyll as and estimation of primary production could be also included to trace its effects over the species. Even the of Chlorophyll effects over this species is not direct as they are strongly associated to the bottom of the water column some interesting patterns may reveal. With the inclusion of appropriate data of Chlorophyll, it would be interesting to analyse food chain webs that sustains the fisheries, nektonic organisms in the case of *C. guatucupa* and benthonic in the case of *M. furnieri*. Analysing the food chain will give a broader picture on how the whole marine ecosystem is affected by climate change and would allow to both easier and earlier predict changes on the ocean resources

Another focus of further investigation would be to analyse the fish behaviour of the whole community. The problem hindering this possibility is that not many attention is placed in the register of the by-catch species by fishermen and past information of this type usually has many gaps. Along these lines, it would be interesting to transfer the analysis of this thesis to the other types of fishing fleets with different target captures; for example, in category A of fishery analyse *Merluccius hubbsi* and bycatch species. This would give Uruguay and its decision-makers a sound understanding on how climate change affects the whole of its fisheries, thus allowing to develop comprehensive policies that promote adaptability and resilience against the serious threat of climate change.

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17. Appendixes.

Appendix 1. In this figure all the variables are correlated between each other, applying Pearson correlation coefficient. On the top half of the square the correlation index is presented. When the correlation is significant it is represented in green or red colour depending if it is a positive or negative correlation. Also, this correlation is graduated by stars, having more stars mean more significance of the correlation. In the bottom half of the squere, graphic of the variables is precented, with the tendency line plot on it.


YEAR
Annual.mean.SST
Anomaly.1982.2018
Z.SST
Capture.M.furnieri
Capture.C.guatucupa
Number.of.trips
CPT.M..furnieri
CPT.C..guatupuca
Runoff
Z.Capture.M.furnieri
Z.CPT.M..furnieri
Z.CPT.C..guatupuca
Price.M.furnieri
Price.C.guatucupa
Annual.maximum.SST
Annual.minimum.SST
AMO.index
AAO.index
ONI.index