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TESI DI LAUREA

“ANOMALIES IN FIN WHALE DISTRIBUTION IN THE PELAGOS SANCTUARY”

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ABSTRACT

The Pelagos Sanctuary is the only pelagic marine protected area in the northwestern Mediterranean Sea.

This area has been established in 2002 for the protection of marine mammals inhabiting the area and their habitat. Here 8 cetacean species are regularly found; among these 7 odontocetes and 1 mysticete: the fin whale, the species target of our study.

the aim of this study is to investigate anomalies in specie distribution pattern and correlate them with anomalies occurring in species habitat.

Our dataset span from 2004 to 2020 We have first analysed environmental parameters directly connected with the spring phytoplankton bloom occurring in the area, such as sea surface chlorophyll concentration and Sea Surface Temperature; Secondly, we analysed fin whale distribution pattern; Finally, we investigate possible correlations.

ABSTRACT IN ITALIAN

Il Mar Mediterraneo è un mare semichiuso che racchiude in sé una grande biodiversità.

All’interno del Mar Mediterraneo, nella parte più a nord, nel 2002, è stata istituita un’area marina protetta pelagica chiamata Santuario Pelagos. Questo Santuario è nato da un accordo tra Francia, Italia e Monaco per proteggere la biodiversità che sta al suo interno.

Una delle specie regolarmente presenti all’interno del Santuario Pelagos è la balenottera comune (*Balaenoptera physalus, Linnaeus 1758*). La balenottera comune è un misticeto i cui maschi posso crescere fino a 22m, mentre le femmine 24m e ha un peso che va dalle 30 alle 80 tonnellate.

Esse hanno la pinna dorsale a due terzi del corpo e a differenza del capodoglio non mostrano la pinna caudale quando si preparano all’immersione.

A livello di habitat, la balenottera comune predilige fondali piatti e fangosi, con profondità che superano i 2000m e con temperature che oscillano dai 17°C ai 26°.

La popolazione presente nel Mar Mediterraneo è una popolazione residente e geneticamente isolata rispetto alla popolazione dell’Oceano Atlantico e ciò è stato dimostrato sia da analisi del DNA sia da analisi acustiche svolte sui maschi riproduttivi attivi. Di conseguenza ciò che possiamo dire è che nel Mediterraneo vediamo due popolazioni, una residente e una visitatrice, che è appunto quella dell’Oceano Atlantico, che entra nel Mediterraneo tramite lo Stretto di Gibilterra solo in alcuni periodi dell’anno.

La balenottera comune è una specie che va incontro ad una variabilità annuale; il che vuol dire che nel corso degli anni vedremo anni ricchi e anni meno ricchi, e una variabilità stagionale; il che significa che ci saranno periodi, come quello estivo, in cui avremo un’abbondanza di individui all’interno del Santuario Pelagos che nei periodi invernali si disperderanno. Questa dispersione invernale non interessa tutti gli individui, infatti alcuni andranno a sud (zona di Lampedusa), mentre altri mostrano una fedeltà all’area del Pelagos.

La balenottera comune si ciba di una specie di krill, l’Euphausiid *Meganyctiphanes norvegica*, che è una specie di zooplancton che ha una variabilità giornaliera e stagionale per quanto riguarda le profondità a cui li si può trovare.

Un’altra preda, presente nel Mar Tirreno e nello Stretto di Gibilterra è il krill Euphausiid *Nyctiphanes couchi*, con il quale le balenottere mostrano una diversa strategia alimentare.

A causa delle molteplici minacce antropiche a cui sono sottoposte le specie presenti nel Mediterraneo e in particolare nel Santuario Pelagos, la balenottera comune è considerata Vulnerabile (VU) dalla Lista Rossa della IUCN.

Ciò che la minaccia maggiormente è il rischio di collisione con le navi, soprattutto in estate, poiché il traffico navale aumenta esponenzialmente in questa stagione.

La nostra area di studio è appunto il Santuario Pelagos; il nostro dataset di balenottere comuni viene dalle osservazioni fatte da barche di whale watching mentre i dati ambientali sono stati scaricati da Copernicus Marine Service.

In entrambi i casi il dataset copre un periodo che va dal 2004 al 2020, anche se per i dati di balenottera c'è una mancanza di dati che va dal 2008 fino al 2015 compresi.

Per l'analisi dei dati ambientali ci siamo dedicati alla concentrazione di clorofilla e alla temperatura superficiale del mare. Questi due parametri son stati scelti perché rappresentativi rispettivamente, della fioritura primaverile, che si pensa influenzi la presenza/assenza di balenottera e di altri parametri come pioggia, vento e irraggiamento solare.

Per quanto concerne l'analisi della concentrazione di clorofilla abbiamo estrapolato la fioritura primaverile in tutti gli anni per vedere se ci sono state delle variazioni.

La temperatura superficiale è stata analizzata in relazione alla fioritura primaverile; quindi, i dati son stati presi per tutti gli anni del dataset ma solo nei mesi del bloom, quindi da gennaio a maggio.

Il nostro dataset è troppo limitato per poter affermare una variazione ambientale, ma abbiamo preso queste analisi solo in funzione della distribuzione di balenottera, non fini a sé stessi.

Grazie a letteratura siamo riusciti a capire come stabilire l'inizio e la fine della fioritura primaverile; abbiamo usato rispettivamente il calcolo dell'anomalia e il metodo Threshold.

Il primo è un metodo che tramite la somma cumulativa dell'anomalia e il suo cambiamento di segno da negativo a positivo, ci ha permesso di risalire, anno per anno, all'inizio della fioritura.

Il secondo metodo è basato sul calcolo della mediana. Siccome siamo nel Mar Mediterraneo, a differenza dell'articolo da cui abbiamo preso spunto, al valore della mediana dobbiamo aggiungere il 20% della stessa, poiché è un mare molto eutrofico.

Questi due metodi son stati calcolati utilizzando il programma Rcmdr, che ci ha aiutato a calcolare anche la regressione lineare.

La regressione lineare ci ha permesso di avere una tendenza statisticamente significativa della media di concentrazione di clorofilla e di altri parametri come il picco di massima concentrazione e la fine della fioritura primaverile.

Quello che è risultato è che la concentrazione media di clorofilla sta diminuendo anno per anno, come stanno diminuendo il picco di massima concentrazione e la fine della fioritura.

Oltre alla tendenza in diminuzione abbiamo notato che vi sono degli anni anomali, al di fuori dell'intervallo di confidenza del trend della concentrazione media di clorofilla.

In seguito, abbiamo analizzato la temperatura superficiale dell'acqua in relazione ai giorni della fioritura e abbiamo visto che la temperatura media nei mesi della fioritura è in aumento anno per anno e anche in questo caso abbiamo riscontrato anni anomali, al di fuori dell'intervallo di confidenza.

In entrambi i casi ciò che abbiamo notato, anche se appunto non possiamo dirlo con certezza poiché il dataset non è abbastanza esteso, è che la concentrazione di clorofilla nel corso degli anni sta diminuendo, mentre la temperatura superficiale

dell'acqua sta aumentando e che la fioritura primaverile sta finendo sempre prima di anno in anno.
Per l'analisi degli avvistamenti di balenottera comune abbiamo utilizzato sempre il programma Rcmdr.
Prima abbiamo fatto un boxplot di avvistamenti in relazione a batimetria a distanza dalla costa: in entrambi i casi quello che possiamo vedere è dove si trova la mediana in relazione a distanza e batimetria.
In relazione a ciò abbiamo utilizzato il Kruskal-Wallis Test e il PostHoc Test che ci mostrano quali anni sono simili tra di loro. Il PostHoc Test viene fatto dopo che nel KW Test il p-value risulta minore dello 0.05.
L'output del PostHoc Test è una tabella in cui compaiono sia gli anni che le lettere, a lettere simili corrispondono anni simili e quindi abbiamo potuto capire quali anni appunto si assomigliano tra loro e quali no.
Un'altra analisi fatta sugli avvistamenti è un istogramma di frequenza in relazione sempre a batimetria e distanza dalla costa. Grazie a questo abbiamo capito con quanta frequenza e dove sono avvenuti gli avvistamenti di balenottera comune.
A questi abbiamo aggiunto come dato lo sforzo di campionamento, ossia le tracce delle barche registrate con il GPS, poiché non si possono confrontare anni con sforzi differenti.
A questo punto abbiamo sovrapposto i dati degli avvistamenti con quelli dello sforzo di campionamento per capire qual è stata la frequenza di entrambi in relazione alla profondità.
Quello che possiamo concludere è che c'è una corrispondenza tra gli anni in cui è stata rilevata un'anomalia nella fioritura primaverile e gli avvistamenti di balenottera comune. Visti i risultati però non possiamo affermare con certezza che c'è una correlazione tra queste due variabili ma avendo un dataset più ampio per quanto riguarda la concentrazione di clorofilla e analisi più approfondite che riguardano anche altre variabili ambientali come vento, pioggia, etc., magari si potrà arrivare ad avere una conferma riguardante questo studio "preliminare".

1. INTRODUCTION

1.1 Ecology of the Pelagos Sanctuary

Pelagos Sanctuary is the only pelagic marine protected area in the Mediterranean Sea. It has been created in 1999 and covers 87.500m^2. It has been established in 2002 through an agreement between France, Italy, and Monaco to protect cetaceans that inhabit the area (Notarbartolo di sciara et al, 2008). This protected area includes the Ligurian Sea and part of the Corsica and Tyrrhenian Sea (Notarbartolo di Sciara et al, 2008). Species mostly found in the area are common bottlenose dolphins (*Tursiops truncatues*), striped dolphins (*Stenella coeruleoalba*), Risso's dolphin (*Grampus griseus*), short-beaked common dolphins (*Delphinus delphis*), sperm whale (*Physter macrocephalus*), fin whale (*Balaenoptera physalus*), Curvier's beaked whales (*Ziphius cavirostris*) and long-finned pilot whales (*Globicephala melas*).

The Pelagos Sanctuary is a key area for Mediterranean cetaceans (Notarbartolo di Sciara et al, 2008) because contains essential habitat and the major summer feeding grounds (Panigada et al, 2017).

Pelagos includes extensive areas of deep waters and have a narrow continental shelf (Jahoda et al, 2003). The dominant circulation is modulated by intense mesoscale activity characterized by cyclonic and anticyclonic fronts (Druon et al, 2012).

Specifically, the Liguria province is an area of cyclonic currents between Corsica and the mainland (Laran and Gannier 2008) which continues south of the Channel of Ibiza where has been renamed "Northern Current".

In summer this current is shallow and wide and displays a reduced mesoscale variability; in winter it becomes thicker and narrower and tends to flow close to the slope. From winter to spring, an intense and barotropic mesoscale propagates and induce seasonal variability (Millot 1999). The "Northern Current" flows along the continental slope, but there is another current that is associated with the North Balearic front (Cottè et al, 2012).

In winter, there is also wind, and the dominant is "minstral", instead, during summer, the wind regime is much changeable, but still capable to strongly affect the upwelling, pumping deep nutrients and other organic substances contributed by rivers into the eutrophic zone (Azzelino et al, 2012; Agostini et al, 2002). Floods events are characteristic of most Mediterranean river systems and, in addiction, Rhone and Ebro rivers dominate the discharge on the north of the Mediterranean Sea (Arnau et al, 2004).

1.2 Fin whale in Pelagos Sanctuary: distribution, ecology, threats and conservation implications

Fin whale (*Balaenoptera physalus*, Linnaeus, 1758) is a cosmopolitan mysticete currently found in all major oceans and it is the second largest whale after the blue whale (Berubè et al, 1998). Male fin whales can grow up to 22meters and female can grow up to 24m (Ray G. 1985), and they can weight from 30tons to 80tons (Lockyer C. 1976).

Fin whale's dorsal fin is placed at two-thirds of the body length, near the back. The species has a straight and 4-6m high blow (Ray G. 1985) and does not show its caudal fin going under the surface (Panigada et al, 1999).

Fin whales show an asymmetrical pigmentation pattern: white or pale grey lower and upper lips and apical third of baleen on the right side of the head, and dark on the left side; a whitish patch extending dorsally and caudally from the right side of the head; and a light V-shaped pattern with a rostrally orientated apex caudal to the blowholes, curving back down on both sides and often brighter on the right side (Notarbartolo di Sciara et al, 2003)

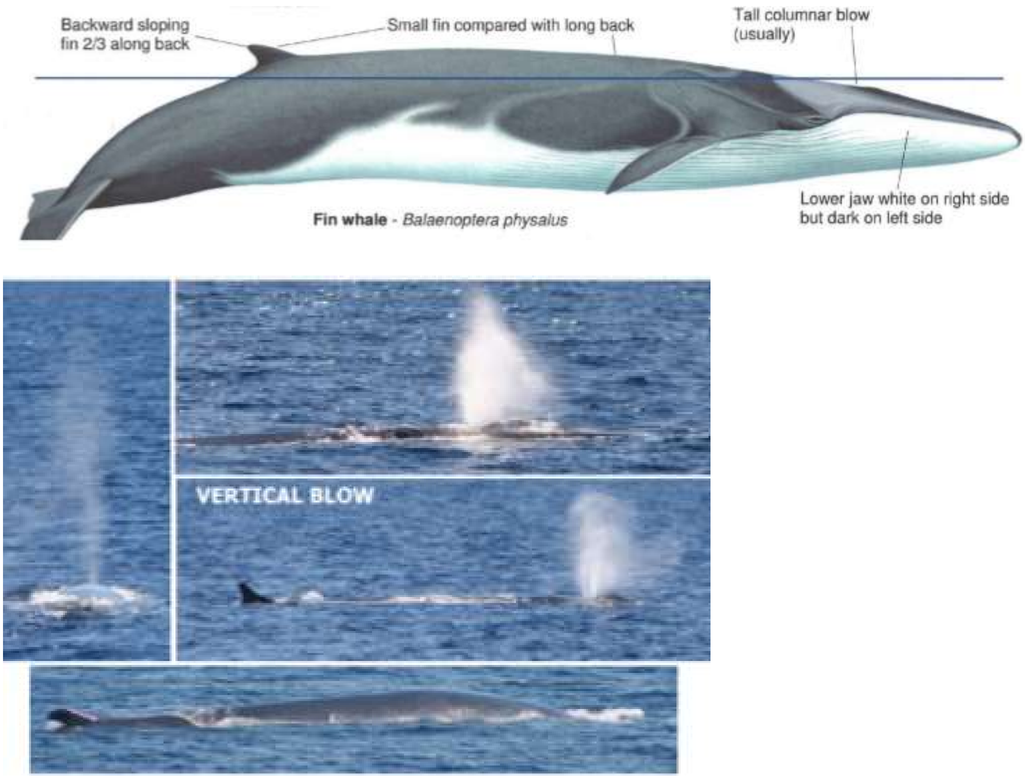


Fig 2 (imagine taken by CIMA Foundation Handbook of Mediterranean species): Fin whale characteristics: dorsal fin 2/3 along back, vertical, and straight blow.

1.2.1 Distribution:

Fin whale is a pelagic mobile cetacean (di Sciara et al, 2013) and its habitat is characterized by depths exceeding 2000m, regions where the seabed is relatively flat and with consistently high chlorophyll concentration during the annual spring bloom (Laran and Gannier 2008; Druon et al, 2012).

Mediterranean fin whales are a resident population, reproductively isolated from the population of the North Atlantic Ocean (Notarbartolo di Sciara et al, 2003). This assessment has been confirmed by acoustic analysis, which identified clear differences between songs from Mediterranean fin whale and North Atlantic fin whale. These acoustic results also demonstrate that some male of North Atlantic fin whale subpopulations cross the Strait of Gibraltar and enter the Mediterranean Sea remaining near the Strait. Male of the Mediterranean fin whale do not include this area in their distribution range.

The northwestern Mediterranean Sea is then a regular area for a resident Mediterranean population, and a seasonal area for individuals from the North Atlantic population (Castellote et al, 2012).

The species is not homogeneously distributed in the Mediterranean basin. Dividing the Mediterranean Sea into sub-regions, moving from north to south it is possible to highlight: Western Basin, Ligurian-Corsican-Provençal Basin and Gulf of Lions, where the species is regularly present; Tyrrhenian Sea where the species is present, Aegean Basin where the species is rare or absent, Levantine Basin where we don't have information (Fig 3).

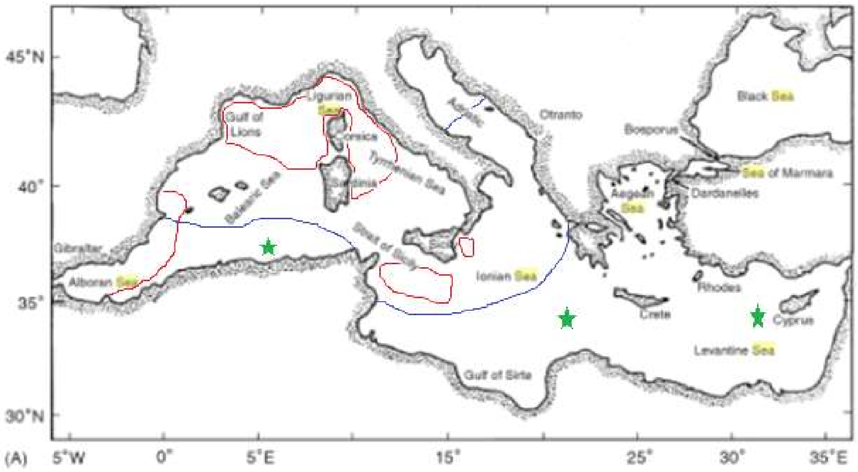


Fig 3: Map of the Mediterranean Sea, showing currently known geographical ranges of fin whale populations: red = Mediterranean sub-population regular, blue = Mediterranean sub-population present, white = Rare or absent, green = Missing information (Geijer et al, 2016).
Mediterranean Sea imagine taken by Malanotte-Rizzoli, 2001.

1.2.2 Ecology:

Mediterranean fin whale prefers sea surface temperatures from 17° to 27°C, with a frequency peak in the range between 20° to 23°C (di Sciara et al, 2013). The species preferred habitat is the pelagic realm above depths ranging from 2100 to 2800m. The species shows a preference for deep slope areas; it has been demonstrated that in fact, with increasing depth and seabed slope, the probability to find fin whale increase (Azzelino et al, 2012).

Their feeding habitat is identified in specific areas: the Alboran Sea, the shelf break area of the Gulf of Lions, the Ligurian Sea, and the southern Adriatic Sea (di Sciara et al, 2013).

Euphausiid *Meganyctiphanes norvegica* (Fig 4), is the target prey of fin whale in the Ligurian Sea and can be found between 0m to 150m during night but between 75m and 800m during the day. They perform a monthly vertical distribution: from January to March the maximum is 150m but in April the maximum is 300m. During months, depth increase and overcome the 1000m depth registered in May; apart from August, in which depth decrease at 700m and continue to become shallower during autumn and winter periods (Panigada et al, 2017). *E. Meganyctiphanes norvegica* also show a large, dense, and deep swimming schools, which is a precautionary behaviour to avoid predation from fin whales (Notarbartolo di Sciara et al, 2007).

In Tyrrhenian Sea and Gibraltar Strait, fin whales feed on another krill species, Euphausiid *Nyctiphanes couchi* (Fig 5) (Brody et al, 2013), this has been demonstrated thank to the observation of a different feeding strategy (Canese et al, 2006).

Fig 4: Euphausiid *Meganyctiphanes norvegica*: Prey chosen by fin whale in the Pelagos Sanctuary area (https://www.marinespecies.org/aphia.php?p=taxdetails&id=110690#images)

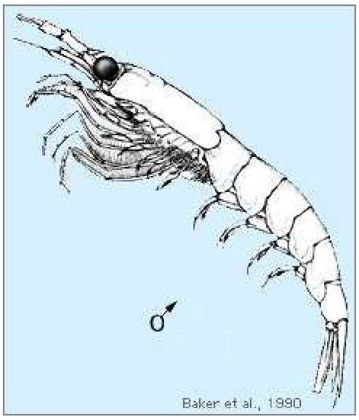


Fig 5: Euphausiid *Nyctiphanes couchi*: Prey chosen by fin whale in Tyrrhenian Sea and Strait of Gibraltar (http://species-identification.org/species.php?species_group=zmns&menuentry=soorten&id=450&tab=multimedia).

In the Ligurian Sea, krill swarm, has been reported in spring, summer, and autumn along the coast of western Liguria, southern France, and Monaco during the winter months (Panigada et al, 2017).

Fin whale use two different diving patterns, in relation to vertical migrations of their prey. They perform shallow and deep dives at different times of the day (Pace et al. 2015), they spent short time at the surface with low breathing frequency and then a short diving-period, which suggest that whales first filter the zooplankton (Notarbartolo di Sciara et al, 2007).

Their way of feeding is different from their usually diving patterns: they generally perform shallow dives of less than 100m with an average duration of 7.1minutes, after them they start performing deeper dives at depth that exceed 500meters (Panigada et al, 1999).

Fin whale's prey presence is related to phytoplankton bloom that thanks to literature we know that appear usually in March, when the surface layer stabilizes but also in autumn when the thermocline is progressively eroded (Bosc et al, 2004).

A potential feeding habitat is based on the persistence of mesoscale productive fronts, which allows a high rate of energy that can attract macro-zooplankton and/or forage fish, a particularly favourable niche for top-predators (di Sciara et al, 2013).

Fin whale distribution, in fact, could be result of the development cycle of the first trophic levels, which means that fin whale grouping is linked to availability of prey, which is determined by primary production (Laran and Gannier 2008).

1.2.3 Threats:

The Mediterranean Sea is a semi-enclosed basin where several human activities take place. Therefore, cetacean population inhabiting the area are exposed to several threats, such as: habitat loss and degradation, interaction with fishery and by-catch, trammel and bottom gillnets, driftnets, longline, trawlers, purse seine, bycatch, mariculture, overexploitation, human disturbance by boat traffic, pollution (chemical, marine litter, noise), genetic erosion, intentional killings, collisions (Pace et al, 2015) (Fig 6).

Fig 6: Here there are two examples of fin whale collisions: the first image shows a wounded fin whale in the Ligurian-Corsican-Provençal basin with propeller scars; the second shows a fin whale left caudal lobe excision, possibly because of a collision with a ship (Photograph by IFAW – Song of the Whale) (Notarbartolo di Sciara et al, 2003)

The intensity of cetacean's response to threats shows differences among areas and species. This suggest that there are many factors involved in each species priorities; these priorities are a combination of specific ecological needs and local environment conditions (Campana et al, 2015).

The Mediterranean fin whale population is listed as Vulnerable (VU) in the IUCN Red List. This assessment is due to the declining in population number and the evidence of human-induced death from ship strikes (Panigada et al, 2017).

The western part of the Pelagos Sanctuary is more interested in traffic from mainland France to Corsica.

If we consider the fact that maritime traffic in this area is unavoidable, the only option is to develop and implement traffic impact mitigation measures. This can be implemented through Marine Spatial Planning framework to identify the spatial overlap between cetacean distributions and anthropogenic pressures (Coomber et al, 2016).

The presence of fin whale along main traffic corridors, results in the presence of risky area (Grossi et al, 2021).

The fact that fin whale feeding habitat and main traffic corridors match, imply their change in swimming and respiratory patterns.

If they are disturbed, they abandon they activity and start with a wide-ranging activity, like travelling with an increased speed. Another avoidance behaviour, consist in a reduction of time spent at the surface (Hamazaki T. 2002).

Considering the impacts of marine traffic on the species, France has issued a decree, on the 8th of March 2017, where vessels must use systems to signal in real time the presence of cetaceans in the Pelagos Sanctuary. These conservation measure has been recently integrated in the Marine Strategy Framework Directive by Italy (DPCM 10 October 2017) (Grossi et al, 2020).

Plastic pollution is another threat in the Mediterranean Sea (Cozar et al, 2015).

Mediterranean Sea and particularly Pelagos Sanctuary, is exposed to risk of microplastics (Fossi et al, 2016), there may be areas where, due to currents, there is an overlap of feeding grounds and areas of high concentration of microplastics, especially in the external part of cyclonic and anticyclonic currents (Druon et al, 2012).

One other important threat is pollution; in some studies, have been highlighted the fact that POPs (Persistent Organic Pollutants), or other contaminants, can have negative effects on fin whale health (Mancia et al, 2021).

A combination of disturbance could contribute to a decline of all already rare maritime species (Sardou et al, 1996).

1.2.4 Conservation implications:

There are conservation implications for the fact that the Mediterranean fin whale is an isolated population from those inhabiting the Atlantic Ocean.

Considering its small size and the partially degraded habitat environment, this population is considered Vulnerable (VU) by the IUCN Red List.

One important strategy to adopt in fin whale conservation involves setting priorities for research.

Feeding and breeding areas must be recognized and protected.

In addition, we must know information about fin whale food requirements, consumption, and availability, especially taking into consideration their capability to switch to other prey types as a potential risk of krill depletion due to environmental degradation or climate change.

Conservation efforts become possible through two agreements in addition to the Pelagos Sanctuary, the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean of the Barcelona Convention, and the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOMBAS) (Notarbartolo di Sciara et al, 2003).

1.3 Variability in species presence

Whales exploit seasonal and spatial habitat in relation to the peak abundance of prey; they can make this thanks to the fact that they are able to track food resources over time (Panigada et al, 2017). This show a wide range of feeding strategies and prey types, which could indicate that whales are generalists and can adapt to forage on whatever prey is locally abundant (Canese et al, 2006).

They concentrate during summer and autumn in a restricted feeding habitat then some of them spreads in winter and spring, probably to the south and east of Sicily, (di Sciara et al, 2013) near Lampedusa, probably for feeding (Panigada et al, 2017), and others spread in the northern part of the basin, during winter, showing a whale-preferred area (Cottè et al, 2011). We can say that most individuals show a regional site-fidelity to the northwestern Mediterranean Sea (Coomber et al, 2016).

Specking about the Pelagos Sanctuary we can find only one regular mysticete, that’s fin whale, whom habitat can be significantly influenced by environmental changes (Azzelino et al, 2012).

Specifically, fin whale distribution during summer months is affected by the variability of spring phytoplankton bloom (Littaye et al, 2004).

Fin whales show inter-annual variability with alternance of high and low presence (Tepsich et al, 2020), especially in the Liguro-Provençal basin.

1.4 Aim of the study

The aim of this thesis is to investigate anomalies in the spring phytoplankton bloom and in the Ligurian Sea in the 2004 to 2020 period and to investigate possible consequences for fin whales such as changes in species distribution pattern.

2. MATHERIALS AND METHODS

2.1 Study area

Our study area is the Pelagos Sanctuary (Fig 7).

Pelagos Sanctuary is composed by internal maritime and territorial waters of France, Italy, and Monaco; furthermore, thanks to his deep-waters and shelf slope, it is adapted to cetaceans needs of foraging and breeding habitats.

Specifically, the continental shelf can be found inside the Sanctuary only where there are coastal plains, in fact, it is mostly narrow and sectioned by submarine deep canyons. In the western part of the Sanctuary there is a uniform abyssal plain 2500-2700m, while, in the east of Corsica the seabed is irregular less deep (Fig 8).

Fig 7: This is the Mediterranean Sea and in blue there is the Pelagos Sanctuary area. Mediterranean Sea imagine is taken by Robinson et al, 2001

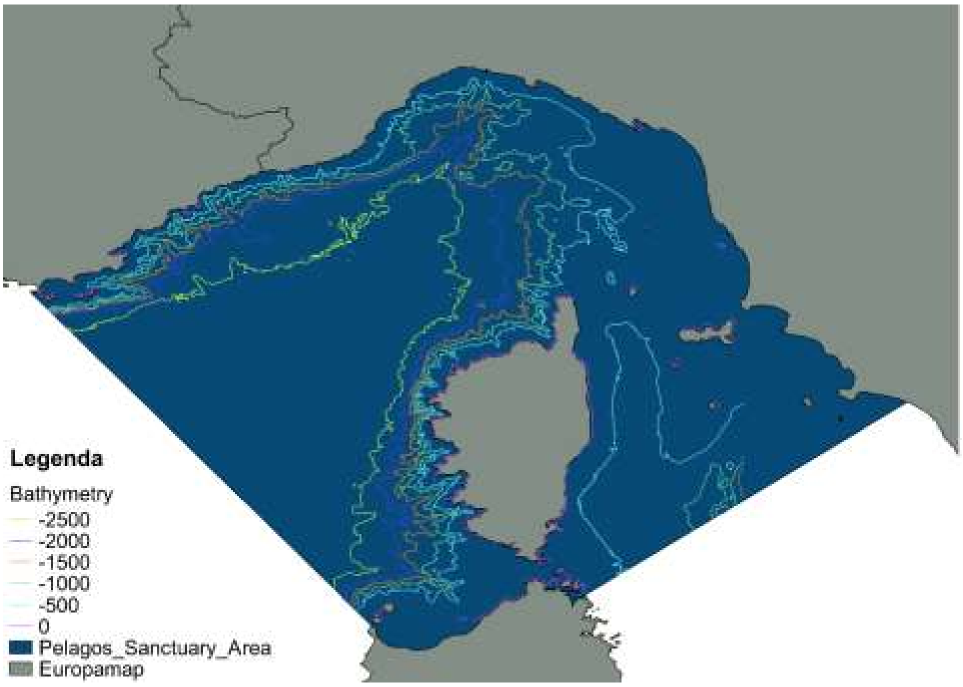


Fig 8: This image shows Pelagos Sanctuary's boundaries and bathymetry. It is situated in the north Mediterranean Sea and is established in 2002 thanks to an agreement between France Italy and Monaco.
Pelagos Sanctuary limits are:
Ovest: N 43°01'70 – E 06°05'90 (western point Giens's Peninsula)
N 40°58'00 – E 08°12'00 (west extremity of Asinara Gulf)
Est: N 41°09'18 – E 09°31'18 (north-east coast of Sardinia)
N 42°21'24 – E 11°31'00 (Italy west coast)
(https://www.sanctuaire-pelagos.org/it/accordo-pelagos-it/area-di-competenza-e-comuni-costieri)

The whole Sanctuary is subjected to considerable pressure like whale-watching tour, ferry traffic and coastal runoff, due to high touristic activities that increase during summer months (Sutton et al, 2021).

In this area there is a dominant cyclonic (counterclockwise) current, flowing north along Corsica and Tuscany and from them it hugs the coast of Liguria and France going to the west.

2.2 Fin whale data

The use of whale watching vessels as platform of opportunity for collecting cetacean data is a standard method (Vinding et al, 2015; Currie et al, 2018) This type of platform can be a valuable resource for the researchers to understand species distribution in short time if you follow a standard protocol to reduce the bias that can occur (Tepsich et al, 2014).

Our fin whale dataset is composed by sightings collected by whale watching vessels operating in the Ligurian sea from 2004 to 2020.

Data were provided by CIMA Research Foundation, Delfini del Ponente ASP and Golfo Paradiso.

Data were either collected by researcher on board or directly by the whale watching vessel crew. Regardless the source, data used for this study included entire track of the vessel obtained by GPS and sightings data obtained by observers using ad hoc protocol.

2.3 Environmental variables

Different environmental variables were considered in this study: Specifically, sea surface chlorophyll concentration and sea surface temperature were analysed to inspect phytoplankton bloom variability, while bathymetry and distance from the coast were chosen as descriptors for species distribution.

2.3.1 Sea Surface Chlorophyll:

Sea surface chlorophyll concentration and sea surface temperature data were taken from Copernicus Marine Service (http://resources.marine.copernicus.eu).

Sea surface chlorophyll concentration data were derived from satellite observations and are provided with a daily temporal resolution and a spatial resolution of 1km.

The dataset taken from CMEMS was: “OCEANCOLOUR_MED_CHL_L4_REP_OBSERVATIONS_009_078”

2.3.2 Sea Surface Temperature (SST):

Sea surface temperature data were taken from two different dataset of Copernicus Marine Service: “SST_MED_SST_L4_NRT_OBSERVATIONS_010_004” and “SST_MED_SST_L4_REP_OBSERVATION_010_021”.

The choice of the SST value is made because it can be considered an aggregate proxy of other oceanographic parameters: rain, sun, and wind, because SST depends on how much rain fall and how much sun and wind there are.

Sea surface temperature analysis are made in the spring bloom function, consequently, even if dataset still covers years between 2004 to 2020, we analyse the spring bloom months, so between January to May of the whole years.

Sea surface temperature in Copernicus Marine Service database is expressed in Kelvin degree, but we decide to convert them in Celsius degree for a better comprehension.

The formula we adopt is:

$$Tc = Tk - 273.15$$

2.3.3 Bathymetry:

Bathymetric data instead were derived from Gebco bathymetry (https://www.gebco.net/).

Bathymetry and distance from the coast can be considered related parameters, because as you go further from the coast, more depth increase.

2.4 Variability of spring phytoplankton bloom:

The northwest Mediterranean Sea and particularly the Ligurian basin is the only recurrent-bloom area in the entire Mediterranean basin (D’Ortenzio et al, 2009). In this region two phytoplankton bloom are known to occur, one during spring, more significant and is affirmed when the surface stabilizes, and a smaller one during autumn, because of the thermocline being progressively eroded (Bosc et al, 2004).

We focus on the variability of the spring phytoplankton bloom, being the main event triggering primary production and known to affect fin whale distribution during the summer (Littaye et al, 2004)

Knowing that the eastern part of the Pelagos Sanctuary is subjected by a huge coastal eutrophication caused by rivers, which is limited to coastal waters (Fig 9), this area has been excluded by the computing sea surface chlorophyll concentration averages (Fig 10).

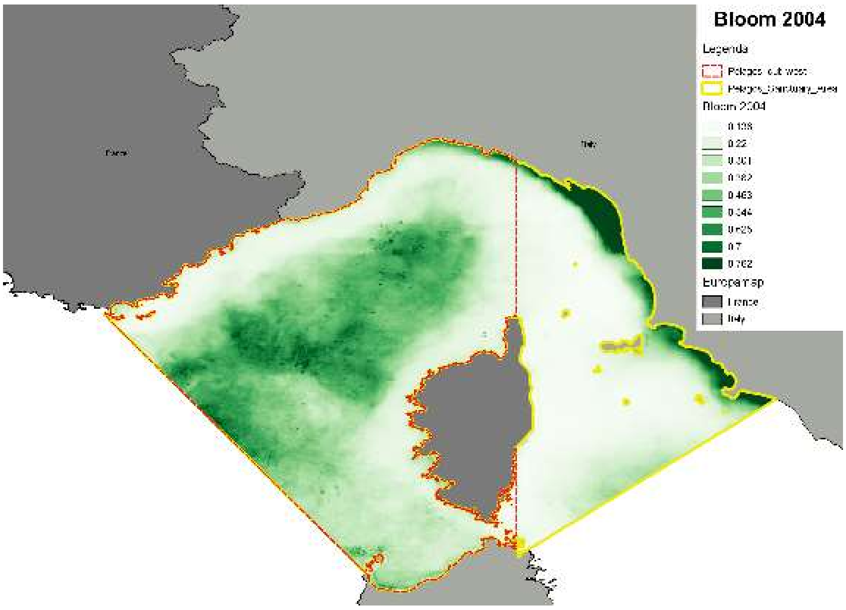


Fig 9: This is an example from our dataset that show the high eutrophication of the rivers. In the east part of the Pelagos Sanctuary, especially in the Tuscany coast and the east of Liguria's coast, we have rivers that could cause a bias in our analysis. To avoid this bias, we decide to cut the eastern part. This cut has been made only for environmental variables analysis.

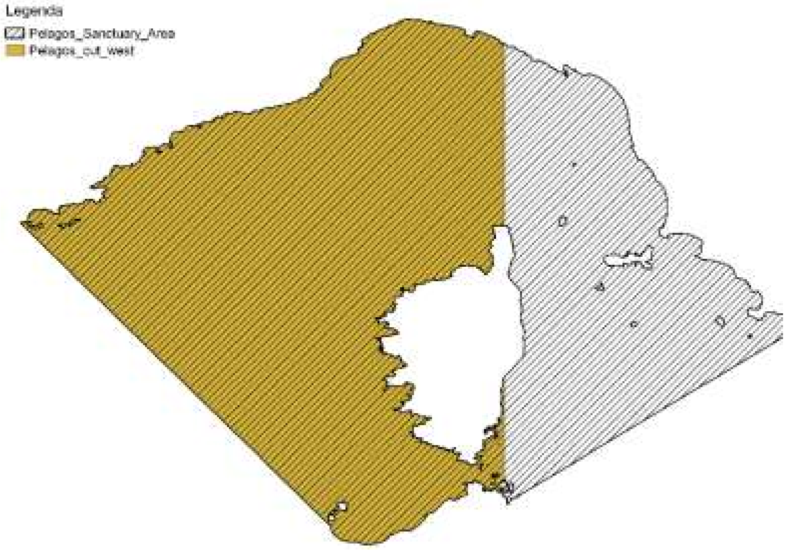


Fig 10: This figure shows exactly the cut made for the environmental variables analysis. In black and white stripe, we have the whole Pelagos Sanctuary, in ochre we have the Pelagos Sanctuary with the cut of the east part.

To define and describe the phytoplankton spring bloom variability we investigated its duration, its intensity and its spatial development following two methods:

a. The beginning of the spring bloom is identified as the first-time step when the cumulative sum of chlorophyll changes signs

b. The end of the spring bloom is identified as the moment in which our data went down an established threshold, identified as, the climatological median plus the 20%.

Both conditions need to be met for least 5 consecutive days, to avoid small peak detections (Fig 11).

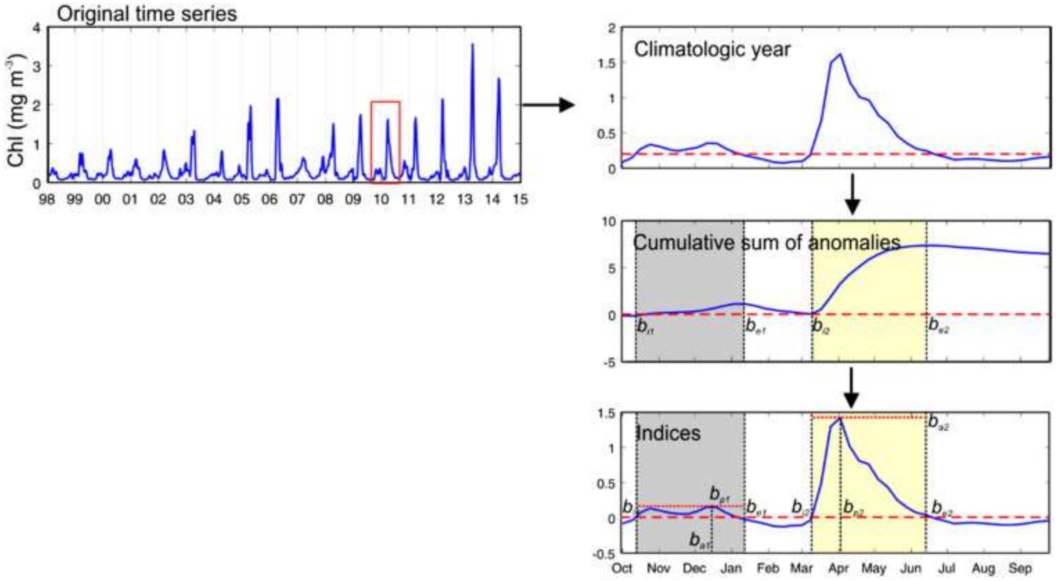


Fig 11: This imagine is an example, taken by Sargado-Hernanz et al, 2019 article. These show the calculous and the graphics that we also made, to calculate the anomaly and to obtain the spring phytoplankton bloom onset.

Start and end date were used to compute the bloom duration. Bloom intensity is computed as the overall mean in the considered region, computed from daily maps from the start to the end date for every considered period. Overall bloom map was also created to investigate spatial variability in the bloom.

Linear regression was applied to investigate possible trends in the above-mentioned indexes.

After phytoplankton analysis we download and import on Rcmdr (R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria) Sea Surface Temperature dataset, and we start its analysis.

First, we import the Pelagos cut boundaries for the whole years then we extract the average in function of these boundaries, and we set the date to appear identical.

Once created a unique data frame, even in this case we make a graph for the trend visualization, and we add to the graph the linear regression to see which results can be considered statistically significant.

As third analysis we take bathymetry and distance from the coast.

Sighting's datasets are composed by all specie sightings, so, once imported the data on QGIS (https://www.qgis.org/it/site/) we must select only the once of our target specie.

QGIS is an application that allows you to view, organize, analyse, and represent spatial dataset.

Once selected what was interesting for us, we use bathymetry and distance from the coast raster to sample the value of the sightings for each year.
Then data has been imported on Rcmdr and we modify them to obtain a unique data frame with a year column on the attribute table.
The same method has been repeated in relation to the distance from the coast and in this way, we create a boxplot and a frequency histogram for both.

2.5 Analysis of fin whale distribution

Fin whale distribution was investigated as related to discrete bathymetric classes (Fig 12): 0m – 500m, 500m – 1000m, 1000m – 1500m, 1500m – 2000m, 2000m – 2500m and over 2500m.

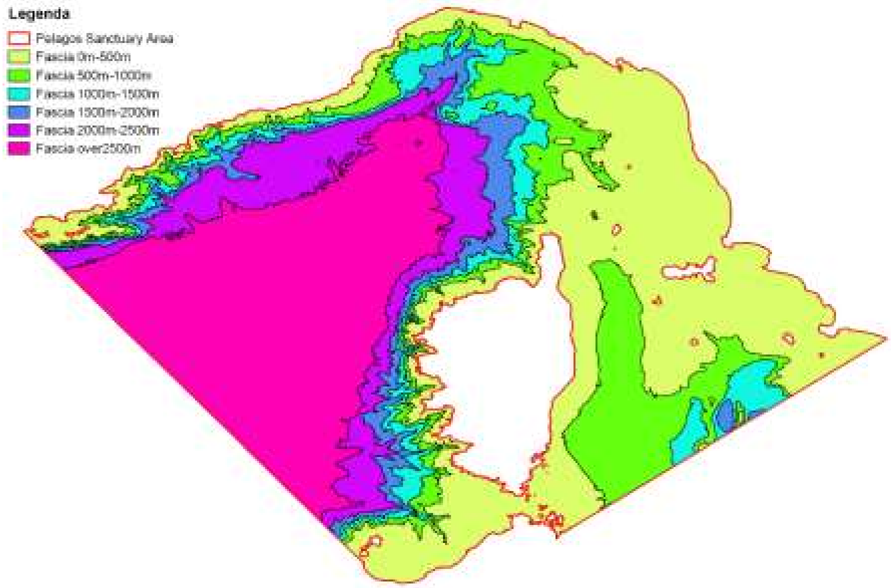


Fig 12: This image shows the different bathymetry bands present in the Pelagos Sanctuary:
yellow = 0m-500m, green = 500m-1000m, light blue = 1000m-1500m, blue= 1500m-2000m, purple = 2000m-2500m and pink = over 2500m.

Boxplots were used to investigate interannual differences in species bathymetric references. To consider sampling effort, species distribution was analysed by computing species encounter rate in the different bathymetry region for every considered year. To avoid possible biases arising from sampling heterogeneity, Encounter Rate were normalized according to the overall number of sightings and surveys available for the considered year. The encounter rate is the computed as:

$$\text{ER} = \frac{a_y^i / A_y}{c_y^i / C_y}$$

Where a is the number of sightings, i is the bathymetric region, y is the considered year, c is the number of surveys. A and C represent overall sum if a and c respectively for the considered year.

The boxplot is representative of where is the median of our data, while the frequency histogram gives us information about how much observation have been done in relation to bathymetry and distance from the coast.
After boxplots we used Kruskal – Wallis Test that is a rank-based test that can be applied to one-way data with more than two groups. This test addresses if it is likely that an observation in one group is greater than an observation on the other. The outcome of this test tells if there are differences among the group but doesn’t tell which groups are different or equal from another group. To determine which groups are different from others, we used Post – Hoc Test.

3. RESULTS

3.1 Variability of the phytoplankton bloom in Pelagos

Overall, 17 maps of sea surface chlorophyll concentration were analysed. Yearly trend shows the clear seasonal pattern for the spring phytoplankton bloom occurring in late February and ending beginning of May. A strong interannual variability is already clear (Fig 13).

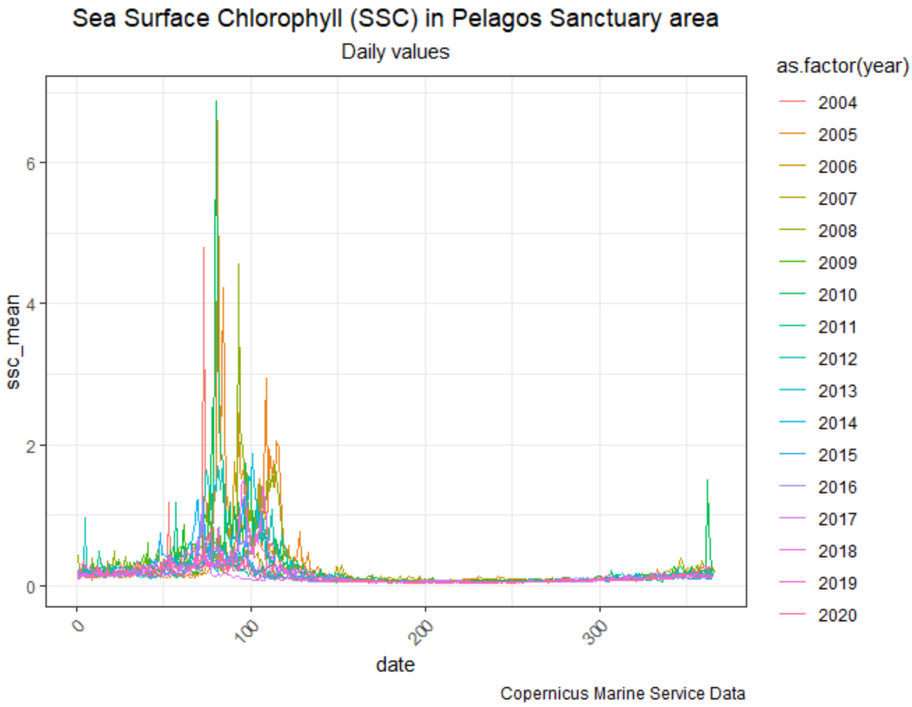


Fig 13: In this figure we have the daily values of chlorophyll concentration of the whole years in the Pelagos area from 2004 to 2020 (day 1 is January 1st, day 365 is December 31st).

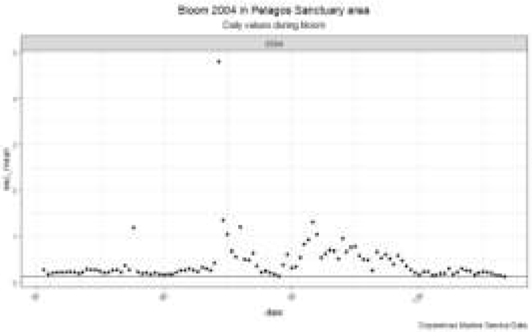
Start and end data, and consequently duration varied among year (Tab 1).

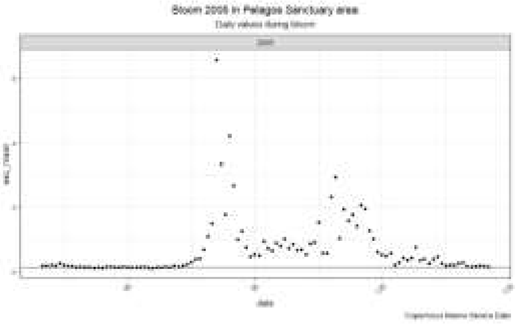
Years	Start day	End day	Duration
2004	32	140	108
2005	40	145	105
2006	32	137	105
2007	67	126	59
2008	8	143	135
2009	9	121	112
2010	21	145	124
2011	5	118	113
2012	18	128	110
2013	3	133	130
2014	6	125	119
2015	8	107	99
2016	1	135	134

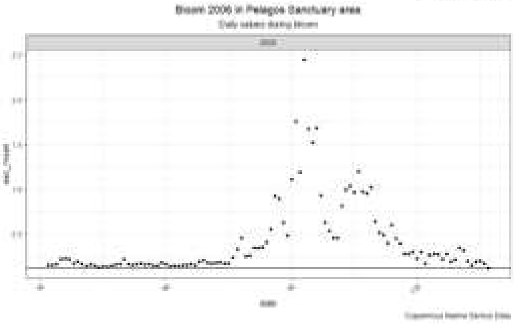
2017	32	89	57
2018	63	125	62
2019	11	137	126
2020	3	101	

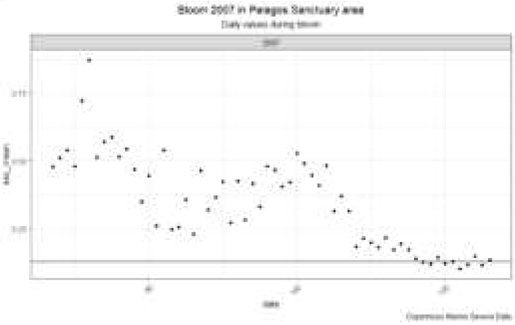
Tab 1: This table show the different start day, end day and duration of the spring phytoplankton bloom recorded during the dataset

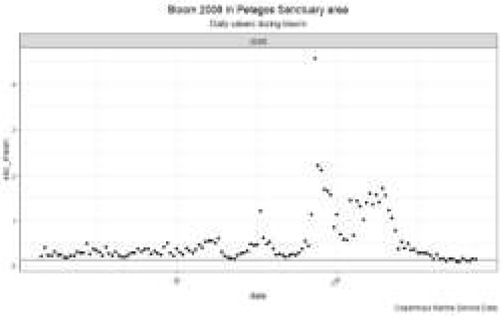
Considering bloom intensity, we analyse it year by year through anomaly and threshold calculous (Fig 14):

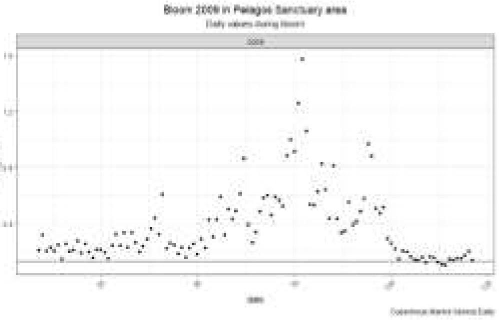


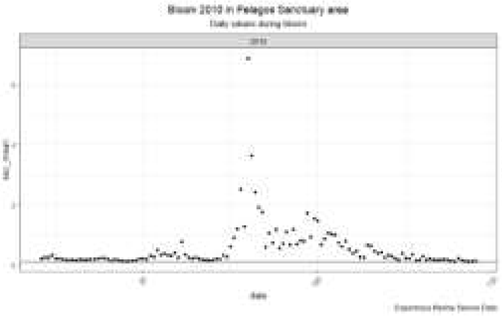


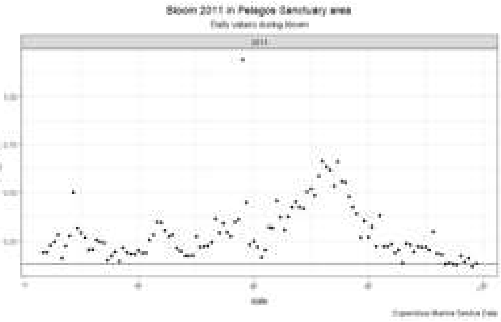












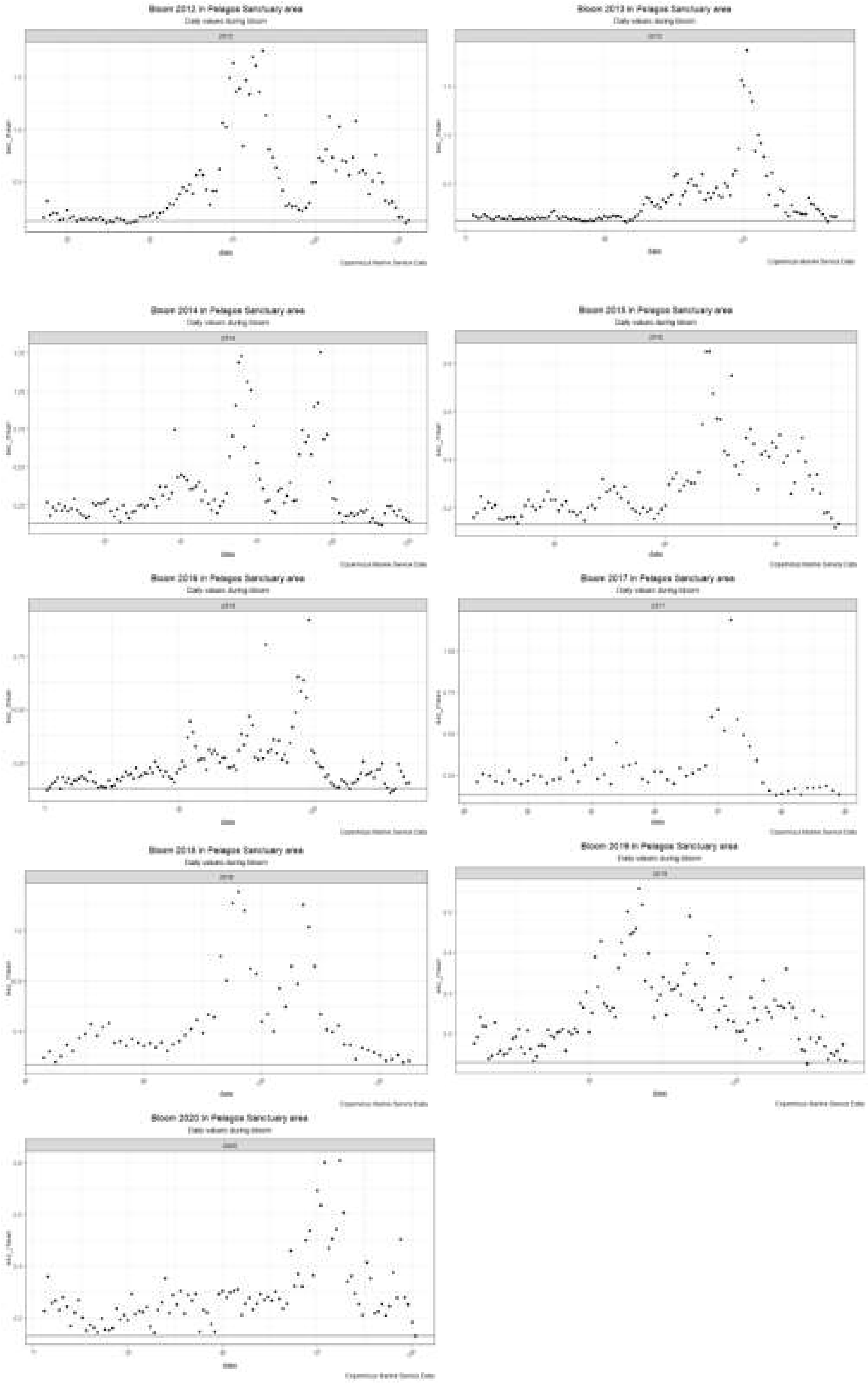


Fig 14: Spring bloom year by year in the Pelagos Sanctuary

Regression analysis was significative for sea surface chlorophyll concentration, evidencing a weak negative trend (Fig 15).

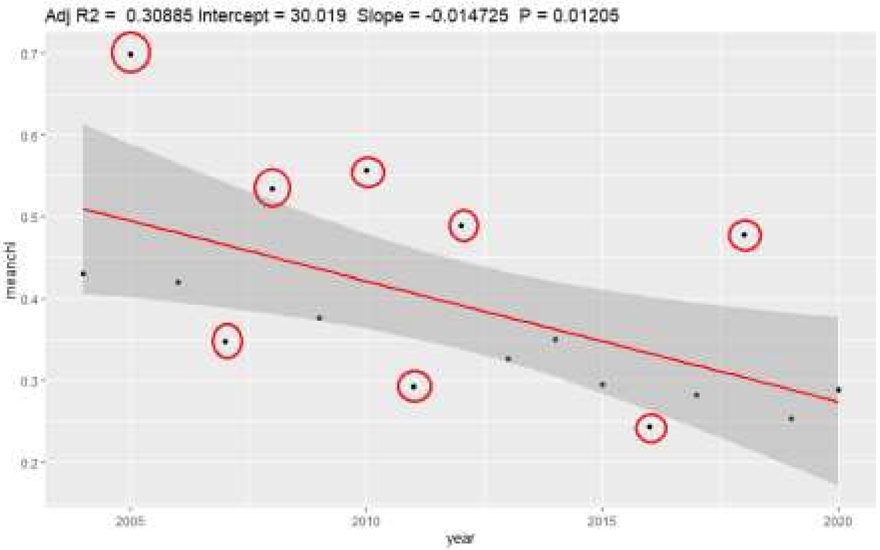


Fig 15: Linear regression of the average chlorophyll concentration during the bloom: shaded are referred to the 95% confidence interval. Anomalous years are evidenced in red

When plotting the 95% confidence interval, several anomalous years are evidenced, with an alternance of positive and negative anomalies.

The anomalous years are 2005, 2007, 2008, 2010, 2011, 2012, 2016 and 2018.

In 2005, 2008, 2010, 2012 and 2018 the average chlorophyll concentration registered is higher than the confidential interval.

In 2007, 2011 and 2016 the average chlorophyll concentration registered is below the trend line and the confidential interval.

Even other parameters, like the beginning, the end and the duration of the bloom and the maximum concentration peak exhibit a trend.

The linear regression of the beginning of the bloom and the duration of the bloom are not statistically significant because their p-value overcome the 0.05 value.

The trend of the other parameters, end of the bloom and maximum peak, are statistically significant (Fig 16).

These trends show, as the average chlorophyll concentration, a decreasing line.

Even in these cases we have anomalous years, but we analyse only years they have in common with sea surface chlorophyll trend.

In 2005 we have a higher maximum concentration peak like in 2010, 2012 and 2018 but in 2016 and 2011 it is lower than our confidential interval; 2011 is the lower maximum concentration peak never registered.

The 2007 and 2008, in this graph are inside the trend.

Speaking about the end of the spring bloom 2010 and 2016 are above the confidential interval, while 2011 is below the trend.

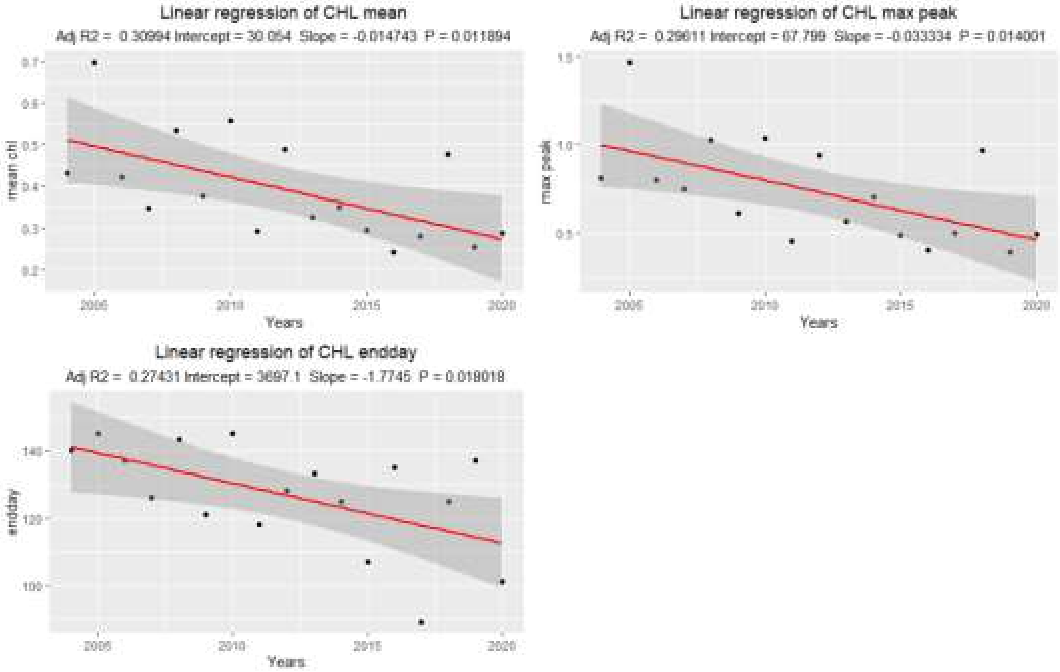
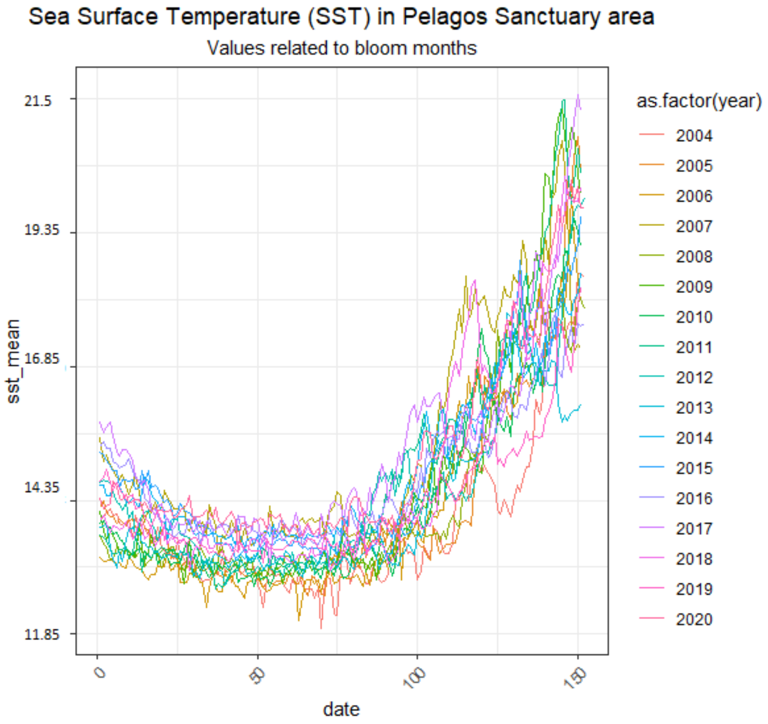


Fig 16: Linear regression of the average chlorophyll concentration, maximum concentration peak, and end day of the bloom

3.2 Variability in Sea Surface Temperature

Sea surface temperature is taken into consideration related with chlorophyll concentration.

Our analyses range from the first of January till the end of May, the months of the spring phytoplankton bloom, from 2004 to 2020 (Fig 17).



Copernicus Marine Service Data

Fig 17: Average Sea Surface Temperature

As expected, sea surface temperature pattern shows a decrease during the triggering phases of the bloom and an increase towards the end for the process. Yearly differences are present, and also anomalous years (Appendix B).
Through Rcmd, such as for chlorophyll concentration, the linear regression show that the trend is rising and that there are some anomalies (Fig 19).

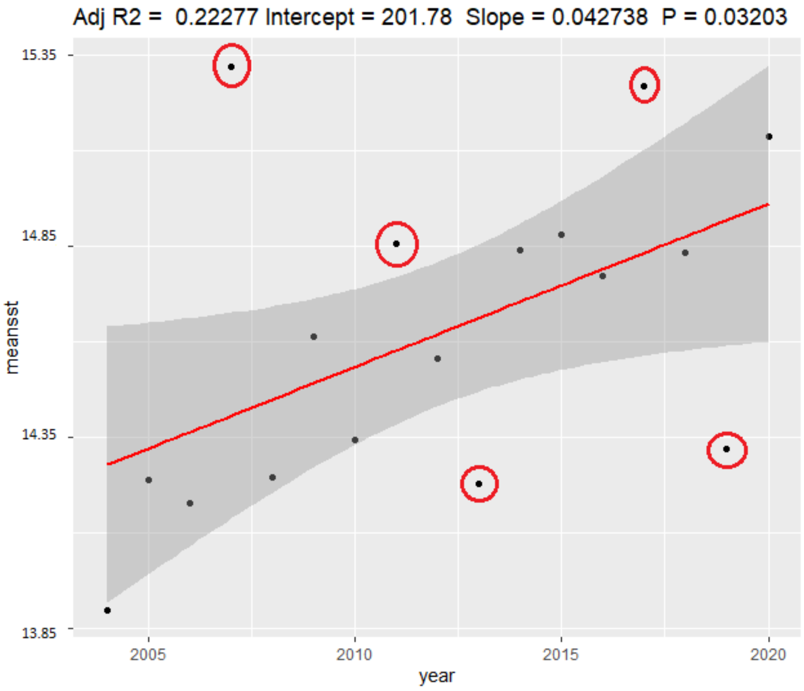


Fig 19: Linear regression of Sea Surface Temperature: This analysis let us to understand the trend of our data and which years are inside or outside our confidential interval; the interval in which we expect to find our data.
The anomalous years are 2007, 2011, 2013, 2017, 2019.

The anomalous years that chlorophyll concentration and sea surface temperature have in common are 2007 and 2011 (Fig 20).
In both cases the sea surface temperature recorded is higher than our confidential interval, moreover, 2007 is the year in which we record the highest Sea Surface Temperature of the whole dataset.

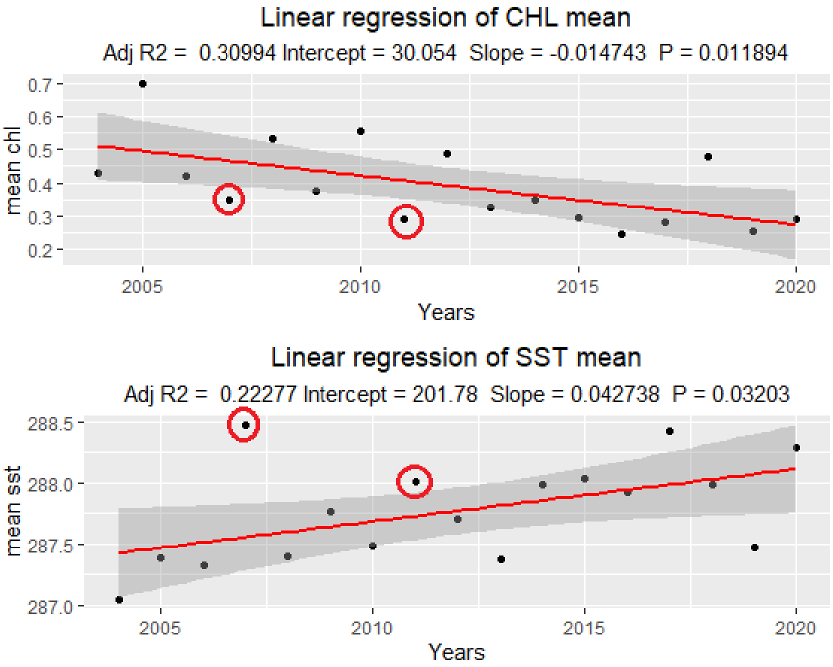


Fig 20: Comparison of CHL trend and SST trend to see if there are some years in common. What we notice is that both in CHL and SST 2007 and 2011 are anomalous and that in the CHL trend the years are below the confidential interval and that in the SST trend the years are above the confidential interval.

3.3 Variability of fin whale distribution in the Pelagos Sanctuary

Overall, 848 surveys were analysed accounting for 317 sightings (Tab 2).

Years	Surveys	Sightings
2004	110	50
2005	189	119
2006	164	48
2007	113	14
2016	41	7
2017	36	46
2018	61	7
2019	50	6
2020	84	20

Tab 2: This table shows the number of surveys and sightings made year by year

The dataset lacks data from 2008 to 2015.

Box plots shows strong interannual differences in species distribution related to bathymetry and distance from the coast (Fig 21).

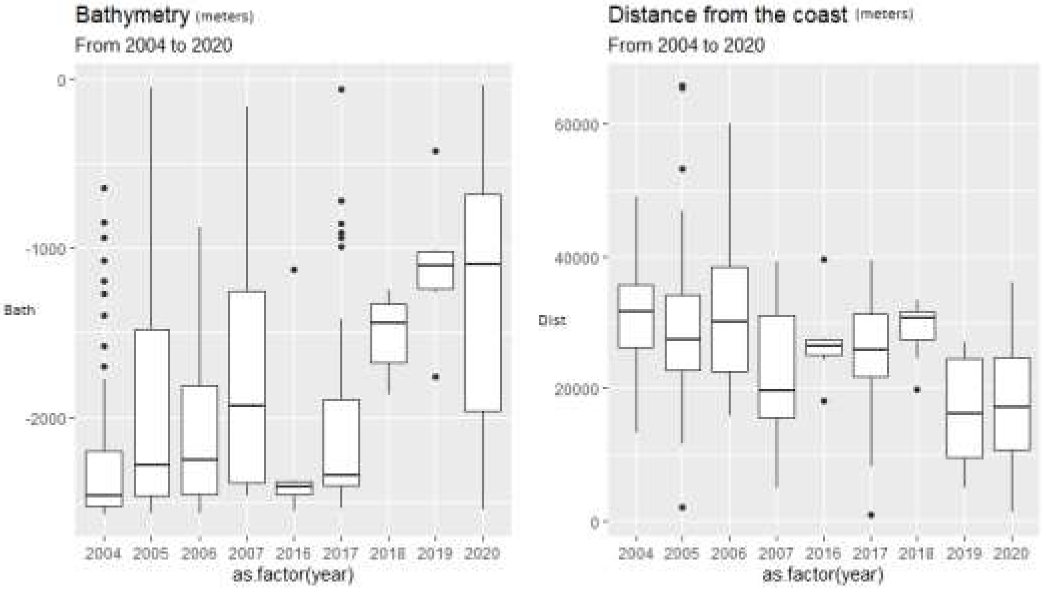


Fig 21: Boxplot of bathymetry and distance from the coast in relation to fin whale sightings.

Boxplots output highlight where the median is.
Kruskal – Wallis test was used to inspect interannual differences in species distribution and Post – Hoc analysis (Dunn Test) with Bonferroni correction was then used to identify anomalous years (Tab 3).
Kruskal – Wallis parameters was chi square = 40.624, df = 8 and the p-value resulting was 0.000002451, below 0.05.

Years	Letters
2004	a
2005	bc
2006	abc
2007	bcd
2016	ab
2017	bc
2018	cd
2019	d
2020	d

Tab 3: In this table we have Bathymetry Post - Hoc output: years and letters. Similar letters correspond to similar years.

To better highlight interannual differences, frequency histograms of sightings for each depth class have been created (Fig 22).
Generally, peaks of frequency for sightings are in water deeper than 1500m, with little or no sightings in water shallower than 1000m (Fig 23).

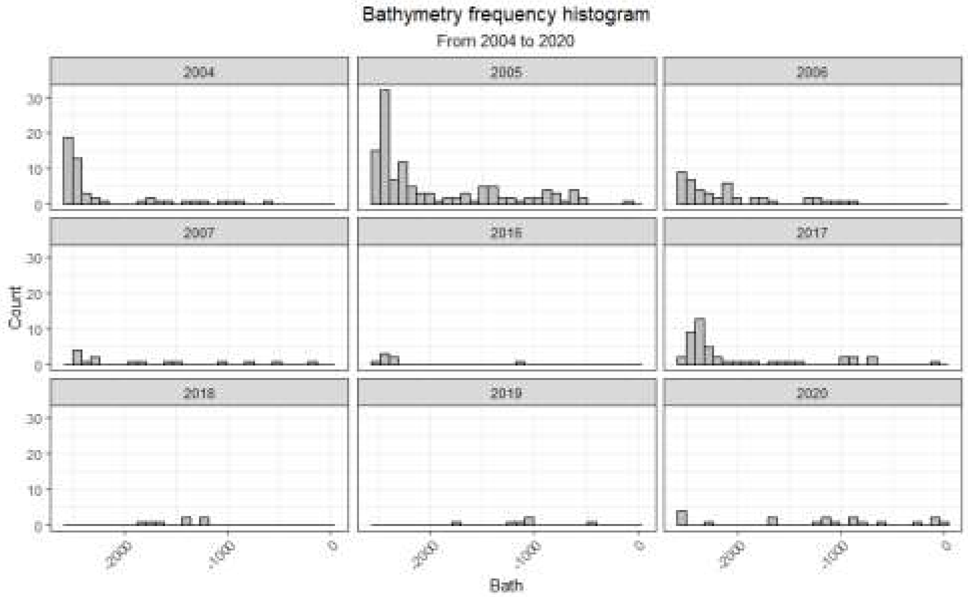


Fig 22:Bathyemtry frequency histogram divided into the different years

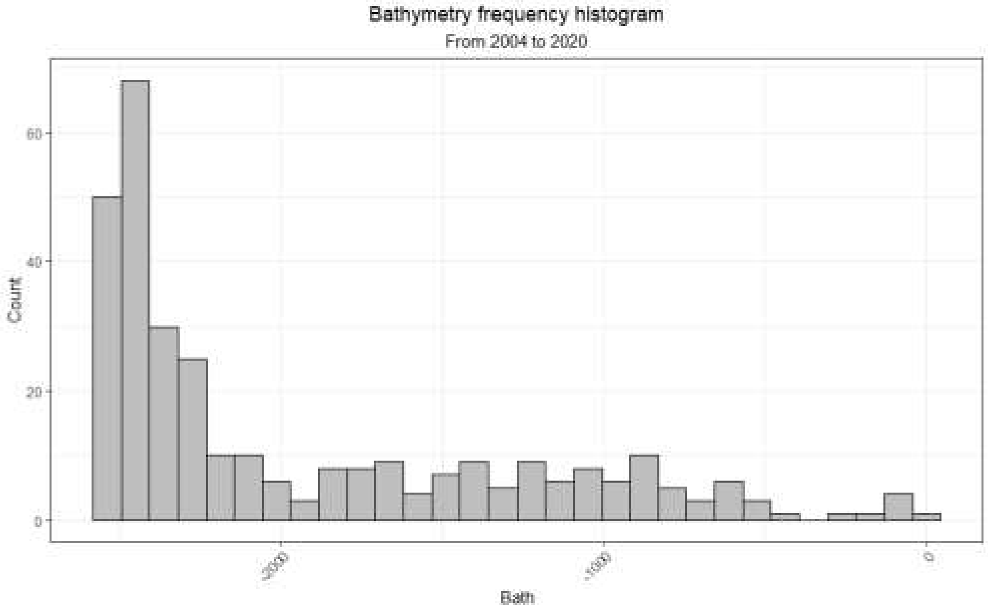


Fig 23: Bathymetry frequency histogram from 2004 to 2020

Similarities evidenced for 2019, 2020 and 2007 are confirmed here, as for those years several sightings have been recorded in waters shallower than 1000m while occasional sightings in shallow waters were recorded also in other years, what emerges is the general lack of sightings 6 in 2019, 20 in 2020, 14 in 2007 and an almost complete absence of the species in waters above 2000m depth.
Looking at the distance from the coast frequency sightings distribution there is one high peak and a decreasing in both sides (Fig 24).

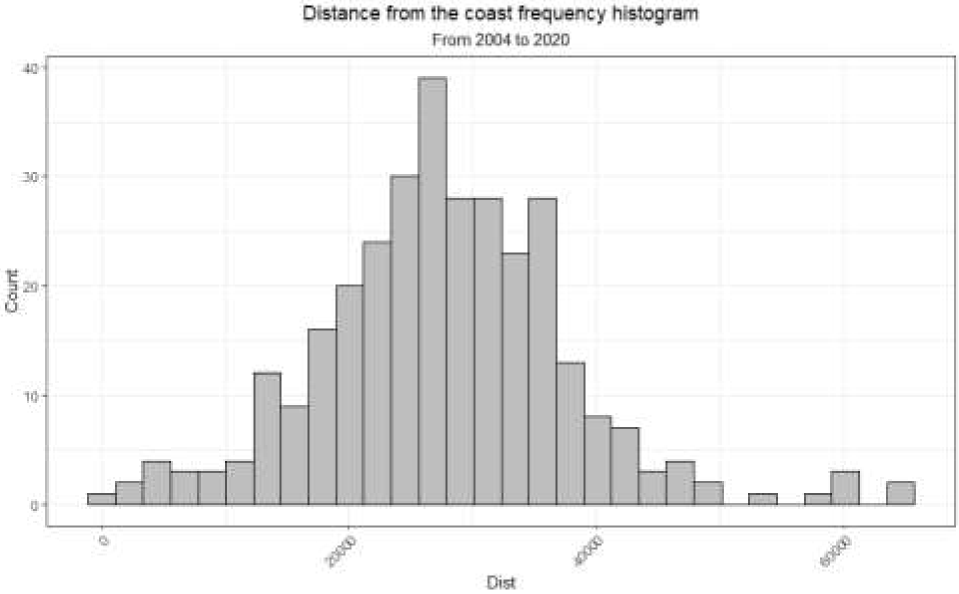


Fig 24: Distance from the coast frequency histogram

The interannual analysis shows that there is higher frequency between 200000m and 40000m and going to coast and to deeper waters the frequency decrease.
In 2019 the major frequency was between 20000m and 30000m, but for the rest of the years, the sightings are below 20000m from the coast arriving also below 10000m (Fig 25).

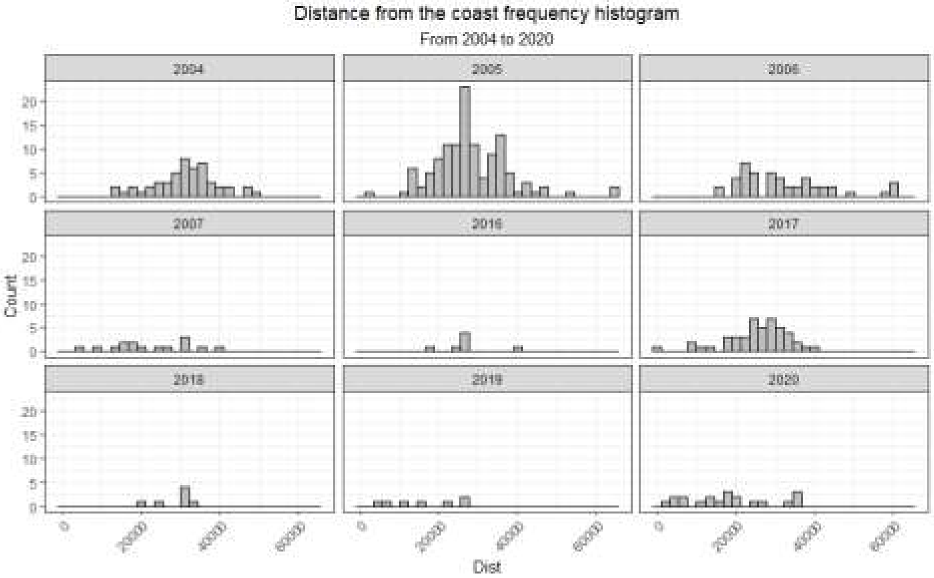


Fig 25: Distance from the coast frequency histogram divided into different years: this situation is like bathymetry situation because of these parameters are correlated.

For distance from the coast analysis, we use again Kruskal – Wallis test and Post – Hoc analysis (Dunn Test) with Bonferroni correction (Tab 4).
Kruskal – Wallis parameters was chi square = 41.463, df = 8 and the p-value resulting was 0.000001708, below 0.05.

Years	Letters
2004	a
2005	ab
2006	a
2007	bcd
2016	abcd
2017	bc
2018	abcd
2019	cd
2020	d

Tab 4: Distance from the coast Post - Hoc output: years and letters. Similar letters correspond to similar years.

As sampling effort can greatly influence the analysis on sightings distribution. Interannual differences were inspected also plotting the encounter rate.
In order to evaluate interannual differences in effort distribution we first plot frequency of surveys for each year for each considered depth class, then we overlay the yearly ER (Encounter Rate) computed for that specific depth class (Fig 26).
To consider interannual differences in effort, all data have been weighted according to yearly overall effort.

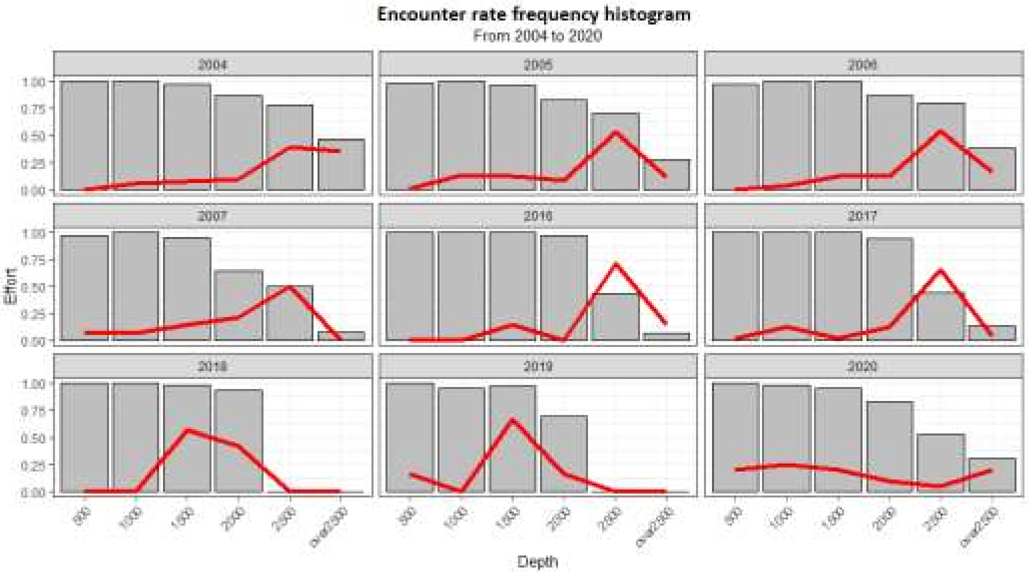


Fig 26: Frequency of surveys and ER for each depth class: Grey represent the frequency distribution of trips and red represent the yearly ER computed for the corresponding depth class.

As expected, every year all trips do survey the shallower area, while an ER > 0 has been recorded only in 2007, 2019 and 2020. Generally, even if the effort is lower at higher depths, peaks of ER are recorded at depth greater than 2000m.

During the last three years shallower peaks have been recorded. It must be noted through that the survey effort also has shifted in shallower waters, as in 2018 and 2019 very few trips surveyed the deeper areas.

4. DISCUSSION

In this thesis, interannual changes in pelagic ecosystem dynamics have been studied. First, interannual changes in the development and strength of the spring phytoplankton bloom have been studied.

While a general known effect of climate change in the Mediterranean basin is considered to be a decrease in primary production.

Chlorophyll concentration as a proxy for phytoplankton biomass, respond rapidly to changes in environmental conditions, such as light, temperature, nutrients, and mixing. Chlorophyll trend in the Mediterranean Sea, for the period 1997 – 2020, is negative over most of the basin (https://resources.marine.copernicus.eu/product-detail/MEDSEA_OMI_HEALTH_OceanColour_trend/INFORMATION).

Our analysis confirmed this negative trend, evidencing it for a core region for the Mediterranean ecosystem. Moreover, our study year is a key area for cetaceans' distribution and consequently high biodiversity.

Generally, our analysis showed that the bloom is lasting less days and with less intensity

The other spring bloom characteristics analysis, like end day of the bloom and maximum concentration peak, show a general decreasing trend; moreover, the decreasing trend of the end of the spring bloom means that it is shifting year by year; the spring phytoplankton bloom is ending year by year earlier.

The statistical analysis confirmed the negative trend for end day of the bloom, maximum concentration peak and average chlorophyll concentration.

While it was not significant for beginning of the bloom and duration of the bloom. Nevertheless, the overall pictured drawn evidence the urgency of deeper studies on the effect of climate change.

The sea surface temperature trend is increasing year by year from 2004 till 2020.

The Mediterranean Sea is a climate change hotspot. The Mediterranean Sea surface temperature has experienced a continuous warming trend since the beginning of 1980s. specifically, since the beginning of the 21st century, the Mediterranean Sea featured the highest SSTs and ocean warming is expected to continue throughout the 21st century (https://resources.marine.copernicus.eu/product-detail/MEDSEA_OMI_TEMPSAL_sst_trend/INFORMATION).

Looking at the two considered parameters together, it is possible to highlight anomalous years.

In 2007 we record less average chlorophyll concentration, and the higher peak of average sea surface temperature never recorded in the dataset.

In 2011 we record, as for 2007, less average chlorophyll concentration and the offset of spring bloom arrive earlier than we expected, but it is also one year in which the sea surface temperature recorded is higher than the confidential interval.

The consequent negative trend for chlorophyll concentration and positive for sea surface temperature confirm that 2020 has been a peculiar year, even if in the studied trend.

In order to inspect possible consequences with cetacean distribution, we analysed difference in presence and distribution of a target species, the fin whale. This species is known to have a marked offshore distribution, with a preference for areas far from the coast and at waters deeper than 2000m (Grossi et al, 2021). In 2007 an anomalous distribution was already evidenced by previous studies (Tepsich et al, 2008).

Our analysis evidence similarities among 2007, 2019 and 2020, and this similarity is coherent with our environmental variables analysis.

Considering 2007 and 2020 frequency histogram we must make a different analysis: even if in both years the major frequency has been recorded in -2000m depth, we have a high frequency of sightings and density also above -500m, at shallower depths.

Through the lack of effort in deeper areas can bias our analysis, it must be evidenced how species distribution shifted in shallower waters.

This shift in distribution must be considered for the possible impacts on the conservation of the species.

The shift of fin whale distribution to shallower areas can cause several damages to this specie. They will be more at risk of collisions and acoustic disturbance by maritime traffic.

In addition, ports and shallower areas are more eutrophicated but there is also more pollution caused by tourism and currents. In fact, plastic and feeding ground can match due to the fronts that are present in this area and this can cause negative impacts on fin whale.

5. CONCLUSION

Pelagos Sanctuary is a marine biodiversity hotspot.
Long term research on cetaceans has been important in guiding management of this protected area (Sutton et al, 2021). In particular, the Ligurian Sea, thanks to its extensive areas of deep waters (>2000m) and thanks to its narrow continental shelf, (Jahoda et al, 2003) represent one of the Mediterranean feeding grounds for the specie target of our study, Mediterranean fin whale.
The aim of our study is to provide first insights into possible influence of climate change in the distribution and presence of the fin whale in this area.
The evidenced anomalies in oceanographic conditions and in species distribution confirm possible shifts of species in shallower waters, closer to the coast, as a consequence the species is more exposed to several threats like those we have mentioned above. These threats can produce problem for fin whale conservation even the presence of the different agreements.

6. AKNOWLEDGMENT

Le persone che prima di tutti devo ringraziare sono i miei genitori. È impossibile spiegare qui tutti i mille modi in cui mi hanno aiutata e supportata nonostante le difficoltà.
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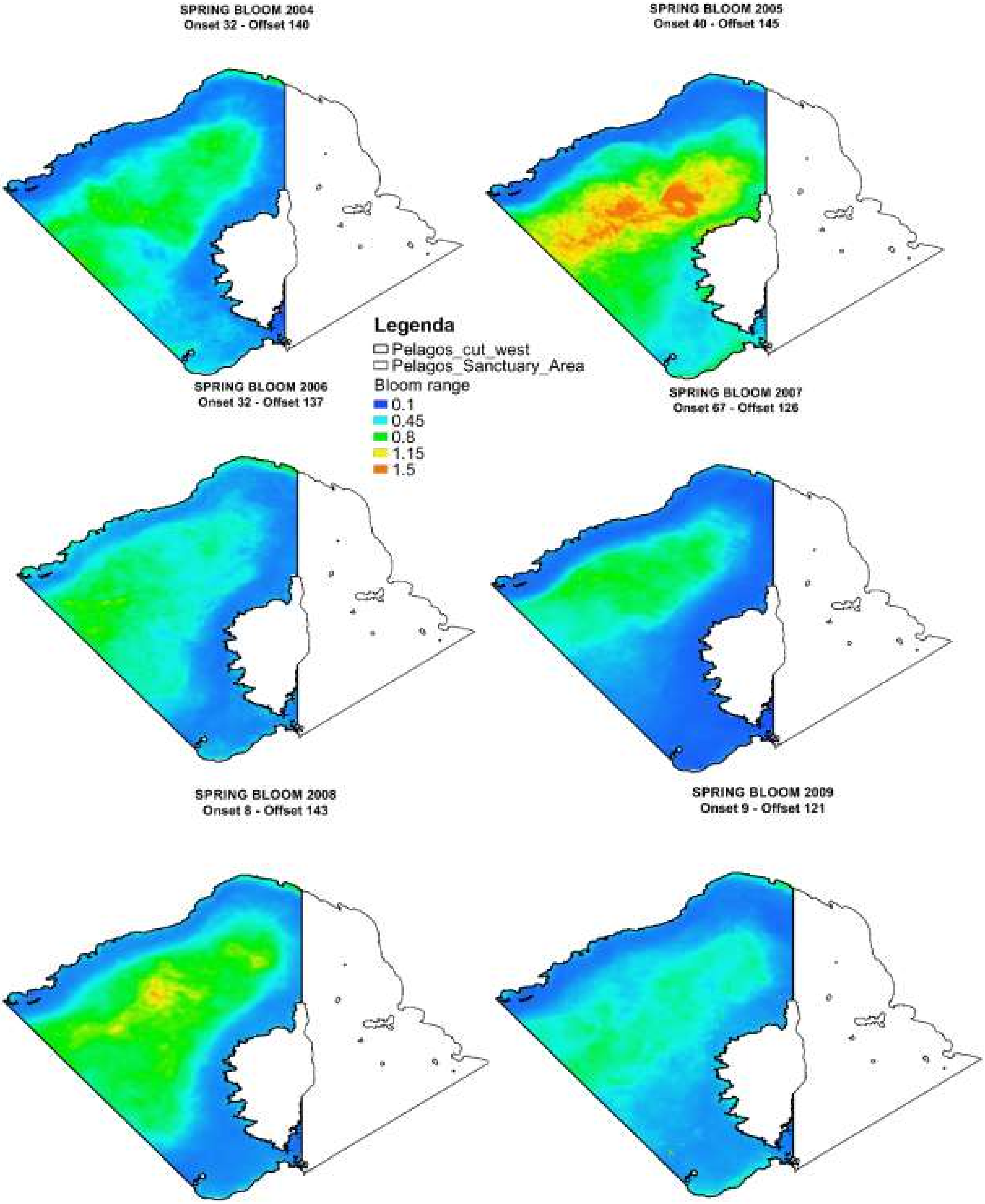
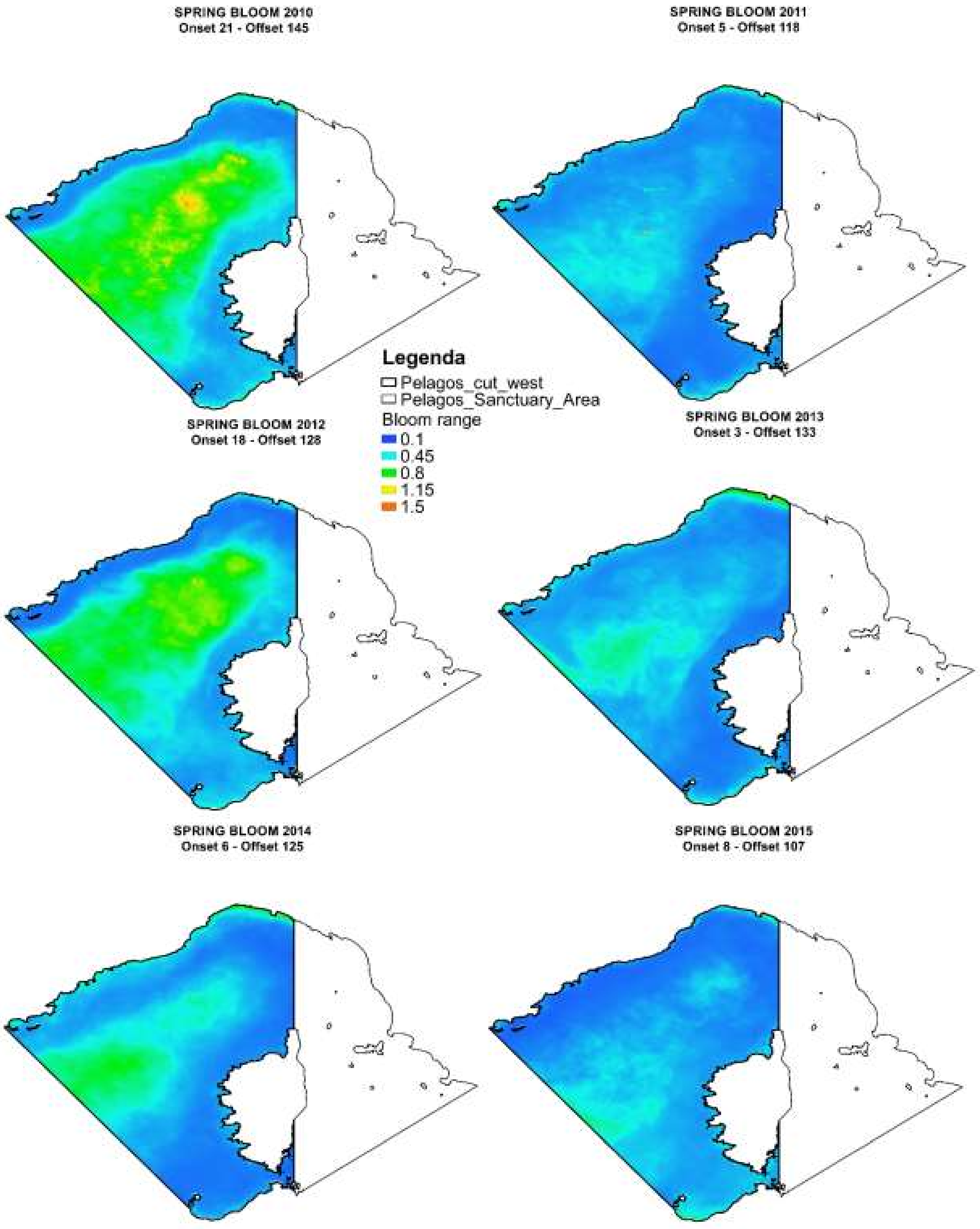
Appendix A:

Daily average chlorophyll concentration during the spring bloom of each year of our dataset:





SPRING BLOOM 2010
Onset 21 - Offset 145

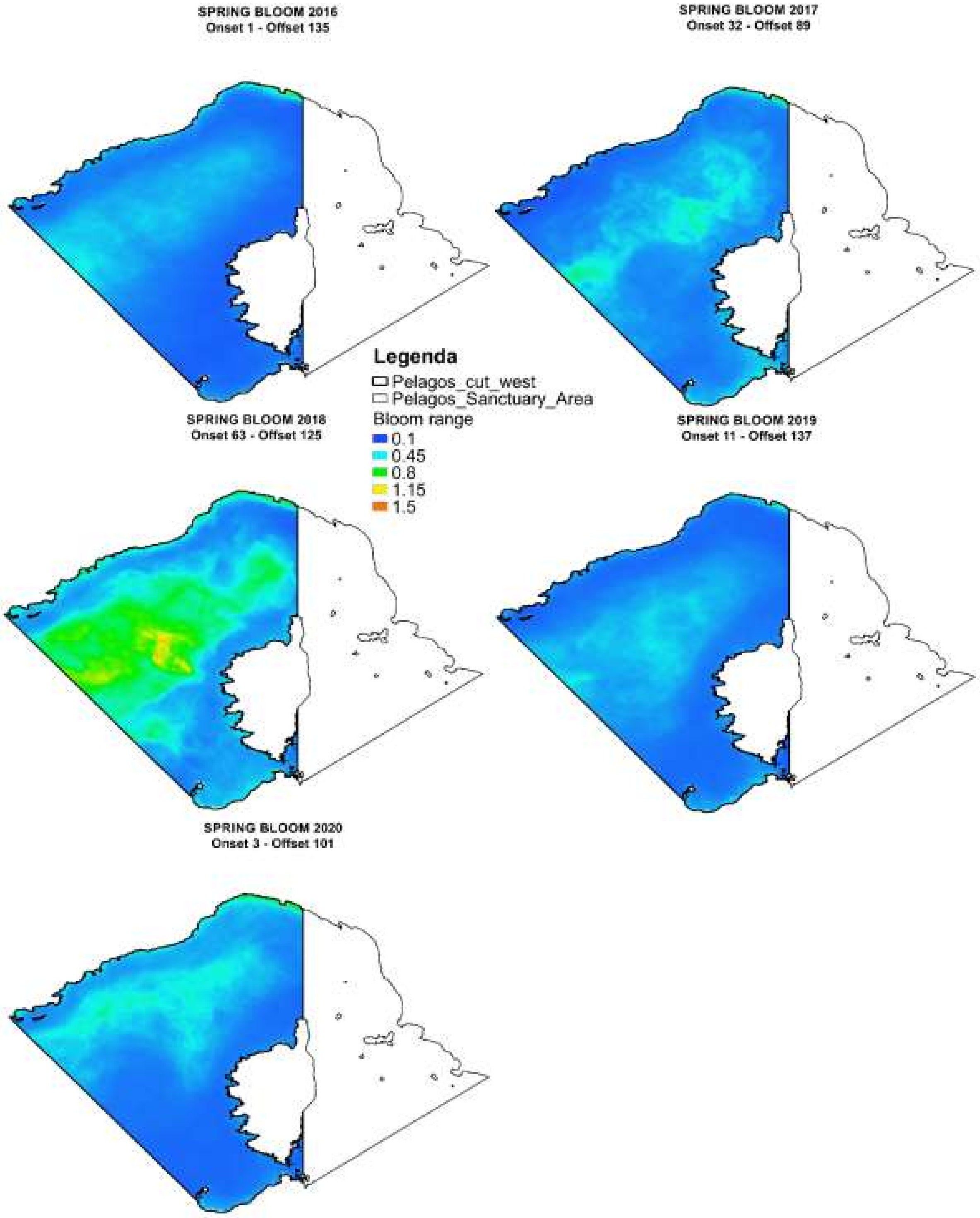
SPRING BLOOM 2011
Onset 5 - Offset 118

SPRING BLOOM 2012
Onset 18 - Offset 128

SPRING BLOOM 2013
Onset 3 - Offset 133

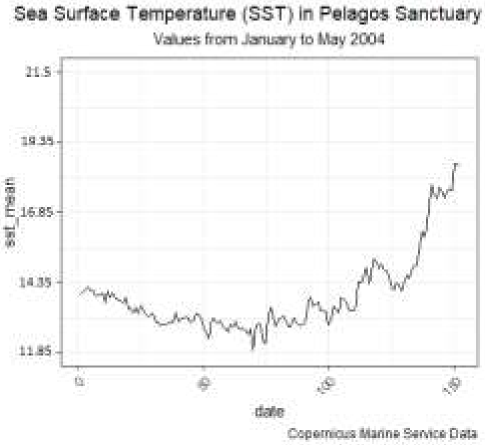
SPRING BLOOM 2014
Onset 6 - Offset 125

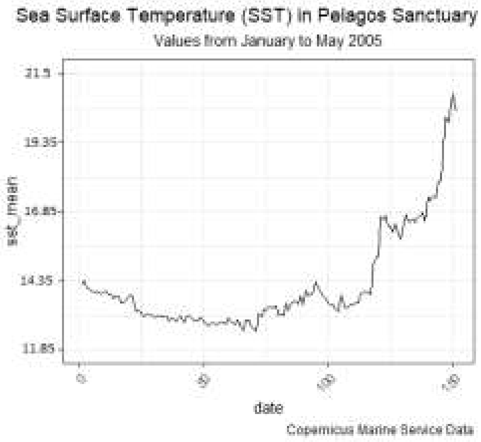
SPRING BLOOM 2015
Onset 8 - Offset 107

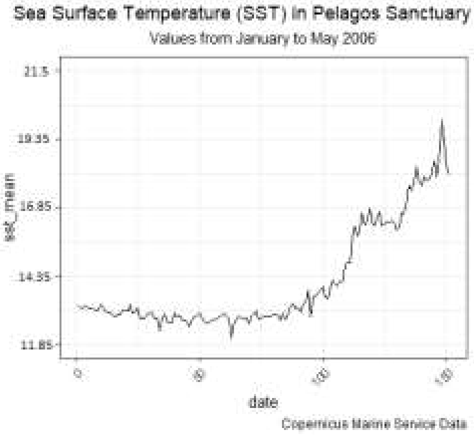

SPRING BLOOM 2016
Onset 1 - Offset 135
SPRING BLOOM 2017
Onset 32 - Offset 89
Legenda
Pelagos_cut_west
Pelagos_Sanctuary_Area
Bloom range
0.1
0.45
0.8
1.15
1.5
SPRING BLOOM 2018
Onset 63 - Offset 125
SPRING BLOOM 2019
Onset 11 - Offset 137
SPRING BLOOM 2020
Onset 3 - Offset 101

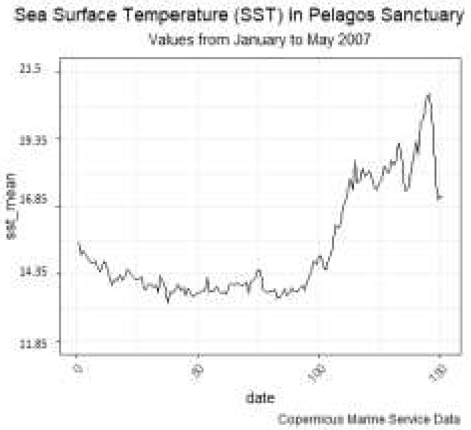
Appendix B:

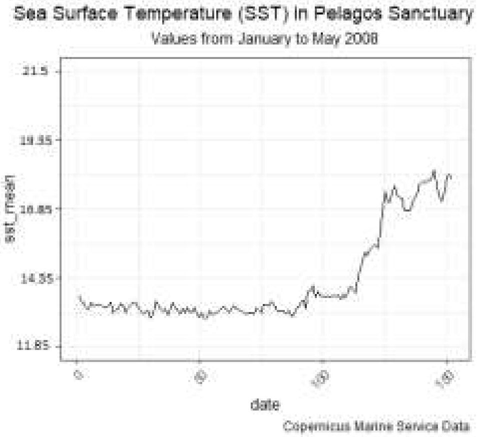
Daily Sea Surface Temperature during the spring bloom of each year of our dataset:

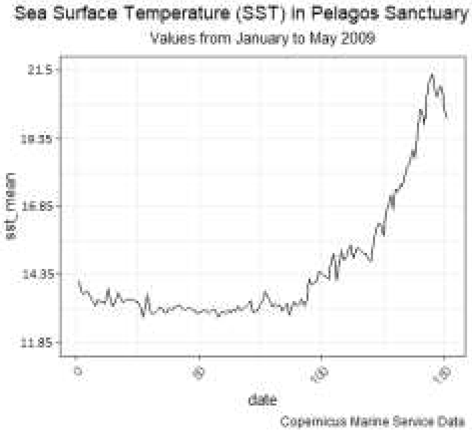


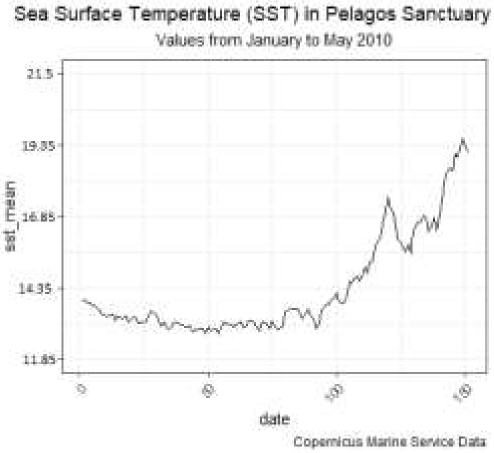






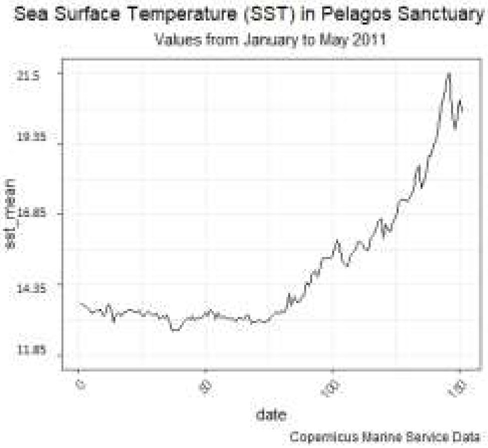





Sea Surface Temperature (SST) in Pelagos Sanctuary

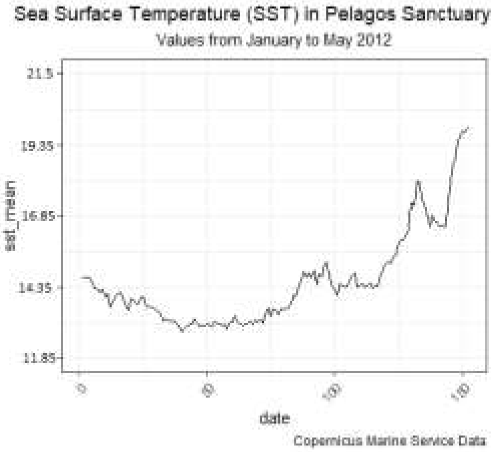
Values from January to May 2010

Copernicus Marine Service Data


Sea Surface Temperature (SST) in Pelagos Sanctuary

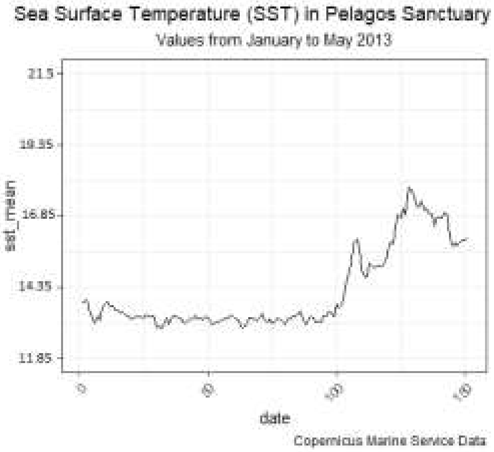
Values from January to May 2011

Copernicus Marine Service Data


Sea Surface Temperature (SST) in Pelagos Sanctuary

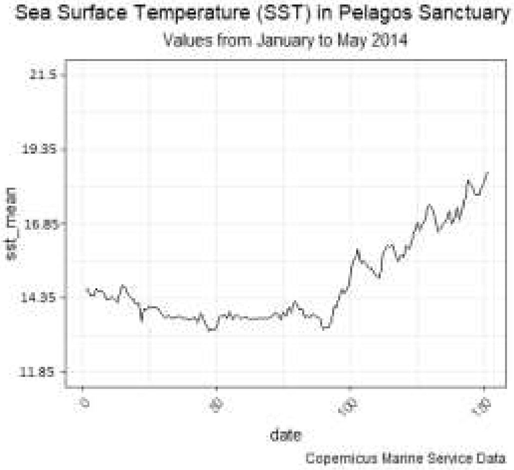
Values from January to May 2012

Copernicus Marine Service Data


Sea Surface Temperature (SST) in Pelagos Sanctuary

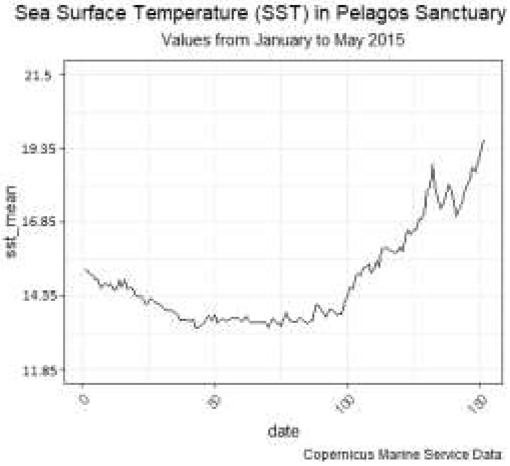
Values from January to May 2013

Copernicus Marine Service Data


Sea Surface Temperature (SST) in Pelagos Sanctuary

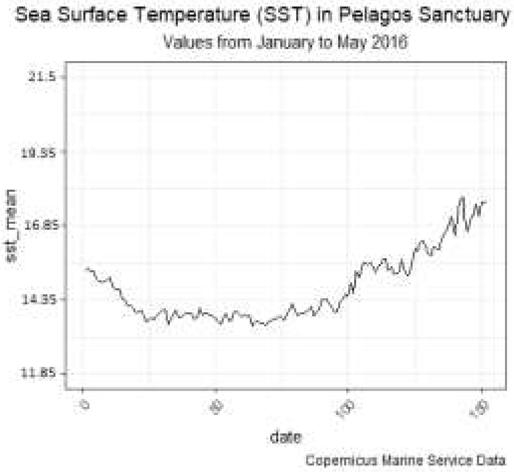
Values from January to May 2014

Copernicus Marine Service Data


Sea Surface Temperature (SST) in Pelagos Sanctuary

Values from January to May 2015

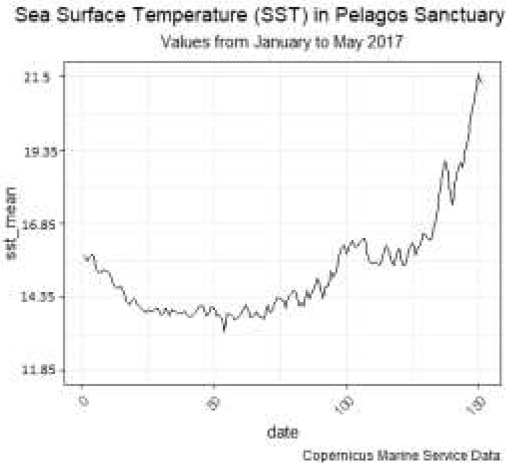
Copernicus Marine Service Data



Sea Surface Temperature (SST) in Pelagos Sanctuary

Values from January to May 2016

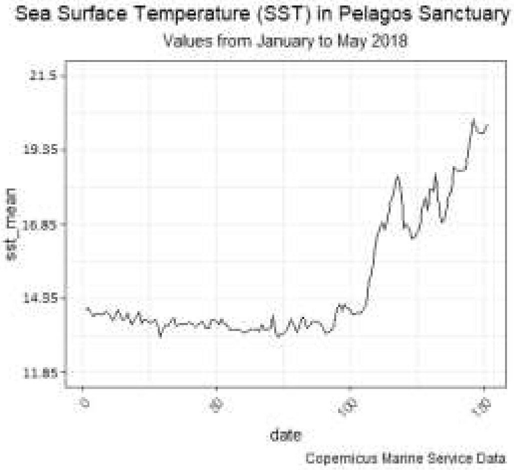
Copernicus Marine Service Data



Sea Surface Temperature (SST) in Pelagos Sanctuary

Values from January to May 2017

Copernicus Marine Service Data



Sea Surface Temperature (SST) in Pelagos Sanctuary

Values from January to May 2018

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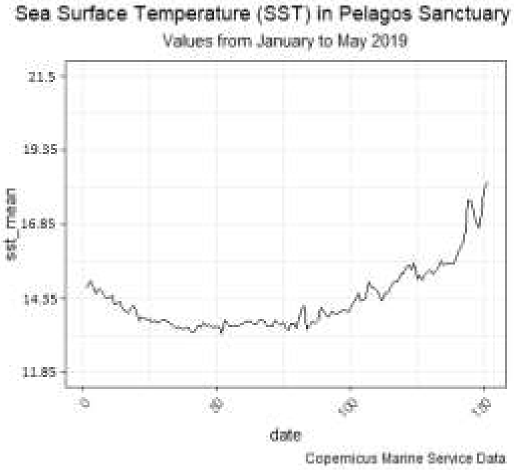

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Values from January to May 2019

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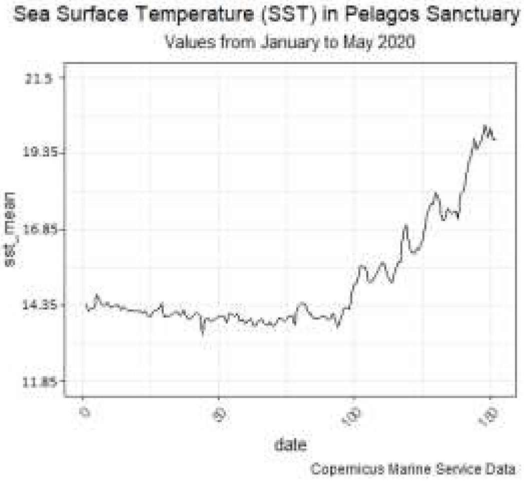

Sea Surface Temperature (SST) in Pelagos Sanctuary

Values from January to May 2020

Copernicus Marine Service Data