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CLIMATE CHANGE AND CETACEANS

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Presented by Léa David, Vice-Chair of the ACCOBAMS Scientific Committee

Issue: review the impact of climate change on cetaceans in the Mediterranean Sea, through recent bibliographic review and new analysis on data in the north-western Mediterranean Sea,

1. Action requested

The Scientific Committee is invited to:

a. **note** the information provided in the review on the impact of climate change on cetaceans;
b. **advise** on recommendations and future actions to be undertaken.

2. Background

Parties to ACCOBAMS expressed their interest in assessing the impact of climate change on cetaceans, through the adoption of the Resolution 4.14 (November 2010, Monaco) stating that necessary actions to reduce anthropogenic contributions to climate change and marine acidification have to be taken.

Moreover, the ACCOBAMS Programme of Work for the triennium 2020-2022 (ACCOBAMS Resolution 7.6) requested that ACCOBAMS cooperates with regional initiatives on climate change, taking into account cetacean conservation.

In 2019, the Italian Ministry of Environment provided a voluntary contribution to ACCCOBAMS in order (1) to compare the evolution of some cetacean populations with environmental changes over a 25 years-period in the North-Western Mediterranean Sea and (2) to propose recommendations on monitoring methodologies to assess climate change impacts.

IMPACT OF CLIMATE CHANGE ON CETACEANS IN THE NORTH-WESTERN MEDITERRANEAN SEA AND PROPOSAL FOR A RECOMMENDATION FOR ITS MONITORING

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This document is intended to review the impact of climate change on cetaceans in the Mediterranean Sea, through recent bibliographic review and new analysis on data in the north-western Mediterranean Sea, with a focus on the Pelagos Sanctuary. Based on the review and the results, recommendations will be given to monitor some parameters to follow the climate change effects on cetaceans of the Mediterranean Sea.

SUMMARY

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Introduction

The Mediterranean Sea is one of the first oceanic regions where the temperature increase was linked to greenhouse effects and global warming, mainly caused by anthropogenic activities since the beginning of the industrial era (Béthoux *et al.* 1998, Sakalli, 2017). Increased concentration of atmospheric greenhouse gases has altered the Earth's energy balance, resulting in the accumulation of thermal energy in the climate system (Trenberth *et al.*, 2014). The increase of the CO2 in the atmosphere has not only an impact on the temperature but also affects the CO2 absorption capacity of the oceans, that mainly leads to a decrease in pH, and is directly influenced by water temperature (Feely *et al.*, 1988 in Sakalli, 2017). Anthropogenic CO2 concentration in the Mediterranean is higher than in other marginal seas and in the Atlantic and the Pacific at the same latitude, and acidification has been detected in Mediterranean waters (Pace, Tizzi & Mussi, 2015; Lacoue-Labarthe *et al.*, 2016). Combined with rising temperatures, acidification may impact cetaceans for example by affecting the availability of their prey (Pace, Tizzi & Mussi, 2015; Lacoue-Labarthe *et al.*, 2016, Nunny & Simmonds, 2019).

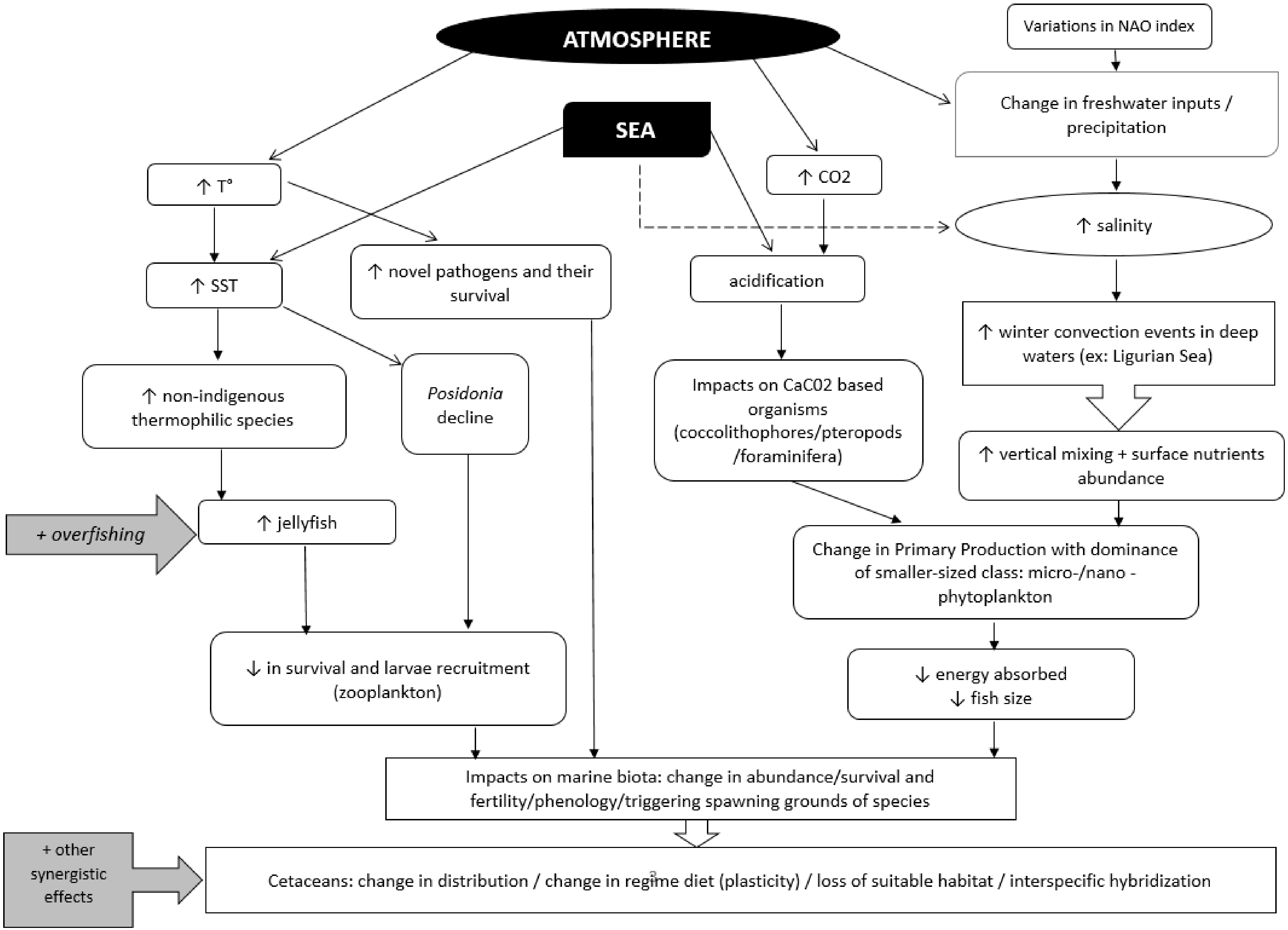
At regional scale, the Mediterranean Sea plays the role of a sentinel (hotspot) of global warming since it responds to climate change (Giorgi, 2006), with various sources of disturbance interacting synergistically (Micheli *et al.*, 2013, Moullec *et al.*, 2019). Warming trends have been observed both in the deep and intermediate layers of the Mediterranean Sea throughout the second half of the twentieth century (Béthoux & Gentili 1999 in Skliris *et al.* 2012, Vargas-Yáñez *et al.* 2010).

It is well known that the Western Mediterranean basin is immersed in a process of warming and salt-increase since the second half of the 20th century (Béthoux *et al.*, 1998, Krahmann & Schott, 1998, Smith *et al.*, 2008, Vargas-Yàñez *et al.*, 2010). A positive North-Atlantic Oscillation (NAO) causes dryer and warmer conditions over the western Mediterranean and cooler conditions over the eastern basin, whereas the contrary occurs during negative phases (Pisano *et al.*, 2020).

The Mediterranean basin is one of the main regions of cyclogenesis in the world and the strongest windstorms are often associated with a cyclone (Lionello *et al.* 2016). Windstorms and cyclones control the Mediterranean Sea circulation. Indeed, winds like the mistral often produce sea surface cooling, and coastal upwellings, and are the main factor involved in ocean convection and deep-water formation (Millot & Taupier-Letage, 2005). The winter deep convection affects the magnitude and the spatial extent of new primary production. This convection derived nutrient, augmented by factors such as frontal systems or Rhone River inputs, support the highest regional scale Chl-a values (up to 3 mg Chl-a L-1) in the Mediterranean Sea (D'Ortenzio & Ribera d'Alcalà, 2009, Donoso *et al.*, 2017). A substantive spring bloom is observed in March in the deep convection zone, when surface stratification begins. The high primary productivity in the NWMS is then expected to stimulate secondary productivity (Donoso *et al.*, 2017).

For example, Marty and Chiavérini (2010) monitored the hydrological changes in the Ligurian Sea and their biogeochemical consequences during the period 1995-2007. The Gulf of Lion is known to be an important area of deep-water formation (López-Jurado *et al.*, 2005) and where intense winter convection occurs (MEDOC Group, 1970 in Marty and Chiavérini, 2010), and less intense events occurred in the Balearic Sea (Salat & Font, 1987 in Marty and Chiavérini, 2010) and in the Ligurian Sea (Sparnocchia *et al.*, 1995). However, from 2003 to 2006, Marty and Chiavérini (2010) reported that the frequency of winter convections appeared to be increasing in the Ligurian Sea. And these convection events are the cause of the abundance of the nutrients in surface layers. The authors (Marty *et al.*, 2002, Marty & Chiavérini, 2010) noticed an increase of biomass (+1.5 mgChla/m2.yr) paralleling increases in temperature and salinity in the NWMS. These meteorological changes, linked to global climate change, impacts the abiotic parameters and successively there is a cascade effect in the Mediterranean Sea environment on the biotic components, from phytoplankton to cetaceans (Figure 1).

Figure 1: Cascading impacts of climate change on marine environment, this scheme was designed based on information from different sources of literature


ATMOSPHERE
Variations in NAO index
Change in freshwater inputs / precipitation
SEA
↑ T°
↑ CO2
↑ salinity
↑ SST
↑ novel pathogens and their survival
acidification
↑ winter convection events in deep waters (ex: Ligurian Sea)
↑ non-indigenous thermophilic species
Posidonia decline
Impacts on CaC02 based organisms (coccolithophores/pteropods /foraminifera)
↑ vertical mixing + surface nutrients abundance
+ *overfishing*
↑ jellyfish
Change in Primary Production with dominance of smaller-sized class: micro-/nano - phytoplankton
↓ in survival and larvae recruitment (zooplankton)
↓ energy absorbed
↓ fish size
Impacts on marine biota: change in abundance/survival and fertility/phenology/triggering spawning grounds of species
+ other synergistic effects
Cetaceans: change in distribution / change in regime diet (plasticity) / loss of suitable habitat / interspecific hybridization

Oceanographic parameters

SST: a key parameter to track climate change

From seasonal to longer timescales (interannual, decadal, and multidecadal), Sea Surface Temperature (SST) responds to both natural climate variability (Deser *et al.*, 2010 in Pisano *et al.*, 2020) and human-driven climate change (Trenberth, 2009).

Sea Surface Temperature is an indicator of the water temperature close to the ocean's surface layer (i.e., from 10 µm to 20 m below the sea surface) in oceanography (Sakalli, 2017). SST variations are mainly controlled by variations in the air–sea heat flux as well as in the vertical mixing and the horizontal advection of heat. The inflow of North Atlantic surface waters at the Gibraltar strait represents an important source of heat for the basin, counterbalancing the net heat loss from the sea surface and from the Mediterranean outflow (Skliris *et al.*, 2012). Recent studies about the rapid increase in sea surface temperature during last centuries shows that it will drastically continue to rise in the future (Meissner *et al.*, 2012; Collins *et al.*, 2013, Sakalli, 2017).

Recent studies on long-term SST variations in the Mediterranean Sea agree to indicate an increase of the SST over the last decades. Indeed, Sakalli *et al.* (2017) found an increase of about 0.4 °C per decade in the basin between 1986 and 2015, which is consistent with the results found by Pisano *et al.* (2020), the authors show an increase of 0.041±0.006°C/year between 1982 and 2018 over the whole Mediterranean Sea.

Also, both studies' analysis suggests an uneven pattern of the Mediterranean SST, with the eastern getting warmer more rapidly, compared to the western basin. The temperature gradients between the east and west Mediterranean basins are mainly caused owing to diffusing of the Atlantic water into the sea through the strait of Gibraltar (Millot, 1999 in Sakalli & al., 2017).

Specifically, the continuous warming trend happened since the beginning of the 21st century (Figure 2 and Figure 3), the Mediterranean Sea featured one of the highest SSTs and this warming trend is expected to continue throughout the 21st century (Kirtman *et al.*, 2013).

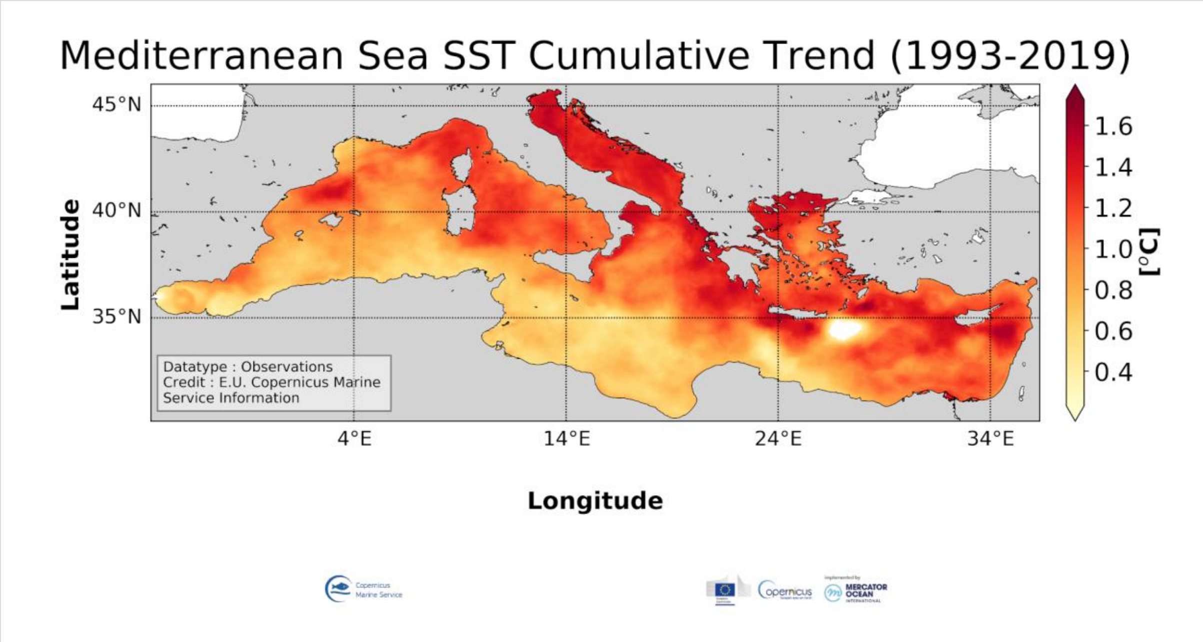


Figure 2: Cumulative SST trend for the Mediterranean Sea over the period 1993-2019 - This OMI (Ocean Monitoring Indicator) is derived from the CMEMS Reprocessed Mediterranean L4 SST product (SST_MED_SST_L4_REP_OBSERVATIONS_010_021, see e.g. the OMI QUID

(http://marine.copernicus.eu/documents/QUID/CMEMS-OMI-QUID-MEDSEA-SST.pdf)

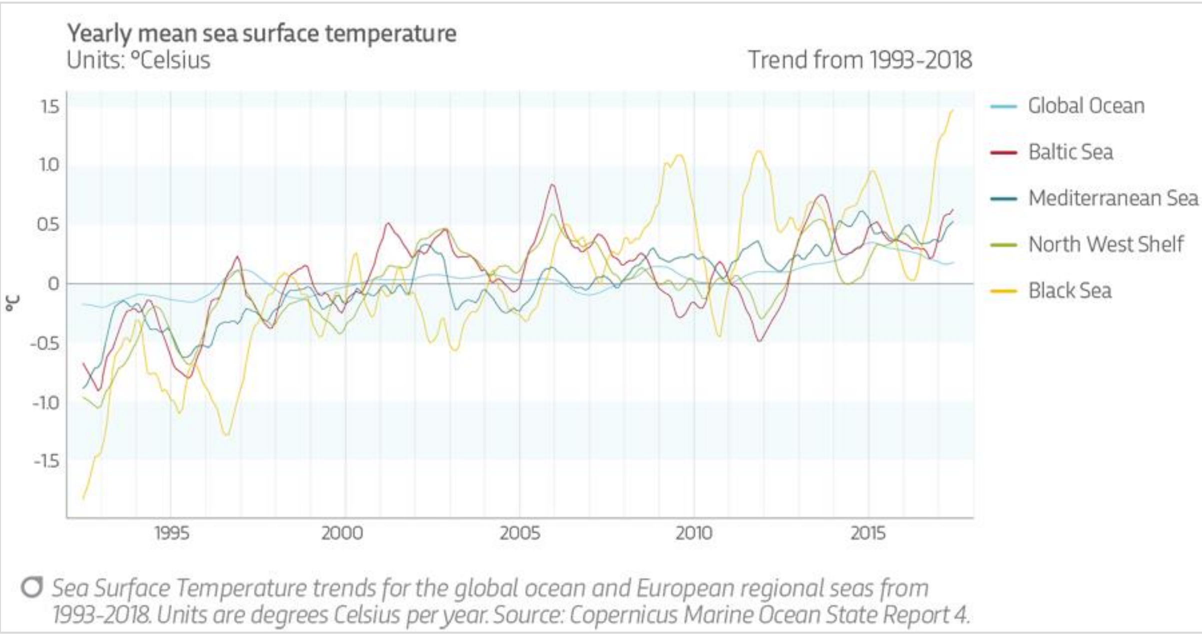


Figure 3: Sea Surface Temperature as important measure of ocean warming - Trend from 1993-2018 - From Marine Copernicus Ocean State Report 4 Summary, 2020

(https://marine.copernicus.eu/pl/node/670)

Chl-a: a proxy for phytoplankton

Chlorophyll concentration - as a proxy for phytoplankton - responds rapidly to changes in environmental conditions, such as light, temperature, nutrients and mixing (Colella *et al.* 2016). The Mediterranean Sea is an oligotrophic basin, where chlorophyll concentration decreases following a specific gradient from West to East (Colella *et al.* 2016). The highest concentrations are observed in coastal areas and at the river mouths, where the anthropogenic pressure and nutrient loads impact on the eutrophication regimes (Colella *et al.* 2016). Generally, the Mediterranean basin shows an average positive trend, mostly due to the western side contribution (Figure 4).

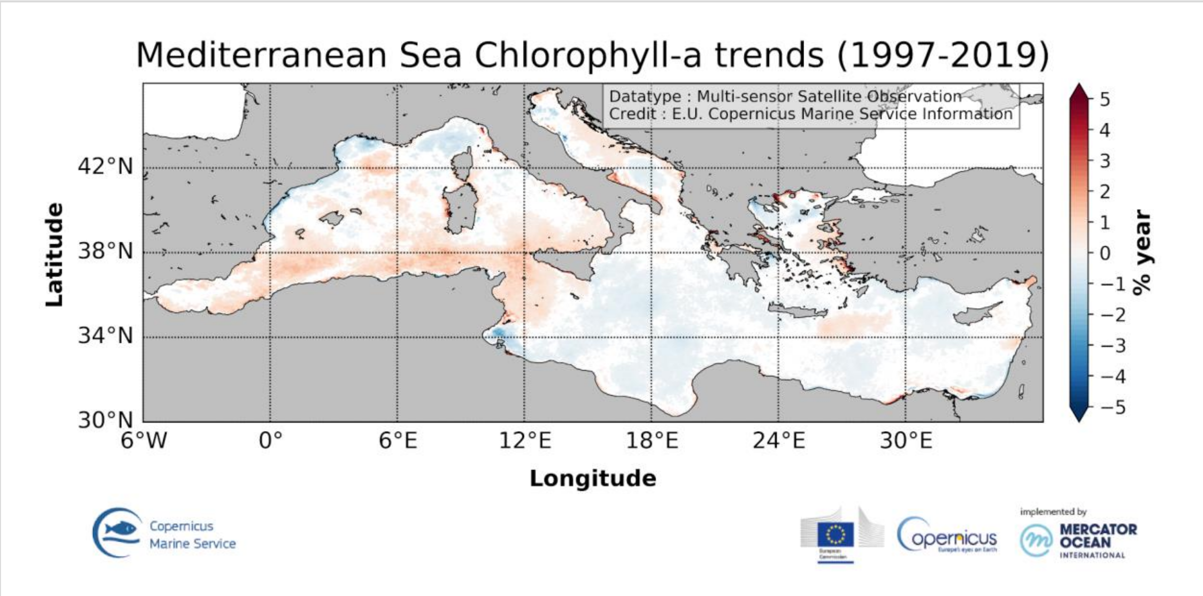


Figure 4: Mediterranean Sea satellite chlorophyll trend map from 1997 to 2019 based on regional chlorophyll reprocessed (REP) products - from Marine Copernicus

In the Mediterranean Sea, while the trend average for the 1997-2019 period is positive, both the amplitude and the baseline of the cycle have continued to decrease during 2017 (Figure 5). In particular, the annual average for the region in 2017 is 0.11 mg m-3, the lowest since 2002. The southern parts of the European regional seas have undergone significant changes during the year 2017: the Mediterranean Sea has been impacted by strong heat wave events during boreal summer in the eastern and western basins (Copernicus Marine Service Ocean State Report, Issue 3, 2019), several events of extreme variability in the western basin, and higher than-average ocean surface and subsurface water temperature.

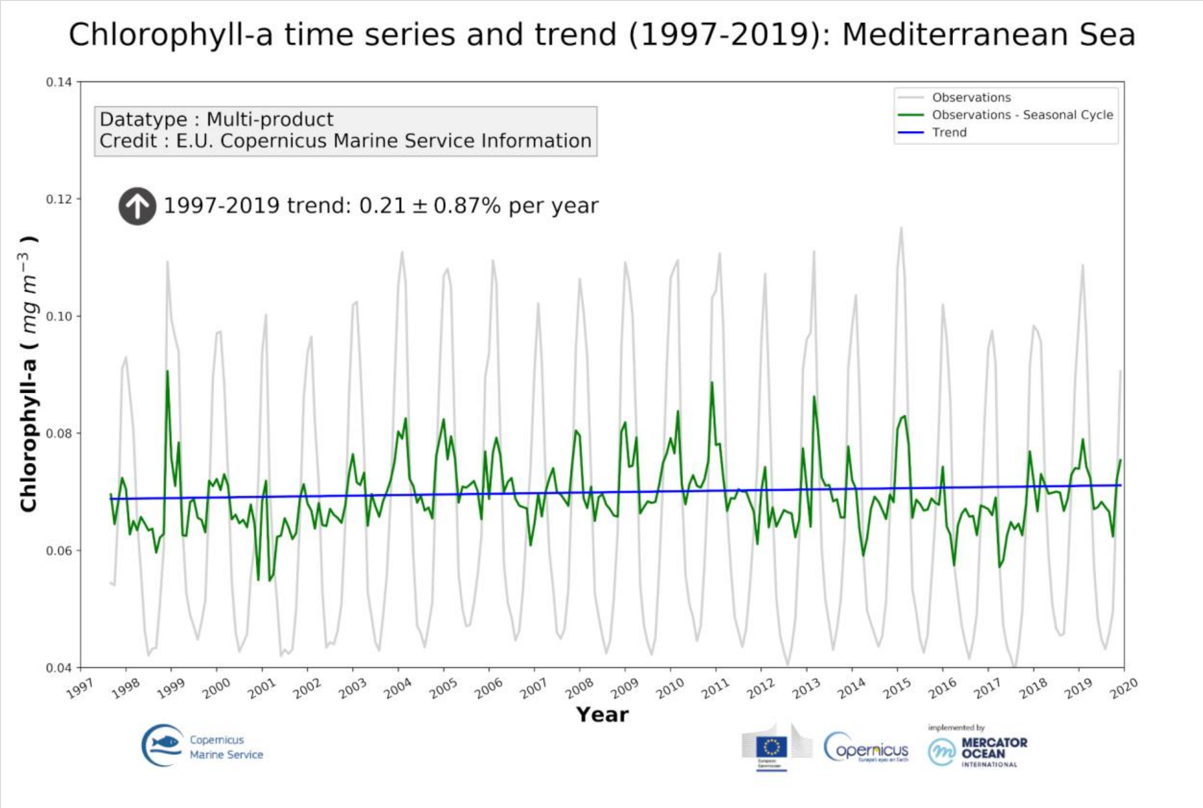


Figure 5: Time series derived from the regional chlorophyll reprocessed products from Marine Copernicus

However, these general trends are true for the entire basin, but looking at a smaller scale, especially in the Pelagos Sanctuary (Figure 4), we can observe a slight decrease of the Chl-a in this area and in the northern part of the Gulf of Lion.

Chlorophyll α concentrations on water masses indicate the presence of phytoplankton species and therefore high chlorophyll α concentration values appear during algal blooms (Kitsiou & Topouzelis, 2014) and is widely used, due to its major role in photosynthesis (Kotta & Kitsiou, 2019).

Food web

Climate change effects on the low trophic levels of the food web: phyto- and zoo-plankton

The Intergovernmental Panel on Climate Change (IPCC) and European Environmental Agency (EEA) have warned of the impact of rising temperatures on many ecological factors including changes in the composition of phytoplankton blooms and changes in the northern boundary of distribution of warm water species (EEA, 2008; IPCC, 2007 in Verborgh *et al.*, 2016). The acidification rate in the Mediterranean waters has ranged between 0.055 and 0.156 pH units since the pre-industrial period, affecting the marine trophic chain (Balzan *et al.*, 2021). Results of the study of Goyet *et al.* (2016) show that the Western basin is acidifying faster than the Eastern basin.

Planktonic calcifying organisms such as foraminifera, pteropods and coccolithophores, important contributors of marine calcium carbonate production, are expected to be particularly affected by ocean acidification and climate change (Balzan *et al.*, 2021). A shift in phytoplankton community, with a dominance of smaller species (picophytoplankton and nanoflagellates) and a decrease in the biomass of the largest size group (i.e., microphytoplankton), are some of the expected outcomes (Moullec *et al.*, 2019, Balzan *et al.*, 2021). However, there are still many uncertainties when it comes to the impact of sea warming and acidification on primary production in the Mediterranean Sea, but it is clear that physicochemical changes will affect the magnitude, timing and composition of phytoplankton blooms, with associated changes in the seasonal distribution of zooplankton (Moullec *et al.* 2019, Balzan *et al.*, 2021) and certainly influencing the next level of the whole food webs.

Cascading effects induce changes in fluxes of matter and energy in trophic webs. They are a potential major mechanism of climate-induced functional change. Planktonic communities are themselves controlled by gelatinous species, through the predation of copepods, fish eggs and larvae (Lejeusne *et al.*, 2010). In a sea highly impacted by the alteration of the trophic chains due to overfishing, seawater warming favors the successful dispersion and growth of jellyfish (Balzan *et al.*, 2021). In this sense, overfishing is noted as an important factor that enhances gelatinous zooplankton populations by reducing their predators and zooplanktivorous fish competitors (Guerrero *et al.*, 2018). Also, temperature is the main environmental parameter driving significant differences in the cnidarian community composition, abundance and spatial distribution patterns in the Mediterranean Sea, and thus jellyfish are considered as a possible group of winners under warming (Guerrero *et al.* 2018, Balzan *et al.*, 2021).

It appears clearly that abiotic parameters are the key parameters driving the changes of the marine environment, and therefore, the key parameters to monitor.

Climate change effects on high trophic levels of the food-web

Footprint of Mediterranean warming have been observed in several marine phylum, including phytoplankton, and macrophytes (macroalgae and seagrasses) but also populations of invertebrates (porifera, cnidaria, polychaeta, mollusca, ascidians, bryozoa, echinodermata, crustaceans) and vertebrates (fishes, reptiles, mammals). However, most (53%) evidence of impacts of warming on Mediterranean biota are reported for fish and cnidaria (Marbà *et al.*, 2015). Temperature has a major direct impact on the physiology, growth, reproduction, recruitment and behavior of marine organisms such as fish. Warming associated with climate change already affects the Mediterranean ecosystem for some benthic and pelagic species (Marbà *et al.* 2015). Cheung *et al.* (2011) whose models predict that if phytoplankton communities shift towards smaller size cells, energy transfer from primary production to higher trophic levels may decline in the future. In marine ecosystems, environmental conditions play an important role in fish recruitment (Moullec *et al.*, 2016a).

In the Mediterranean Sea, projected changes in primary and secondary productions suggest that trophic mismatches between fish pre-recruits and their prey could increase in the future, with negative consequences for recruitment success (Lejeusne *et al.* 2010, Moullec *et al.*, 2016a). By affecting primary and secondary production and timing, climate change may have repercussions on the life cycles of fish predators timed to exploit seasonal peaks (Evans & Waggitt, 2020). And this in turn may affect top predators, such as seabirds and marine mammals, particularly those that have timed reproductive activities to coincide with these peaks (Evans & Waggitt, 2020).

Interpreting global scale simulation results at a regional scale can be hazardous and more dedicated fine scale regional studies are needed (Moullec *et al.*, 2016b). Nonetheless, changes in assemblage-level body size structure suggest that climate and ocean changes will cause dramatic modifications of food web dynamics (Moullec *et al.*, 2016b). Fishes in warmer waters are expected to have a smaller maximum body size and smaller size at first maturity with possible higher natural mortality rates (Sumaila *et al.*, 2011).

Global warming will also increase the number of alien species with tropical and subtropical distributions and Indo-pacific origin entering the Mediterranean Sea (Zenetos *et al.*, 2011), their N-NW expansion rate and their relative abundance thus altering the stability and equilibrium of the Mediterranean ecosystem food webs. Expansion records of Indo-Pacific species indicate that a number of species are likely already favoured by increased temperatures, exhibiting their northernmost records in the Mediterranean or pushing their way into cooler western Mediterranean waters (Zenetos & Galanidi, 2020).

Case of a top-predator: the Atlantic bluefin tuna

The Atlantic bluefin tuna is one of the examples of how fish can be impacted by climate change. SST is a significant variable determining the timing of bluefin tuna spawning in the Mediterranean (Garcia *et al.*, 2005). Spawning begins at ∼19-20°C and the embryo developmental time decreases with increasing temperature (Gordoa & Carreras, 2014 in Alvarez-Berastegui *et al.*, 2016). The location of spawning areas has been also associated with salinity, which in turn are associated with frontal areas (Alvarez-Berastegui *et al.*, 2016). If the Mediterranean Sea warms up earlier in the year, spawning may also start earlier, with a potential mismatch between favorable feeding conditions and tuna reproduction. In addition, the migration patterns and spatial distribution of highly mobile large pelagic fish, such as bluefin tuna, may be indirectly altered by climate-induced changes in prey abundance (Walther *et al.* 2002). Historical data from the Mediterranean Sea suggest that bluefin tuna may change their migration routes and spawning behaviors in association with long-term fluctuations in temperature (Ravier & Fromentin 2004 in Moullec *et al.*, 2016b). As a result, the migration routes of bluefin tuna may vary and adapt to climate change and potentially explore new spawning grounds in the Atlantic (Moullec *et al.*, 2016b).

Climate change effects on cetaceans

SST used as a key parameter to investigate climate change effects on cetaceans

In addition to non-dynamic parameters, such as bathymetry, depth etc, marine mammal distributions are influenced by a host of variable environmental factors, such as SST. Changes in SST may be indicative of oceanographic processes that ultimately determine marine mammal occurrence across a number of different temporal scales (Au & Perryman 1985 in Kaschner *et al.*, 2004, Tynan, 2005, Azzellino et al, 2008, MacLeod, 2009). Significant correlations of marine mammal species with SST have been demonstrated in different areas and for a variety of different species. Indeed, when selecting habitat in the Ligurian Sea, fin whales (*Balaenoptera physalus*), striped dolphins (*Stenella coeruleoalba*) and sperm whales (*Physeter macrocephalus*) are all also influenced by SST and, therefore, distribution of cetaceans in this area may alter in response to climate change (Azzellino *et al.*, 2008). Likewise, in the Alborán Sea, Cañadas and Vázquez (2017) found that looking at the relationship between density of the short-beaked common dolphins (*Delphinus delphis*) and SST anomaly, the general pattern was an inverse relationship between animals' density and SST. The authors highlighted a strong pattern of higher density of groups towards the west where the water is cooler and decreased progressively towards the east where the water becomes warmer. Also, they indicate that there would be likely a general decrease in density and reduction in suitable habitat for common dolphins in the Alborán Sea towards the west if SST continues to change at the rate it has done over the last three decades at the local level (Cañadas & Vázquez, 2017). As this subpopulation has already been listed as endangered in the IUCN Red List due to declines in numbers over recent decades, this could have serious implications (Nunny & Simmonds, 2019).

Several studies have reported the strong relationship between SST and pilot whales' distribution, migration and abundance and Miralles *et al.* (2016) found that for short-finned pilot whales, increasing SST in the North Atlantic may cause northward range shift, which may lead to interspecies hybridization with the long-finned pilot whale. Indeed, the warmer SST anomalies in the last decades in northern latitudes are particularly intense and coincide with the reproduction season of *Globicephala*. Thus, increasing water temperature during mating season facilitates northward incursions of *G. macrorhyncus*, and therefore may have increased opportunities for interspecific mating between pilot whales (Miralles *et al.*, 2016).

Despite the large potential impacts of warming waters on marine mammals, the global vulnerability of them to global warming is poorly understood (Albouy *et al.*, 2020). Marine mammals are eurytherm species, so probably not directly concerned by some SST changes, but most probably they are influenced by lower trophic levels which may be impacted by SST changes. Marine mammals are important drivers of ecosystem functioning and fulfill key ecological roles worldwide, mostly via trophic dynamics due to their role as consumers at most trophic levels and their role in nutrient cycling (Bowen, 1997, Roman & McCarthy, 2010, Albouy *et al.*, 2020). So, if lower trophic levels (the preys) are impacted, cetaceans as top predators may also reflect these changes.

Prey availability and change in regime diet of cetaceans: examples that already occur in several areas of the world

Movement patterns and habitat preferences of higher-trophic-level marine predators such as cetaceans, are typically related to the distribution of their prey (Gowans *et al.*, 2007 in Henderson *et al.*, 2014). And cetaceans which are confined in restricted areas with limited ranges are likely to be most vulnerable to climate change (Learmonth *et al.*, 2006, Simmonds & Isaac, 2007). Change in key prey species distribution is the main driving factor defining geographical range and habitat preference in cetaceans (Simmonds, 1994, Agardy, 1996, Maze & Würsig, 1999 in Gambaiani & al., 2009). For instance, as water surface becomes warmer in the Norvegian Sea, prey species such as krill and amphipods may have shifted their spatial distribution to more northern latitudes, and fin whale and minke whale have adapted their feeding to focus more on pelagic fish such as Norwegian spring-spawning herring (*Clupea harrengus*) (Nøttestad *et al.*, 2015). The authors indicate that it is not an unusual finding, and Vikingsson *et al.* (2014) found that minke whales in Icelandic waters have shifted their distribution and diet composition during the last years from a diet dominated by sandeel and macro-zooplankton to a fish diet dominated of herring and gadoids.

The case of *Balaenoptera physalus* in the NWMS

In the Mediterranean Sea, the fin whale mainly feeds on *Meganyctiphanes norvegica*, which is on the limit of its distribution (Notarbartolo di Sciara *et al.*, 2003). The thermal limit of *Meganyctiphanes norvegica* in the Mediterranean Sea is 18°C (Fowler *et al.*, 1971 in Gambaiani *et al.*, 2009). And because of the land barrier in the Mediterranean Sea, *Meganyctiphanes norvegica* will not be able to move northward (Gambaiani *et al.*, 2009, Simmonds *et al.*, 2012), whereas, as cited previously, a shift of prey species towards more northern latitudes due to temperature warming in the Norwegian Sea was possible.

Bentaleb *et al.* (2011) investigated the foraging ecology of Mediterranean fin whales using satellite tracking and baleen plates stable isotopes. They provided evidence that some fin whales migrate from the Mediterranean Sea to the Atlantic Ocean, but most individuals remain within the western basin during fall and winter. *Meganyctiphanes norvegica* is the predominant prey of this population of fin whales (Notarbartolo di Sciara *et al.*, 2003, Astruc, 2005). Bentaleb *et al.* (2011) do not exclude that Mediterranean fin whales are also feeding on other unknown prey species. However, they rule out that they mainly feed on small mesopelagic fishes such as sardines or anchovy, as they are occupying the same mean trophic level (Pinnegar *et al.*, 2003 in Bentaleb *et al.*, 2011). According to the authors, the potential impact of the decadal changes of the NAO is not excluded, causing drier (normal) Mediterranean conditions during the negative (positive) phase. Since 1980, except for 1996, NAO has been positive. The complex combination of circulation alteration, temperature increase (Conversi *et al.*, 2010), nutrient availability and anthropogenic impacts are likely affecting marine communities of the Mediterranean sub-basins.

The shifts in the primary producers are likely to influence the Mediterranean food web and consequently fin whales (Bentaleb *et al.*, 2011). So, either fin whales will shift their distribution to follow their main prey, either they will shift their main prey.

The case of *Delphinus delphis* in the Alborán Sea

Cañadas & Vázquez (2017) used a two-decades long dataset on the common dolphins in the Alborán Sea from 1992 to 2011, with data collected from motor boats during summer months (from June to September). The authors showed that SST plays a significant role in the common dolphin distribution and density. They highlighted a shift in distribution from eastern warmer waters towards cooler western waters. They also showed that common dolphin density seems to vary inversely with SST, with higher densities in cooler waters and vice versa. At this local level, this study reflects how climate change affects this species distribution and abundance.

The case of *Stenella coeruleoalba* in the NWMS

Climate change has the potential to increase pathogen development and survival rate, disease transmission and host susceptibility (Harvell *et al.*, 2002 in Simmonds & Eliott, 2009). Simmonds & Mayer (1997) noted that the unusual warm and dry winter of 1989-1990 led to reduced nutrient input into the eastern Mediterranean causing a decline of the dolphin's common prey. And this could have explained why many of the carcasses recovered at this time had depleted body fat reserves. Poor nutrient conditions could have caused the dolphins to be more susceptible to infection (i.e., the development of the epizootic) in the first place and potentially rendered less able to fight off the effects of the infection (Simmonds *et al.*, 2012).

The case of *Physeter macrocephalus* in the NWMS

In the northwestern Mediterranean Sea, a great change has been documented for Sperm whales over two decades (Di-Méglio *et al*., 2016): between 1992 to 2002, it was known that sperm whales present there where lone animals, barely by two, and mostly big males. Over the decade 2005-2015, the proven presence of females, newborns and large groups corresponding to social units has been witnessed (Di-Méglio *et al*., 2016) and this phenomenon is still visible nowadays. The reason for that change is not demonstrated. But it has been shown that the distribution of sperm whales in the northwestern Mediterranean is influenced by the presence of cold surface temperatures, significant chlorophyll concentrations (Praca & Gannier, 2008) and thermal fronts separating water masses such as the Balearic front (Gannier & Praca, 2007). So, any changes of those parameters may have an indirect influence on the distribution of sperm whales. But no precise estimation of population over a large period is available.

The case of *Grampus griseus* in the NWMS

The recent results from different studies seem to show a change in the distribution at large scale and abundance at local scale for the Risso's dolphin (see IUCN ongoing and ACCOBAMS CMP Grampus griseus for a review). Indeed, the ACCOBAMS Survey Initiative (aerial survey in summer 2018, ACCOBAMS 2021) and Fix Line Transect Network (surveys from ferries, 2008-2018, Arcangeli *et al.* 2019) seems to show a reduced range of the species compare to previous knowledge, mostly concentrated in the westernmost part of the Mediterranean basin. Habitat suitability models in the northwestern Mediterranean confirmed in the 2000s a strong preference with steep slope habitat (Praca and Gannier 2007, Azzellino *et al.* 2008) and a narrow band of suitable habitat in proximity to the 200 m contour (Praca and Gannier 2007). The most recent studies (Azzelino *et al*., 2016; Lanfredi et al., 2018, Laran *et al*., 2021) highlighted changes in distribution and habitat in the northwestern Mediterranean Sea, with low encounters over the coastal and continental slope in recent years compared to what was known on the species before, while the presence seemed to be stable in the most pelagic area. At a local scale, long-terms studies in the Ligurian-Corso-Provençal provided a first indication of a decreasing trend for the species over 25 years (Airoldi *et al.,* 2015, Azzellino *et al.,* 2016). Again, only hypothesis may link those changes with climate change or other drivers (human activities, competition with other species like Bottlenose dolphin).

STUDY CASES

As a summary of the bibliographic review, it appears that changes in abundances and shifts in distribution of cetaceans as a result of a warming climate have been documented (Cañadas & Vázquez, 2017, Evans & Waggitt, 2020, Henderson *et al.*, 2014, Nøttestad *et al.*, 2015, Salvadeo *et al.*, 2010) and substantial future shifts in distribution have been predicted (Becker *et al.*, 2018, Lambert *et al.*, 2014, Learmonth *et al.*, 2006, MacLeod, 2009).

SST and chlorophyll-a are among physiographic and remote sensed variables that can be today easily accessible and therefore widely used to investigate the relationship between cetaceans and physical and biological variables (Azzelino *et al.*, 2008, Cañadas & Vázquez, 2017, Druon *et al.*, 2012, Laran & Gannier, 2008, Littaye *et al.*, 2004).

SST is one of the essential climate variables (Pisano *et al.*, 2020) and changes in SST have been linked to changes in all levels of the food web, from immediate phyto- and zoo-plankton responses to lagged alterations in numbers, diet, and even reproductive success of higher-level organisms such as fishes, seabirds, and marine mammals (Henderson *et al.*, 2014). It follows that cetaceans' populations would response to such variations in SST.

Surface chlorophyll content is considered a good proxy for fin whales prey availability, and seems to be a parameter affecting their distribution (Druon *et al.*, 2012; Littaye *et al.*, 2004; Panigada *et al.*, 2008, Fossi *et al.*, 2017). There are time lags between chlorophyll peaks and zooplankton blooming peaks, and in turn between zooplankton peaks and observed fin whale aggregations (Littaye *et al.*, 2004). The spring bloom is observed in March, and high values of Chl-a should be observed at this time of the year. In the Ligurian Sea, it has been demonstrated that when the phytoplankton bloom occurs, there is a time lag of 8 weeks when zooplankton communities are increased by a factor of three between the two periods (Vandromme *et al.*, 2011). Thus, it appears important to extract values of Chl-a both in spring and summer.

In the Ligurian Sea, Vandromme *et al.*, 2011 highlighted a clear opposite evolution of zooplankton vs. Chl-a, suggesting a strong "top-down" control of phytoplankton spring in bloom (and in autumn) by the zooplankton. This might reflect that fin whales in the NWMS, aggregate in areas with high zooplankton biomass.

Available evidence demonstrates that krill are most abundant in areas with the highest-productivity within their habitats (Atkinson *et al.*, 2004 in Shabangu *et al.*, 2017). Negative krill-phytoplankton relationships were found in the Southern Ocean and this may reflect locally high krill densities that drive down the phytoplankton biomass (Whitehouse *et al.*, 2009 in Shabangu *et al.*, 2017). Thus, high krill densities can be associated with low Chl-a concentrations. Shabengu *et al.*, 2017 found a negative relationship between the acoustic occurence of blue whales and Chl-a concentrations. Knowing that, investigating the relationship between fin whales and Chl-a concentration appears to be an important aspect of this research.

Considering the impact on cetaceans, it appears clearly that following all parameters of cetacean's attributes (diet, life cycle, distribution, abundances, health…) is not feasible. Therefore, this study will investigate the relationships between the SST and the chlorophyll-a and cetaceans.

Material and methods

Cetacean sightings data

Long-term data on cetaceans using the same method and the same type of platform to collect data do exist in the NWMS and mainly in the Pelagos area. These long-term data applying the line transect method are rare and allow to give as a result densities and abundances of the animals. Researches undertaken in the existing literature led to find 2 studies with relative long-term sets of coherent line transect data in the same region : "**Trends in summer presence of fin whales in the Western Mediterranean Sea Region: new insights from a long-term monitoring program**" from Tepsich *et al.*, 2020 and "**Evolution of the fin whale and striped dolphin populations over 25 years in the North-Western Mediterranean Sea**" from David *et al.* (2020).

From Tepsich *et al.*, 2020 study, fin whale data were collected in summer months from 2008 to 2018. Data were collected from dedicated observers embarked on board ferries along fixed routes (known as the Fix Line Transect network or FLT), covering the western Mediterranean and Adriatic region. From this study, results of fin whales' annual densities (animals per 100km^2) within the Pelagos Sanctuary area were keeped for the analysis conducted here.

From David *et al.*, (2020) study, data on fin whale and striped dolphins were collected from platforms with similar characteristics with the line transect method applied, between 1994 and 2018, during summer periods from June to September. We extracted results of annual absolute abundances from Kriging methodology (annual number of individuals) corresponding to this 25 years-period in the NWMS and Pelagos Sanctuary.

Considering methods for the calculation of animal abundances or densities, please refer to the respective published paper.

Those two existing studies will allow us to investigate the relationship of SST and Chl-a and cetaceans for two species: the fin whale and the striped dolphin. The first species is a top predator of a short food web as it preys on zooplankton, and moreover it is stenophagous (feeds mainly on one main prey). The second is a top predator of a longer food web, as striped dolphin feeds on squids and fishes, and is more opportunistic. Secondly tests will take into account two time-scales, 10 years and 20/25 years. And thirdly, two spatial-scales will be investigated, the Pelagos Sanctuary and the larger whole North-western Mediterranean Sea (NWMS).

Study area

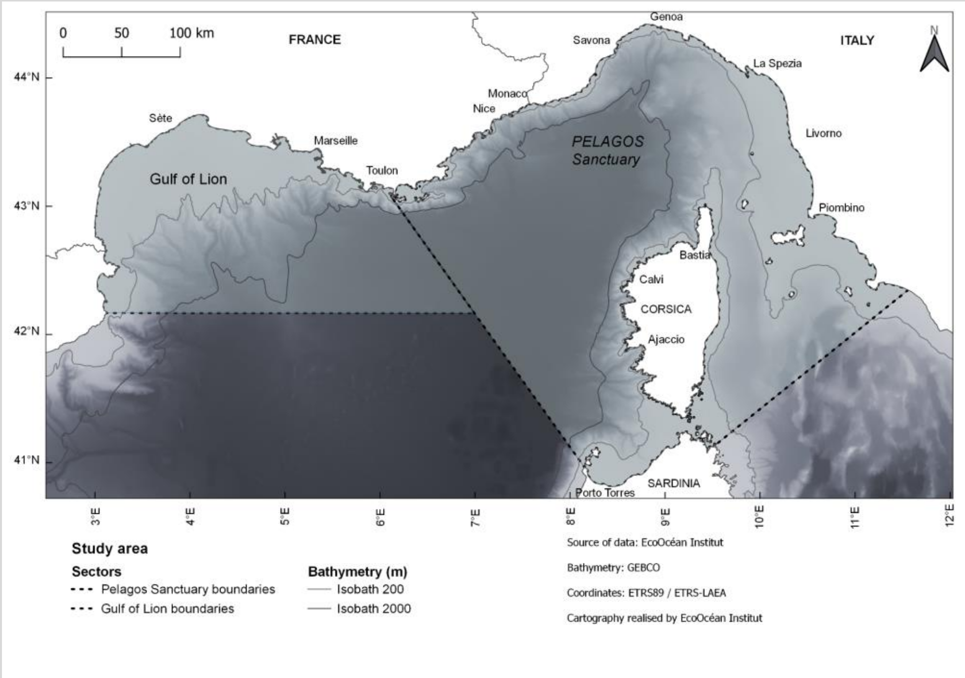


Figure 6: Map of study area (from David et al., 2020)

The study area encompasses an area extending from 3°00E' to 11°31'E and 40°58' to 44°50'N (Figure 6), corresponding to a large part of the NWMS (126,178 km^2), including the Pelagos Sanctuary (87,358 km^2) and adjacent waters located in the Gulf of Lion offshore (38,820 km^2). The entire study area corresponds to the one of David *et al.* (2020) for the striped dolphin and the fin whale sightings, whereas only the results of Tepsich *et al.* (2020) inside the Pelagos sanctuary were kept.

SST and Chl-a parameters

SST data used in the present study were extracted from Marine Copernicus Ressources website (https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=MEDSEA_MULTIYEAR_PHY_006_004). This SST parameter is the temperature of sea water near the surface, the temporal resolution chosen is the monthly mean each year. Resolution of the data collected is 0.042° x 0.042°. SST have been extracted for spring months (march/april/may) and for summer months (june/july/august/september) between 1994 and 2018.

Chl-a data have been extracted from the Marine Copernicus Ressources website (https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=OCEANCOLOUR_MED_CHL_L4_REP_OBSERVATIONS_009_078) and downloaded for the period corresponding to 1997 - 2018 (no Chl-a data were available before September 1997). Resolution is 1km x 1km (surface only). Mediterranean Sea monthly reprocessed surface chlorophyll from multisatellite observations were extracted for march/april/may for the spring period, and june/july/august/september for the summer season.

Finally the variables presented in the Table 1 below were used here:

Table 1: Variables and their correspondent acronym

Variables acronym	Correspondence variable name
Ab_Sc_Med	Striped dolphin abundance in the NWMS
Ab_Bp_Med	Fin whale abundance in the NWMS
Ab_Sc_Pel	Striped dolphin abundance in Pelagos
Ab_Bp_Pel	Fin whale abundance in Pelagos
SST_spring_Pel	SST in spring in Pelagos
SST_spring_Med	SST in spring in the NWMS
SST_summer_Pel	SST in summer in Pelagos
SST_summer_Med	SST in summer in the NWMS
CHL_spring_Pel	Chl-a in spring in Pelagos
CHL_spring_Med	Chl-a in spring in the NWMS
CHL_summer_Pel	Chl-a in summer in Pelagos
CHL_summer_Med	Chl-a in summer in the NWMS

Analysis

For each variable, the normality of the data is tested using Shapiro-Wilk test, helping to adapt the type of test used afterwards.

A PCA is first applied to visualize the overall shape of the data and highlight correlations within the datasets from Tepsich *et al.*, (2020) and from David *et al.* (2020). To test the correlation between variables, Pearson's test method for Normal data and Kendall test method for non-normal data were applied, with scatter plot for significant correlations. Test were performed with the significance level set at 5%, as classical use and also at 20% as suggested by ICES (2008, 2010).

Time-series are built for significant parameter and a mean value of monthly means has been calculated for each season (spring and summer) for each year. Then a parametric linear regression (or Theil-Sen method in case of non normal data) is applied on data which follow a normal distribution for trend visualization and to assess if there are significant differences in the values of the parameter over the time-period.

Relationship between environmental conditions and fin whale densities in the Pelagos Sanctuary between 2008 and 2018

A PCA is applied with the 5 variables below in order to highlight which are the environmental parameters involved in the variations of the fin whale density.

- densities of fin whales in summer in Pelagos (Dens_Bp)
- SST in summer in Pelagos (SST_summer_Pel)
- SST in spring in Pelagos (SST_spring_Pel)
- Chl-a in summer in Pelagos (CHL_summer_Pel)
- Chl-a in spring in Pelagos (CHL_spring_Pel)

75% of the information is contained in the first 2 dimensions. The first dimension is mainly built by 3 variables: SST in spring, and Chl-a in spring and in summer (Table 2). The second dimension is mainly constituted by the fin whale density and the Chl-a in summer.

Table 2 : Contribution of variables in the different dimensions

	Dim.1	Dim.2	Dim.3
Dens_Bp	5.32816	5.373843e+01	23.362673
SST_summer_Pel	16.97826	2.055325e+01	45.464338
SST_spring_Pel	25.74281	1.197684e+01	9.128716
CHL_summer_Pel	27.84227	8.238083e-04	4.809549
CHL_spring_Pel	24.10849	1.373066e+01	17.234724

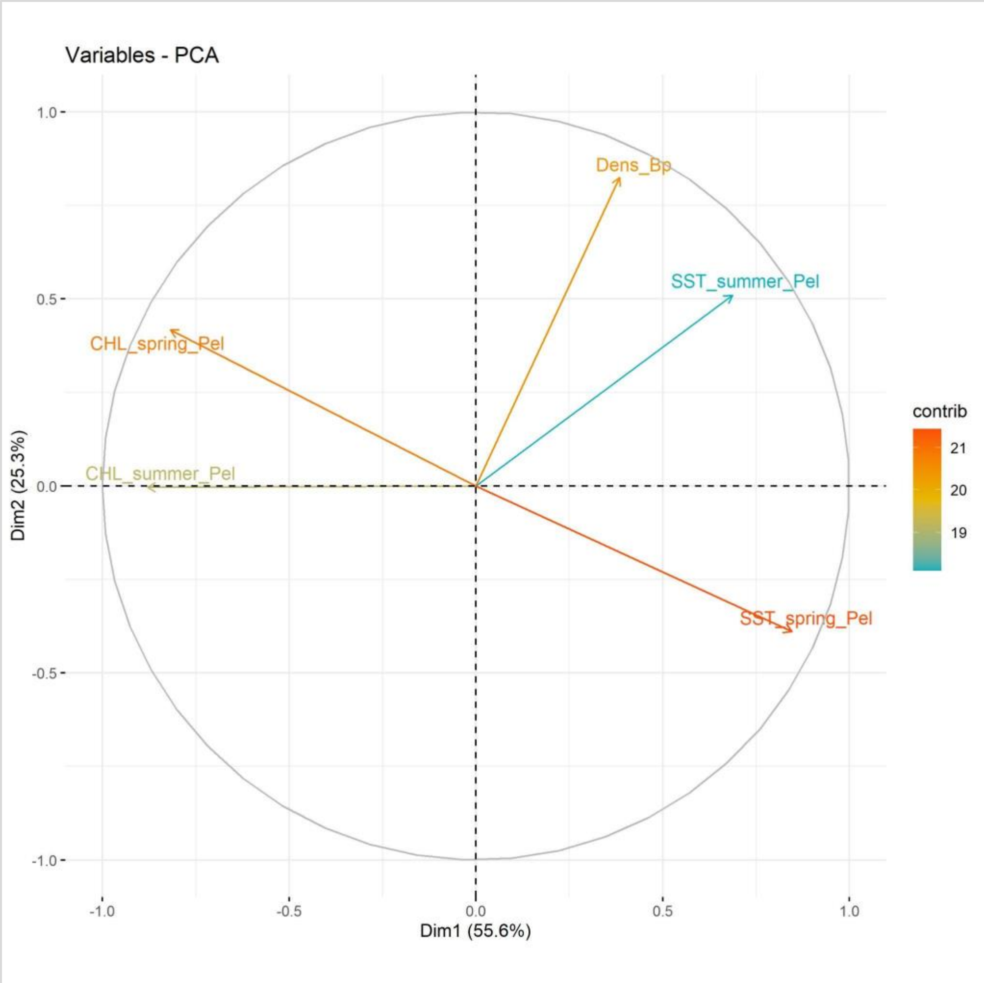


Figure 7: Graph of variable contributions to the principal axes in the dimensions 1 and 2, between 2008 and 2018

Correlations appear in the PCA graph and the colour of the variables refers to their contribution to the main axes (from blue for the lowest contribution up to red for the highest contribution of a variable to the principal axis, Figure 7). The fin whale density and the SST in summer seem to be positively correlated, even if the contribution of the SST variable in summer to the main axis is low. Chl-a and SST in spring show clearly negative correlation.

Since the fin whale density and the SST in summer show a normal distribution (p-value >0.05, from the Shapiro-Wilk normality test) a Pearson correlation test can be applied on normal data.

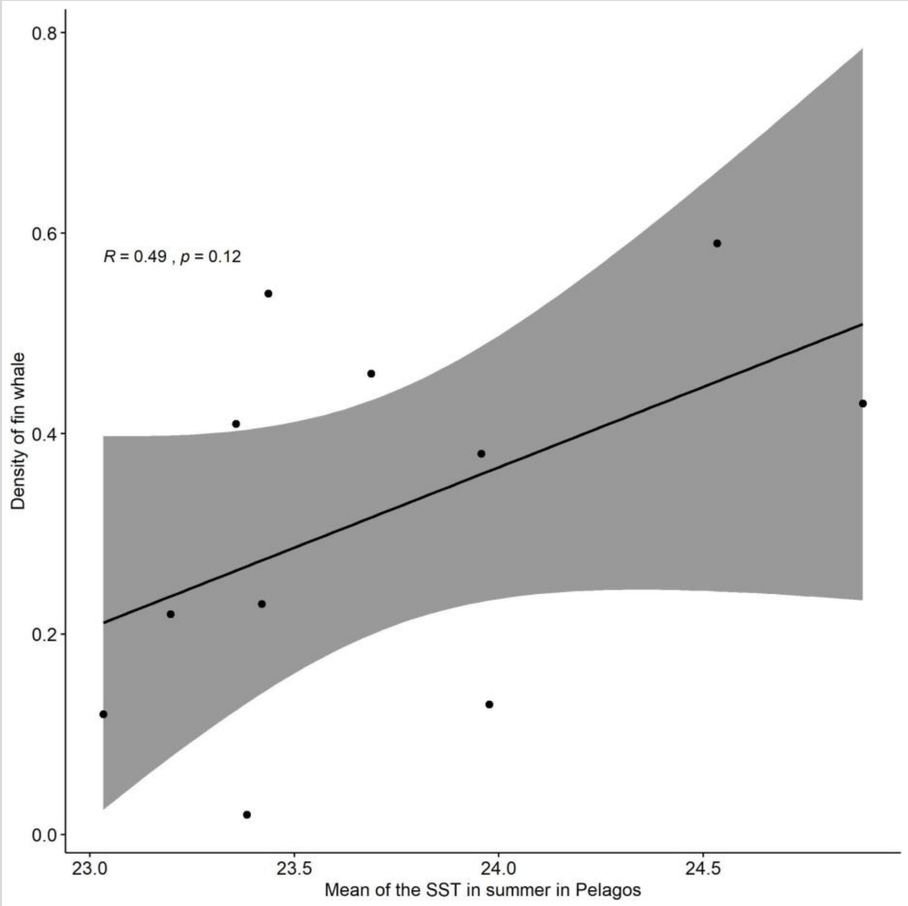


Figure 8: Correlation between the fin whale density (animals*$100km^2$) and the SST (°C) in summer in Pelagos - scatter plot using Pearson method, the confidence interval (95%, α=5%) is in grey

Based on Pearson's correlation test below, the degree of relationship between the two variables appears positive but not very high (R=0.49, p-value = 0.12 (<α =20%), Figure 8). The relationship may suffer from a low number of samples (N=11).

Table 3: P-values from Pearson correlation test between variables

P

	Dens_Bp
Dens_Bp	
SST_summer_Pel	0.1220
SST_spring_Pel	0.9492
CHL_summer_Pel	0.3371
CHL_spring_Pel	0.7698

For the other variables, the p-value is not significant for α=20%. (Table 3). Thus, according to these results, the SST in summer is the most important parameter to take into account since it may have an influence on the variation of the fin whale density in Pelagos, compared to the other environmental parameters investigated here.

Trends of fin whale density were investigated in relation to annual mean of SST in summer for the 10 years period. Year(s) with low density are followed by year(s) with higher density, however fin whale density does show a slight increase over the decade (Figure 9), at a rate of +0.037 animals.100km^2 per year. SST also shows an inter-annual variability and the fluctuations of SST are following a similar global design of fin whale density as well as a positive trend. Between 2008 and 2018, SST increases in Pelagos Sanctuary at a rate of +0.169 °C per year.

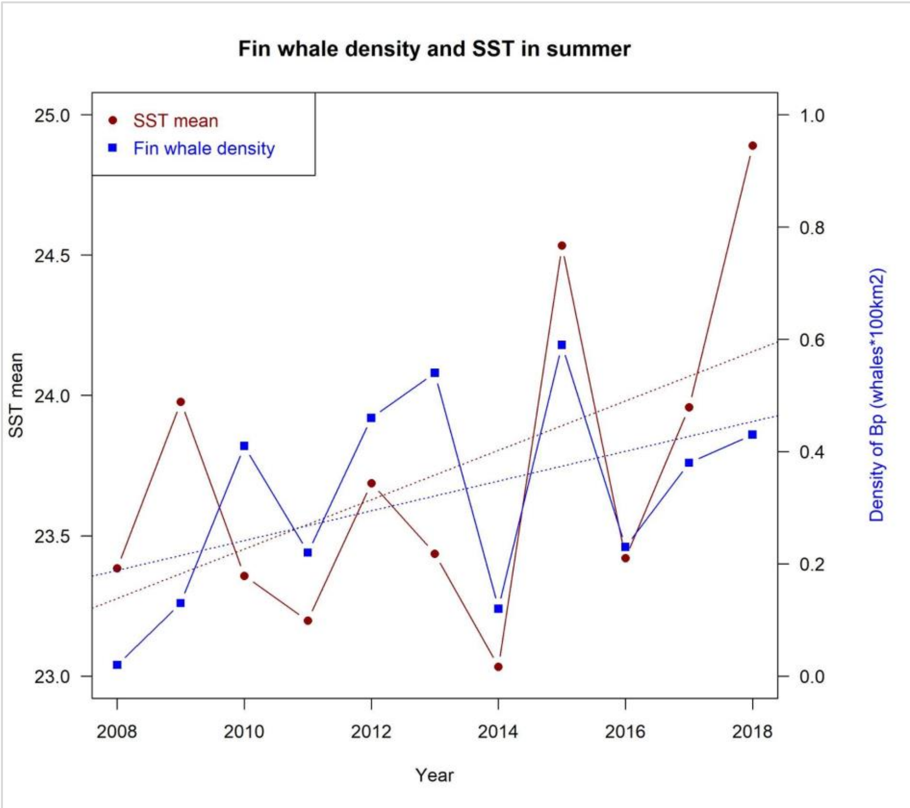


Figure 9: Density of fin whale (animals.*100km^2, blue line) from Tepsich et al. (2020), and its trend line (blue dashed line), and mean SST in summer (°C, red line) and its trend line (red dashed line), overall 10 years (2008-2018) in Pelagos Sanctuary

Relationship between environmental conditions and abundances of two cetacean's species, in the NWMS and in the Pelagos Sanctuary, over 25 years-period

To visualize potential correlations between the abundances of animals and environmental variables, a PCA is applied on 12 variables in both study areas.

Correlation between variables in the two study areas

What is observed first is that there is a redundancy between the variables in the NWMS and within the Pelagos Sanctuary (Figure 10).

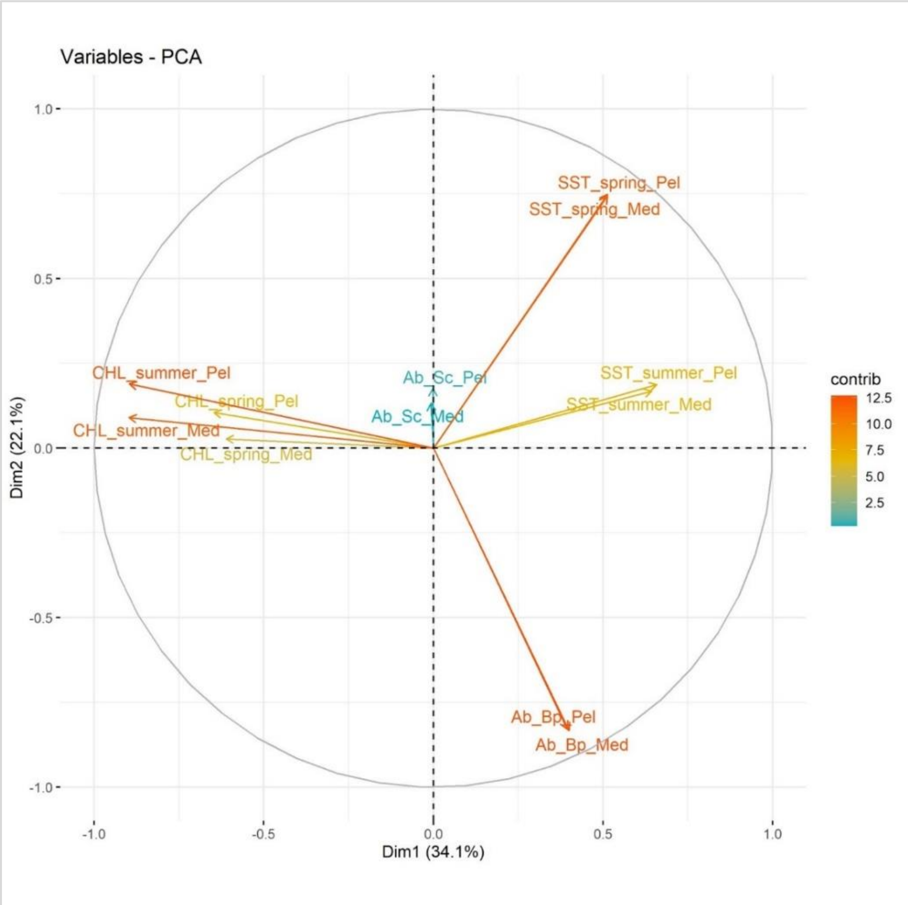


Figure 10: Graph of variable contributions to the principal axes in the dimensions 1 and 2, between 1994 and 2018 in the Pelagos area and in the NWMS.

The correlation of cetacean abundances between the Pelagos Sanctuary and the NWMS is quantified and presented in the table below (Table 4).

Table 4: Correlation tests of cetacean abundances between the two study areas

Variable	Method	Correlation value	p-value
Ab_Bp_Med ~ Ab_Bp_Pel	Pearson	0.995	< 2.2e-16
Ab_Sc_Med ~ Ab_Sc_Pel	Kendall	0.965	< 2.2e-16

The cetacean abundances of the two study areas are highly correlated. We treat then the variables relationships separately by study area.

Correlation between variables in the NWMS

The relationship between cetacean abundances and environmental variables is further investigated in the NWMS. Only the fin whale results are presented here, since the striped dolphin abundance did not show a significant correlation with any of the variables (p-value >0.20).

Table 5: Correlation test between fin whale abundances and environmental parameters within the NWMS

Area	Variable	Method	Correlation value	p-value
NWMS	Ab_Bp_Med ~ SST_spring_Med	Pearson	-	0.310
	Ab_Bp_Med ~ SST_summer_Med	Pearson	-	0.997
	Ab_Bp_Med ~ CHL_spring_Med	Pearson	-	0.255
	Ab_Bp_Med ~ CHL_summer_Med	Pearson	-	0.216

As the results are not significant between cetaceans and any of the variables (Table 5), we do not apply a PCA for this area of study.

Correlation between variables in Pelagos area

The results show that more than 75% of the information is contained in the three first dimensions (Table 6).

Table 6: Eigenvalues of dimensions

	eigenvalue	variance.percent	cumulative.variance.percent
Dim.1	2.1248200	35.413667	35.41367
Dim.2	1.2759434	21.265723	56.67939
Dim.3	1.1383497	18.972496	75.65189

- The first dimension is mainly built by the Chl-a in summer (~33%) and in spring (~25%) (Table 7)
- The second dimension is constituted by the abundances of striped dolphins and fin whales (respectively 29 and 27 %) and by the SST in spring (29%)
- Finally, the third dimension is mainly shaped by the SST in summer in Pelagos (~43%) (Table 7)

Table 7: Contribution of variables in dimensions 1, 2 and 3

	Dim.1	Dim.2	Dim.3
Ab_Sc_Pel	0.4642212	29.187915	6.124531
Ab_Bp_Pel	10.9141238	27.071324	23.839871
SST_spring_Pel	13.9958967	29.161400	3.921763
SST_summer_Pel	15.2069790	1.381798	43.825542
CHL_spring_Pel	25.7802774	6.478446	20.563604
CHL_summer_Pel	33.6385019	6.719117	1.724689

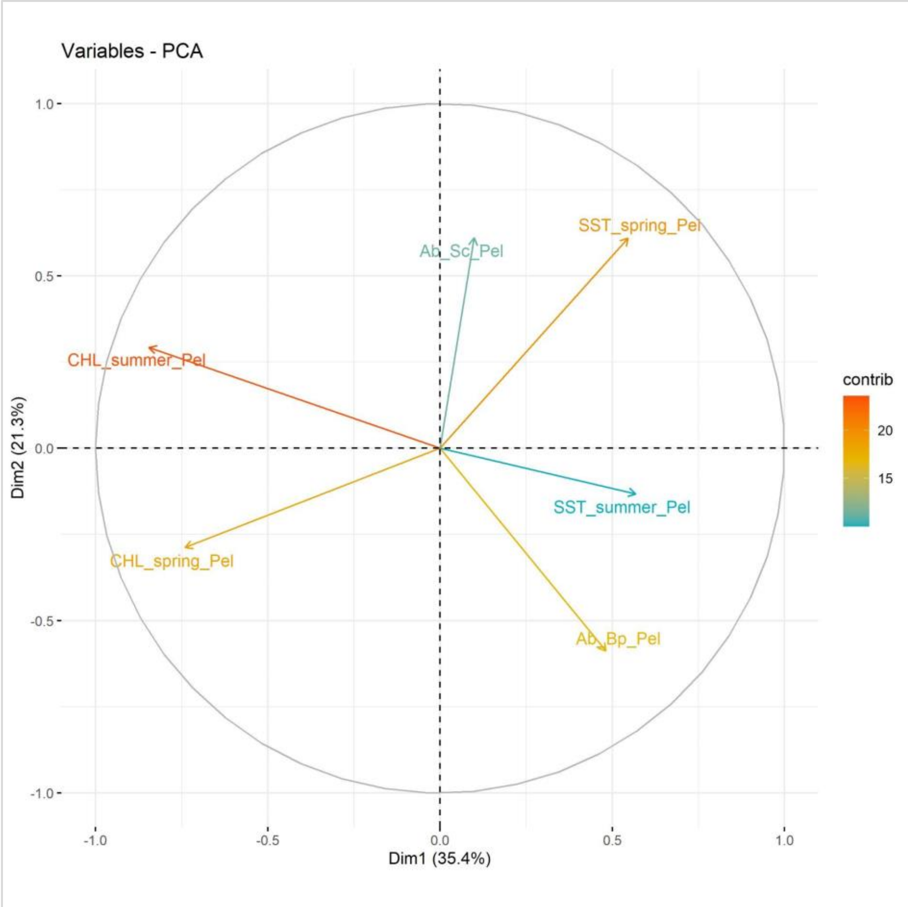


Figure 11: Graph of variable contributions to the principal axes in the dimensions 1 and 2, between 1994 and 2018 in Pelagos area

Fin whale abundances evolve in the opposite direction of the Chl-a in summer (Figure 11). Also, fin whale abundance seems to evolve in a different direction from Chl-a in spring and the SST in spring. There are very low contributions of the striped dolphin abundance and the SST in summer in these two dimensions, as these variables appear in blue in the PCA.

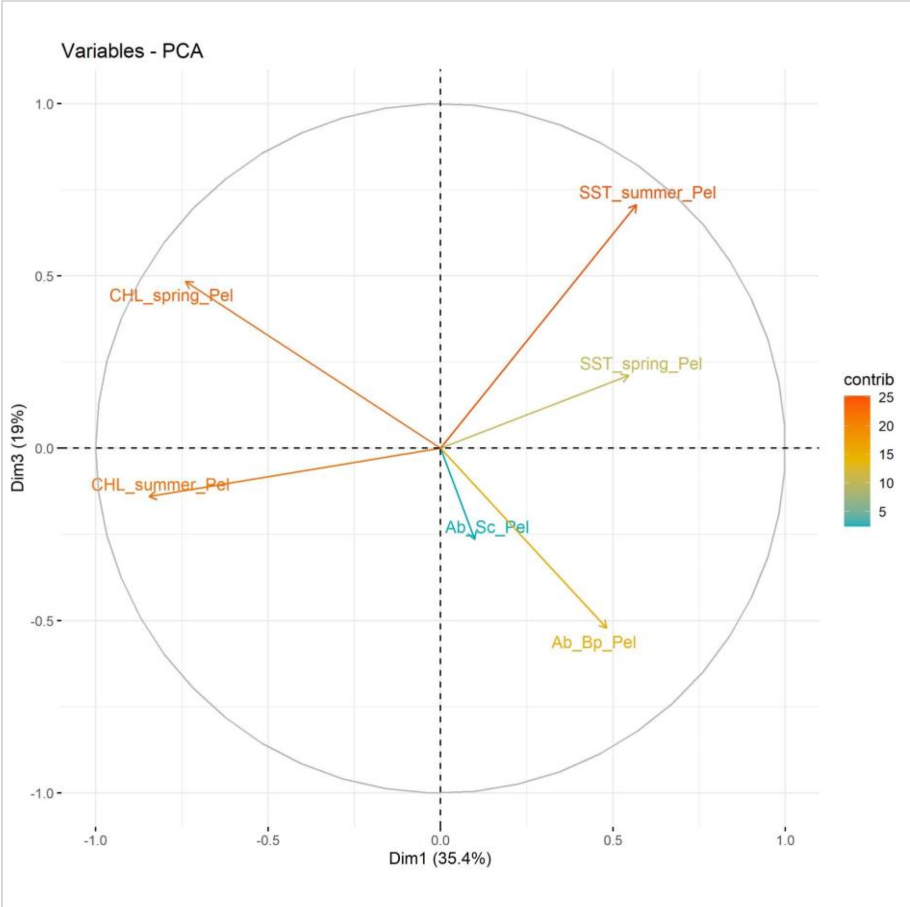


Figure 12: Graph of variable contributions to the principal axes in the dimensions 1 and 3, between 1994 and 2018 in Pelagos area

Again, the contribution is low for the striped dolphin abundance in these dimensions 1 and 3 and the length of the arrow is short, and it appears here that fin whale abundance evolves in the opposite direction from the Chl-a in spring (Figure 12) . Also, fin whale abundance seems to evolve in a different direction from the SST in summer and the Chl-a in summer.

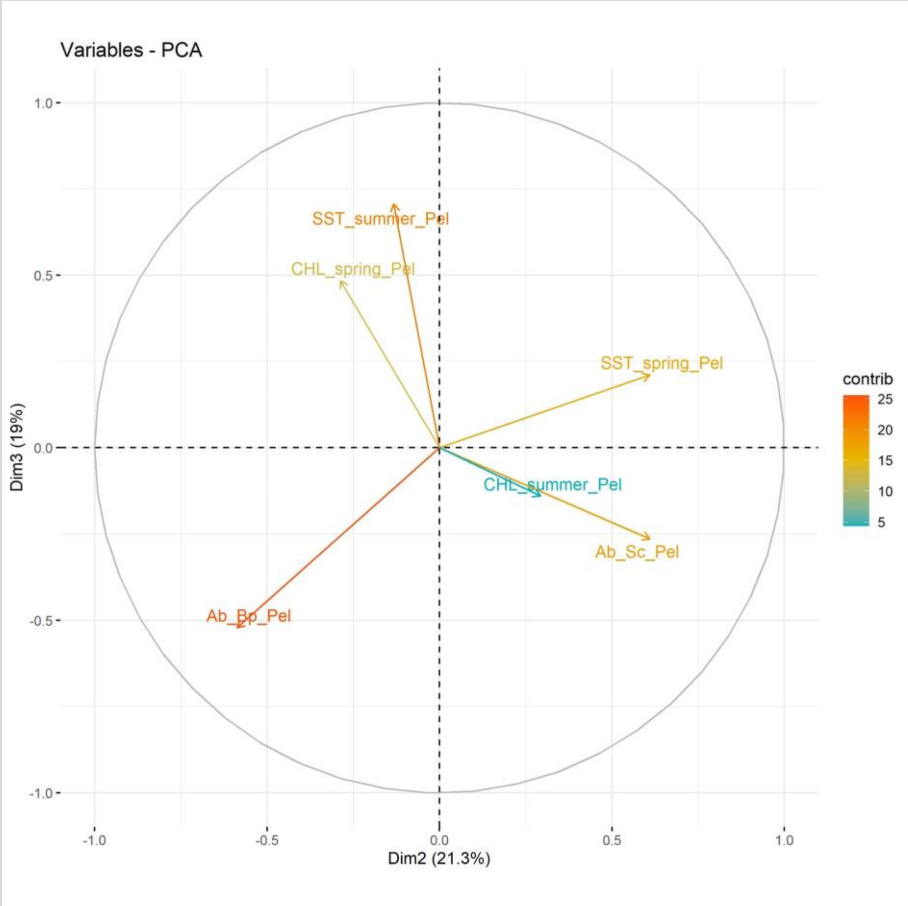


Figure 13: Graph of variable contributions to the principal axes in the dimensions 2 and 3, between 1994 and 2018 in Pelagos area

In the dimensions 2 and 3, fin whale abundance evolves oppositely to the SST in spring, but this latest variable has a yellow shape, meaning that its contribution to the main axes is intermediate.

Correlation tests between animals abundances and environmental parameters in Pelagos area

The relationship between cetacean abundances and environmental variables is further investigated within the Pelagos Sanctuary. Only the fin whale results are presented here, since the striped dolphin abundance did not show a significant correlation with any of the variables (p-value >0.20).

So, for fin whale, it appears that only the Chl-a in spring and in summer in Pelagos show a moderately negative correlation with the fin whale abundance in Pelagos, for a p-value with $\alpha<0.20$ (table*).

Table 8: Correlation test between fin whale abundances and environmental parameters within the Pelagos Sanctuary

Area	Variable	Method	Correlation value	p-value
Pelagos Sanctuary	Ab_Bp_Pel ~ SST_spring_Pel	Pearson	-	0.518
	Ab_Bp_Pel ~ SST_summer_Pel	Kendall	-	0.571
	Ab_Bp_Pel ~ CHL_spring_Pel	Pearson	**- 0.38**	**0.129***
	Ab_Bp_Pel ~ CHL_summer_Pel	Pearson	**- 0.48**	**0.049****

*correlated at α<0.20
** correlated at α<0.05

The next graphs illustrate the correlation between the fin whale abundance and the mean of the Chl-a in Pelagos in spring (Figure 14) and in summer (Figure 15). From these, highest abundances were found for lower values of Chl-a and the trend is the same for both seasons.

The scale of Chl-a values is different for the two seasons, as the [chl-a] increases in winter and decreases in summer in the Mediterranean Sea (Mignot *et al.*, 2014).

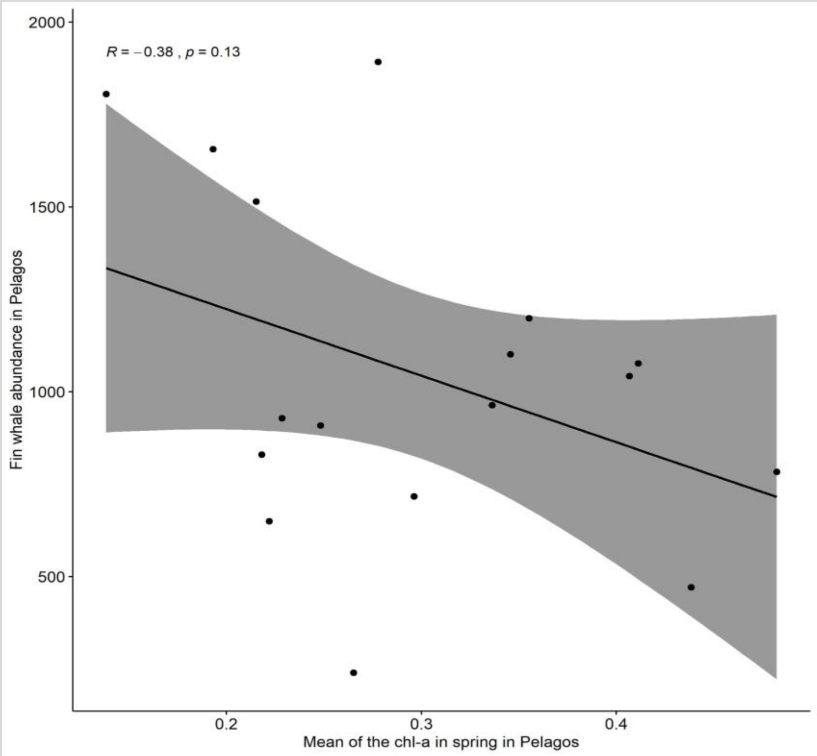


Figure 14: Correlation between the fin whale abundance (number of individuals) and the Chl-a ($mg.m^{-3}$) in spring in Pelagos - scatter plot using Pearson method, the confidence interval (95%, α=5%) is in grey

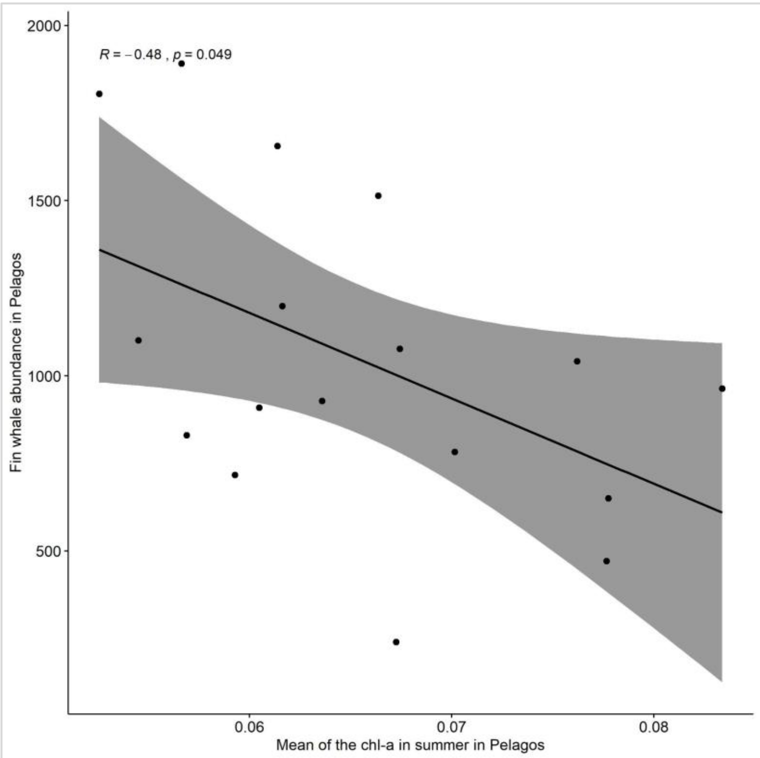


Figure 15: Correlation between the fin whale abundance (number of animals) and the Chl-a ($mg.m^{-3}$) in summer in Pelagos - scatter plot using Pearson method, the confidence interval is in grey (95%, α=5%)

Evolution over 25 years in Pelagos area

Data on the mean of Chl-a values for spring and for summer seasons are following a normal distribution (p-value=0.309 and p-value=0.333 respectively), thus a parametric linear regression is used to evaluate the evolution of each of these variables from 1998 to 2018. Results indicate that Chl-a values in spring can be considered as **not significantly different** (α=5%) over the period (R-squared =0.0094 and p-value=0.676), neither summer values of Chl-a over 20 years (p-value=0.066 and a R-squared = 0.167), even if this value is very close to the threshold.

As the correlation is globally significant and negative between fin whale abundance and Chl-a in spring and summer in Pelagos, the evolution of these variables were plotted together (Figure 16).

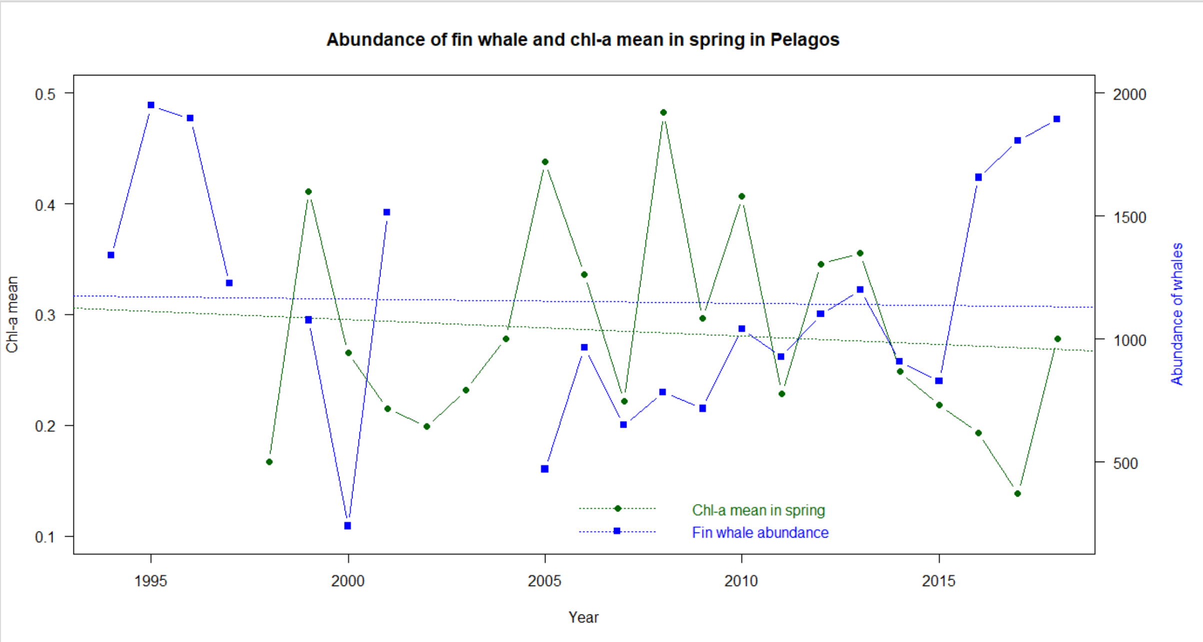


Figure 16: Abundance of fin whale (blue line) from David et al. (2020), and its trend line (blue dashed line), and mean Chl-a in spring (green line) and its trend line (green dashed line), overall 25 years (1994-2018) in Pelagos Sanctuary

Fin whale abundance shows a stable trend, the mean density corresponds to 1 151 (+/- 486) fin whales in summer in Pelagos (David *et al.*, 2020), with a succession of "poorest" years and "richest" years. Mean values of Chl-a in spring season does not show a significant trend, varying between 0.14 (2017) and 0.48 (2008), with a mean of 0.28. The lowest value of Chl-a is found during the year 2017. No clear pattern appeared between both variables (Figure 16).

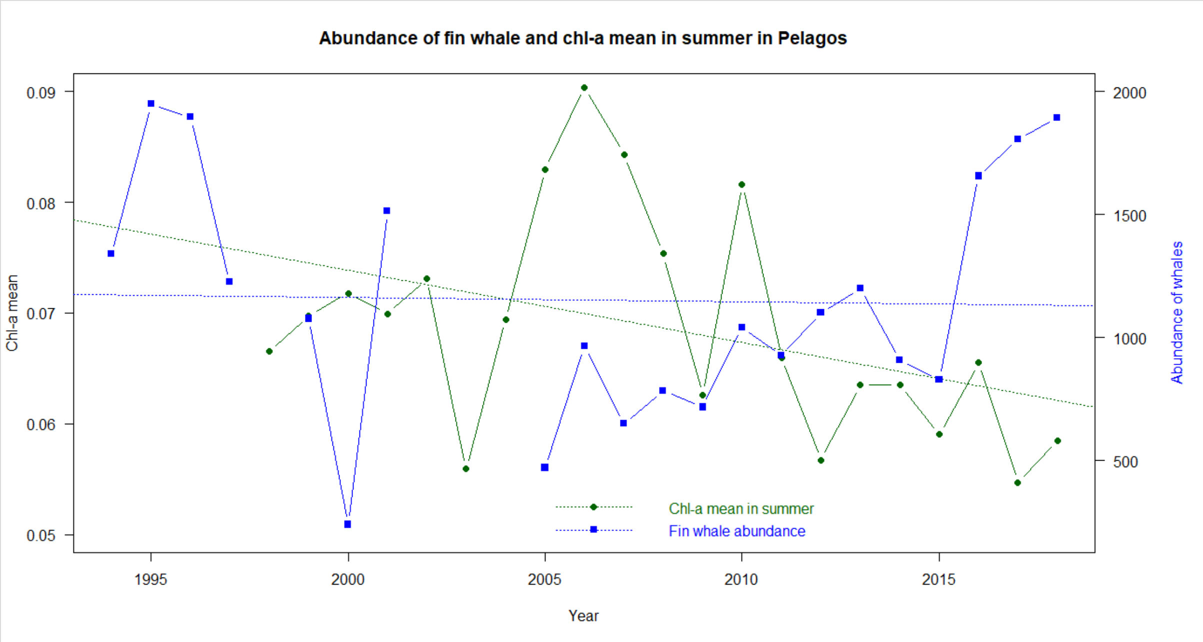


Figure 17: Abundance of fin whale (blue line) from David et al. (2020), and its trend line (blue dashed line), and mean Chl-a in summer (green line) and its trend line (green dashed line), overall 25 years (1994-2018) in Pelagos Sanctuary.

Chl-a annual means vary between 0.055 (2017) and 0.09 (2006), the mean of the annual Chl-a in Pelagos in summer is 0.069. As for the spring season, the lowest value corresponds to the year 2017 (Figure 17).

Summary of the results

Finally, considering the case studies, it appears that on a decadal time-scale within the Pelagos Sanctuary (Tepsich *et al.*, 2020):

- Density of fin whales and SST in summer are moderately positively correlated cor=0.49
- No relationships were highlighted considering SST spring, Chl-a spring or Chl-a summer

From the study on fin whale and striped dolphin over more than 20 years and at two spatial scales (David *et al.*, 2020) :

- Chl-a in spring and in summer are moderately negatively correlated to fin whale abundances in Pelagos (respectively -0.38 and -0.48)
- No relationships were highlighted considering SST in spring neither in summer with fin whales
- No correlation has been shown for striped dolphin abundance and environmental parameters
- The significant relationships between fin whale abundances and Chl-a were found only inside the Pelagos Sanctuary, not at a larger scale.
- Results are different for the SST from Tepsich *et al.* (2020) and David *et al.* (submitted). The differences might be related to (i) the time scale (10 years and 25 years), (ii) the field methodology which consists on fixed line transects (Tepsich *et al.*) vs. ad hoc trajectories (David *et al.*), (iii) the data analyses consisting on Distance Sampling and Generalized Additive Models (Tepsich *et al.*) and Kriging method (David *et al.*).

RECOMMENDATIONS ON MONITORING CLIMATE CHANGE IMPACTS ON CETACEANS

Based on the previous bibliographic review and case studies, it appears that some synoptic oceanographic parameters and some specific protocoled cetacean's data can be useful to monitor the impact of climate change on cetaceans within the ACCOBAMS area.

Abiotic parameters

Satellite-derived SST and Chl-a can be downloaded through Copernicus Marine Service website. Copernicus portal gives access to free marine data across the global ocean, among these SST and Chl-a values or anomalies, but also other variables such as sea level, salinity, currents etc. The data are pooled from multi-satellites observations and the advantage is that long-time series, daily or monthly means are available.

CIESM - the Mediterranean Science Commission - works on several programs including the TRANSMED which aims to monitor the surface water characteristics: sea surface temperature and sea surface salinity, over the whole Mediterranean Sea. It consists on a thermosalinometer installed on ships of opportunity (container, ferry…) and records data every 10 seconds (the resolution is <100m) along regular ferry or shipping routes, using time series. Data can be used to do relevant statistics as it works in real time and records the data also during decades, allowing to have long-time series to work on. Time series of analyses and forecasts are available since 2007, and in the Western Basin, it is used to validate the Copernicus Marine Service global operational system in the area (Beuvier *et al.*, 2019).

Cetaceans monitoring

Fin whales are then considered as a relevant species indicator to monitor climate change. This species is regularly encountered and is common in the area. The result of this study shows that fin whale abundances are sensitive to annual variabilities of environmental parameters such as Chl-a and SST. Consequently, fin whales might be vulnerable to either gradual long-term changes or abrupt and persistent short-term changes or variability of those key environmental factors. It is an indirect link, as certainly it goes through its main and almost exclusive prey, less easily to monitor, the euphausiid *Meganyctiphanes norvegica*. Considering the knowledge on the increasing values of the SST in Pelagos during summer, and knowing that this euphausiid is at its thermal limit (18°) in the Mediterranean Sea (Gambaiani *et al.*, 2009), increasing temperatures could lead this krill species to its local extinction. For that reason, the fin whale population in the Mediterranean Sea is already considered at risk from climate change because of expected impacts on the availability of its food source (Gambaiani *et al.*, 2009, Grose *et al.*, 2020). Still, it is unknown to what degree fin whales can change their range in pursuit of changing patterns of food distribution (Grose *et al.*, 2020).

In order to ensure coherence in the collected data on fin whales for monitoring reasons, it is recommended to use data of the same quality and collected with the same method over the long-term. For that reason, recommendation is made to use the data of an existing monitoring program, such as the Fixed Line Transect (FLT) network. Since 2007, systematic yearly round cetacean monitoring using ferries as observation platforms along fixed transect lines lead to a continuous monitoring of cetacean presence within the Pelagos Sanctuary. Data from this monitoring deliver information about yearly and seasonal species distribution and relative abundance on all cetacean's species. The temporal resolution of the surveys allows to investigate monthly, seasonal and yearly patterns in distribution and abundance. Lines already monitored and from which data have been used in the paper of Tepsich *et al.* (2020) and in the case study of this document should be used also for the next steps in following years.

The second cetacean dataset that could be used is the one using methodology to gather existing and upcoming boat-based surveys (mainly small motor boat and sailing vessels) from numerous partners working at sea, as done by David and colleagues.

Other data could be used for some tests regarding climate change in this area, namely the aerial surveys lead by France, Italy and/or ACCOBAMS (ACCOBAMS Survey Initiative). They are more punctual, but will bring interesting and relevant points of reference.

From all those types of data with effort collected with the line transect method, abundances or densities can be calculated, which is one of the parameters that can reveal changes and impacts on cetaceans. Finally, all type of data (ferry, sailing vessel, airplane) merged might help to get a long-term series on cetaceans, and this approach tested by several scientists will become more robust in the upcoming years.

Pilot sites

Apart from the **Pelagos Sanctuary and the fin whale**, already presented, other areas and species could be brought to attention regarding climate change and the possibility of monitoring the impact of climate change within the ACCOBAMS area.

In fact, any monitoring scheme that could afford existing data from which abundance at least could be calculated on the long-term (at least a decade) could be used for climate change impact monitoring. Other data sets might exist in the Mediterranean Sea and could be helpful for testing the impact of climate change. One obvious one seems to be the **Common dolphin in the northern part of the Alborán Sea**. This example could be a second pilot area to monitor for climate change impacts. Supporting the launching of new missions at sea applying the same conditions to collect data as the old datasets, would give the opportunity to pursue the study with at least one decade more.

Furthermost, the Alborán Sea is a transition area between the westernmost part of the Mediterranean Sea and the Atlantic Ocean, two basins which have radically different oceanographic characteristics (IUCN-MMPATF, 2017). This area, designated as Important

Marine Mammal Area (IMMA), contains an important diversity of cetacean species, the highest such diversity observed within the Mediterranean Sea (IUCN-MMPATF, 2017). This transition area contains important habitat for the short-beaked common dolphin (*Delphinus delphis*, Linnaeus, 1758).

The Alborán Sea is an important hotspot for the species, significant population abundance in this area seems to be related to an important feeding and breeding ground (Bearzi *et al.*, 2003, Bearzi *et al.* 2012), At a global level, the common dolphin is listed as Least Concern by the International Union for Conservation of Nature (IUCN) Red List (Hammond *et al.*, 2008). However, at a regional level, the IUCN status for the Mediterranean subpopulation has been listed as Endangered since 2003 due to its decline since the 1960s (Bearzi *et al.*, 2003, 2008; Piroddi, Bearzi, Gonzalvo, & Christensen, 2011 in Vella *et al.*, 2021).

Also, it appears obvious that **analysis on sperm whales** within the **north-western Mediterranean Sea**, where long-term series of data already exist and where a change already occur in terms of abundance, composition and distribution of animals, should be launched. Those analysis of abundances/distribution/use of the area versus the evolution of oceanographic parameters may help in order to highlight if this area and this species could be a good candidate for the aim of monitoring the impacts of climate change on cetaceans. In the same idea, analysis of the evolution of **Risso's dolphin** abundance and distribution should be launched toward the evolution of oceanographic parameters as SST and CHl-a, as this specie also show a change in its abundance and distribution in the last decades.

Finally, the legal framework of MSFD (EU) and EcAp (Barcelona Convention) required a monitoring scheme on biodiversity (Descriptor 1) and oceanography parameters, and those data will also fill the climate change impacts exercises in the future.

Recommendations

Considering that long-term series datasets collected using standard and constant method (line transect) are needed to get trends on abundance and distribution of animals, and that regular surveys are needed over the same area to highlight potential changes that are not only due to inter-annual variability,

It is recommended to support the continuation of the collect of such regular and standard data (e.g. : FLT) over specific areas on the long-term,

Considering that Fin whale is a relevant species indicator to monitor climate change, that this species is common and frequent in the Pelagos Sanctuary and that this entity has been intensely surveyed during the two lasts decades,

It is recommended for the climate change impacts monitoring within ACCOBAMS to designed the Pelagos Sanctuary as pilot sites for the monitoring of Fin whales,

Moreover, considering the work done in the northern part of the Alboran Sea, the already existing long-term datasets (1992-2011), and the prediction of the reduction in suitable habitatand density for common dolphins due to an increase of Sea Surface Temperature, it is recommended to launch similar surveys in order to collect the same type of data and monitor if the changes occur.

Furthermore, considering the changes in abundance, distribution and other parameters (composition of groups, uses of the area) documented for sperm whales and Risso's dolphins in the north-western Mediterranean Sea, it is recommended to support analysis that look for the effects of climate change on those changes for both species based on existing datasets.

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