BIODIVERSITAS
Volume 25, Number 8, August 2024
Pages: 3325-3341

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250804

Review: The effect of climate change on the distribution pattern of small pelagic fish around the world

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Manuscript received: 27 May 2024. Revision accepted: 3 August 2024.

Abstract. *Yuniar A, Zainuddin M, Hidayat R, Srioktoviana SK, Safruddin, Mustapha MA, Farhum SA. 2024. Review: The effect of climate change on the distribution pattern of small pelagic fish around the world. Biodiversitas 25: 3325-3341.* Small pelagic fish populations, which are critical to marine ecosystems and play a crucial part in food availability worldwide, are significantly impacted by climate change. Variations of small pelagic catch could be indicated by indices of climate variability such as AMO (Atlantic Multidecadal Oscillation), ENSO (El-Nino Southern Oscillation), IOD (Indian Ocean Dipole), and Monsoon. The purpose of this study was to provide important insight into the relationship of climate variability with the distribution of dominant species of small pelagic fish such as European sardines, mackerel, *Decapterus* sp., anchovy, and *Sardinella* sp. from 1974-2022. On average, the temperature optimum of small pelagic fish is generally 28.31±1.97°C, chlorophyll concentration of 0.68±0.37 mg.m^{-3}, and salinity of 31.44±2.40 psu. In North Atlantic Waters, the dynamic migration and abundance of pelagic fish are influenced by the climate variability of AMO tharough the warm phase and cold phase. The impact of ENSO, IOD, and chlorophyll variability affect the distribution pattern and abundance of small pelagic species (mackerel, lemuru, anchovy, indian scad, and sardine) in tropical and subtropical waters. In the context of climate change impacts, the results show that small pelagic fish with a preference for warm temperatures tend to migrate to higher latitudes. Understanding the effect of climate change on the spatial and temporal dynamics of small pelagic fish could help improve the performance of future small pelagic fishing strategies and management around the world.

Keywords: Climate change, oceanographic condition, small pelagic fish, subtropical waters, tropical waters

Abbreviations: AMO: Atlantic Multidecadal Oscillation, ENSO: El-Nino Southern Oscillation, IOD: Indian Ocean Dipole

INTRODUCTION

Oceans are among the Earth's biomes most impacted by human activities and exhibit rates of environmental change similar to mass extinction events and ecosystem collapses recorded in Earth's geological record (Fidelman et al. 2012; Halpern et al. 2015; Magliozzi et al. 2023). Changes in ocean circulation and physiochemical parameters caused by climate change can alter the distribution, structure, and function of marine microbial communities, thereby altering the function of biological carbon pumps (Evans et al. 2011). One region undergoing current and future change is the Antarctic Zone (SAZ) southeast of Tasmania, Australia. Westerly-south wind shifts appear to push warmer macronutrient subtropical water into the SAZ (Evans et al. 2011). Climate and fisheries often interact with each other (Hasan and Widodo 2020). They can disrupt the functioning of marine ecosystems, threatening seafood and the livelihoods of the communities that depend on it (Tsikliras et al. 2019). A holistic and integrated approach that aims to assess spatial overlap between these key pressures is critical to identifying key marine areas and fish species that require conservation priorities to avoid future disturbances (Paramo et al. 2003; Ramírez et al. 2022; Hasan et al. 2023). Climate change and fishing pressures adversely affect small pelagic stocks, but focusing future fisheries on the positive can support sustainable growth in the medium term. These fish play a key role in regulating ecosystems (Ainsworth et al. 2008; Asiedu et al. 2021) by providing the transfer of energy and nutrients from low trophic levels (plankton) to high trophic levels (apex predators) (Feuilloley et al. 2020).

Small pelagic fish are economical fish with a high fishing target (Barange et al. 2009; Apriansyah et al. 2023). *Sardinella aurita* is one of the small pelagic fish, perhaps the most widespread small pelagic fish, with remarkable global genetic homogeneity and the Western Pacific Ocean as possible sources of future speciation (Stern et al. 2018). Small pelagic fish spend most of their lives in the surface layers of the water column so it is very vulnerable to temperature fluctuations (Putri et al. 2022). The preferred temperature is 26-29°C with a chlorophyll concentration ranging from 0.46-1.00 mg.m^{-3} (Kurniawati et al. 2015).

One of the advantages of using small pelagic fish resources is good environmental control in fisheries (Patterson 1992). This is because the sustainability and productivity of small pelagic fish are influenced by various factors (Brosset et al. 2017), one of which is the climate (Lehodey et al. 2005; Puspasari et al. 2016; Báez et al. 2022; Cabral 2024). On a large scale, climate change is expected to affect aquatic resources through changes in ecosystem primary production (Merino et al. 2010). Environmental variables are key factors in small pelagic ecosystems such as sardine and anchovy, in addition to the influence of food availability and depth selection also affect the potential of small pelagic fish (Bonanno et al. 2014). In the context of environmental fisheries, the IPCC (Environmental Panel of Climate Change) projects that the average global ocean temperature will increase between 1 and 4°C (Garcia-Soto et al. 2012; IPCC 2021; Lima et al. 2022). Temperatures in the region fluctuate from year to year (Guerra et al. 2021), and the use of satellites to monitor them is influenced by various factors (Garcia-Soto et al. 2012). A study by Henson et al. (2017) explains that the impact of climate change has a significant impact on ecosystems, especially affecting sea surface temperature and various other environmental factors. Climate change will change the marine environment, so it will have a major impact on marine fish populations (Tanner et al. 2019), especially on the distribution and abundance of species (Zhu et al. 2024). In the context of climate change, increasing surface temperature is the main parameter of the impact of climate change itself. The increase in sea surface temperature is caused by surface air temperature. Based on historical analysis, the rise in sea surface temperature is predicted to increase by 0.65℃ in 2030, 1.1℃ in 2050, 1.7℃ in 2080, and 2.15℃ in 2100. This change is certainly changes oceanographic conditions such as the ENSO phenomenon (La Niña and El Niño occur more frequently at intervals of 3-7 years to 2-3 years, thereby changing sea level height, and marine climate and triggering extreme waves as high as 2-5 m (Bappenas 2018).

Discussions related to climate change are complex discussions that have now become global issues (Research map of climate change**)** Shows that climate-related research has only been conducted since 2015 and above. Research trends or research novelty from the topic of climate change become a reference for the importance of the study of climate change on small pelagic fish and its relation to oceanographic conditions of waters around the world.

CLIMATE CHANGE IMPACT

Globally, climate change has an impact on ecosystems. Both terrestrial and aquatic ecosystems are mainly small pelagic fish (Pincinato et al. 2020; IPCC 2021; Han et al. 2023). Changes in ecosystem conditions cause changes in global fisheries production and uncertainty in the future of the economy (Blenckner et al. 2015; Galligan and McClanahan 2024). Climate change causes changes in pelagic physical and biological dynamics, which give rise to ecological, hydrological, and environmental impacts that propagate horizontally and vertically (surface-seabed) (Halpern et al. 2015; Menéndez-Delgado et al. 2023). Climate change will change the physical and chemical properties of the oceans, affecting marine ecosystems. Here, we review evidence of marine life responses to recent climate change in ocean regions, from tropical to polar oceans. Observed changes in evaporation rates, populations, abundance, distribution, and phenology of marine species (Poloczanska et al. 2016).

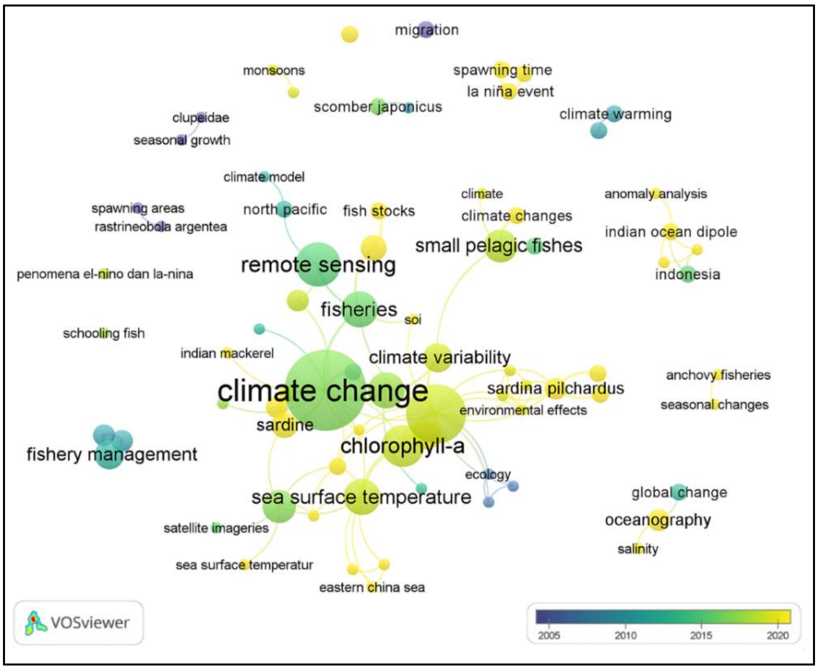

Figure 1. Research map of climate change (Baidya and Saha 2024)

The negative impact of climate change is felt when the Earth experiences an extreme increase in global temperature, making it difficult to make adjustments to maintain the balance in the distribution of pelagic fish species suddenly (Huang et al. 2021). Climate variability over time and up to several decades plays a role in changing the physiochemical and biological characteristics of habitats occupied by small pelagic fish species (Valencia-Gasti et al. 2015). The impacts of climate change (global warming) are increasing Sea Surface Temperatures (SST), increasing the frequency and intensity of extreme weather, and changes in rainfall patterns due to ENSO events (El Niño and La Niña) so that the impact on ecosystems is very large according to several explanations of previous researchers (Ngurah et al. 2016). Ocean temperatures continue to increase every ten years (NOAA 2021) and will continue to increase globally, currently global temperatures are around 0.41°F or 0.23°C. The climate fluctuations will result in an unbalanced environment, such as in some pelagic species. Phenological incompatibility with preferred prey, less than optimal thermal regimes result in the extinction of an ecosystem if not followed up in the long term (Peck et al. 2013). Species responses to climate change vary widely, but as warming approaches, some species respond quickly to change, making them vulnerable to fish abundance and pelagic fish distribution (Perry et al. 2005; Nos et al. 2023). Research by Sekadende et al. (2020) showed that the impacts of climate change are potentially abundant, and pelagic behavior is diverse and complex, which affects water temperature, circulation patterns and domain boundaries impact on reproduction, survival and distribution of fish, intensity of predator-prey relationships and zoogeography through bottom-up processes (Hollowed et al. 2012).

Small pelagic fish account for more than 30% of the total weight of marine fishery landings in Japan and the rest of the world. Their population dynamics tend to be dramatic and cyclical in nature in response to climate variability on multi-decade time scales (Checkley et al. 2009; Takasuka 2018; Ngando et al. 2020; Retnoningtyas et al. 2024). Pelagic fish are species that are sensitive to environmental fluctuations (Safruddin et al. 2018a; Pennino et al. 2020). In northwest Africa, small pelagic fish make up the majority of the catch in the region, with total catches of major species ranging from 1.7 to 2.5 million tonnes in recent decades. Many of the most important pelagic stocks lie outside the subregion's 200 nautical mile boundaries and are spread bilaterally or subregionally among West African countries. These natural resources on the West African coast are used by local fleets from both small and industrial sectors as well as long-distance fishing vessels from Europe, Asia, and Central America (Lakhnigue et al. 2019). Therefore, the importance of a broad understanding of impacts is exacerbated by the lack of continuous ocean observations and regional biochemical models in interpreting existing variability and regionalizing future trends. Other things that influence it based on research (Lima et al. 2022). Due to changes in the match mismatch dynamics of sensitive species. It is also stated that Sea Surface Temperature (SST) and salinity, as well as the interaction between current speed and distance to the nearest coast, are the main factors that cause the main impact on the distribution of pelagic species (Fernandes et al. 2020). Evidence of change in small pelagic communities comes from studies in European Waters, where the distribution of small pelagic changes throughout the Northeast Atlantic and may be a response to long-scale climate variability such as the Atlantic Multidecadal Oscillation (Suca et al. 2018).

There are several lists of the distribution of pelagic fish species in several world waters (Table 1). Dominating in some scattered waters are sardines, anchovies, and mackerel (Figure 2).

Table 1. Small pelagic species in the world

Region	Small pelagic species	Scientific name	Research
North Atlantic	Anchovy	*Engraulis encrasicolus*	(Alheit et al. 2014)
	Sardine	*Sardina pilchardus*	
	Sardinella	*Sardinella aurita*	
	Herring	*Clupea harengus*	
Canary Island (Spain)	Atlantic Chub	*Mackerel colias*	(Jurado-Ruzafa et al. 2019)
	Horse mackerels	*Trachurus* spp.	
	European pilchard	*Sardinella* spp.	
Western Iberia	European pilchard	*Sardinella* spp.	(Garrido et al. 2017)
Bali Strait (Indonesia)	Lemuru	*Sardinella lemuru*	
	Scad	*Decapterus* sp.	(Sartimbul et al. 2020)
	Mackerel	*Rastrelliger* sp.	
	Sardine	*Sardinella* sp.	
	Selar	*Selaroides leptolepis*	
Artic Ocean	Antartic Gegat	*Pleragramma antarticum*	(Wassmann 2011)
Pasific Ocean	Chub Mackerel	*Scomber japonicus*	(Yukami et al. 2009)
	Pasific Scury	*Collabis saira*	
	Pasific Sardine	*Sardineps melanosticus*	
	Anchovy	*Engraulis ringers*	
Atlantic Ocean	Sardine	*Sardina pilchardus*	(Garrido et al. 2017)
	European Anchovy	*Engraulis encrasilocus*	
Western Africa	Sardinella	*Sardinella aurita*	(Binet et al. 2001)
	Sardinella	*Sardinella maderensisi*	
	Horse mackerels	*Trachurus* spp.	

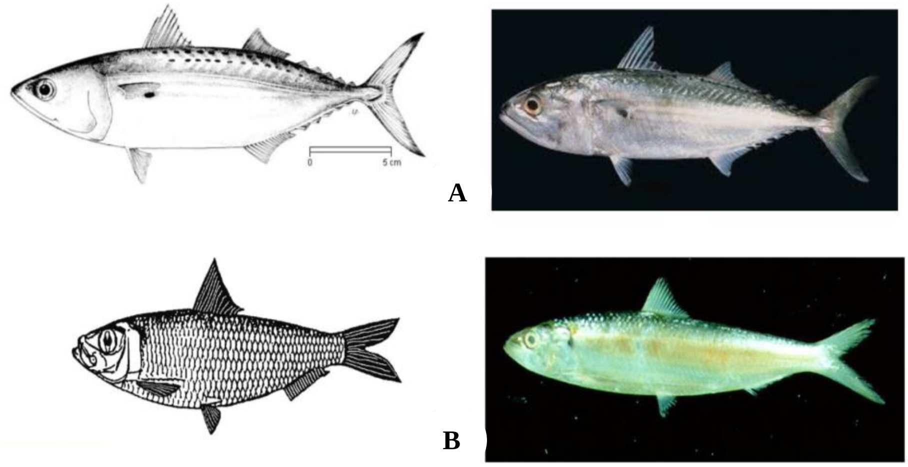

Figure 2. The type of dominant small pelagic fish (A) *Restrallinger kanagurta* and (B) *Sardinella lemuru* (Potier et al. 1995)

Fish are distributed in concentrated kesil groups ranging between 23 and 411 kg.ha^{-1} (Couperus et al. 2016). Research is also trying to find the cause of the decline in small pelagic fish stocks, such as in the Lion Gulf. Research by Saraux et al. (2019) shows sardines and anchovies have a worldwide distribution and are well known for their prevalence in five border current systems (Benguela, Humboldt, California, Canary, Kuroshio), although populations are also important in other regions, such as the northeast Atlantic, South Atlantic, and Northeast Atlantic. Recently, significant changes have been observed in pelagic ecosystems. Since 2008, the most common small pelagic species, sardines *Sardina pilchardus* (Walbaum 1972) and anchovies *Engraulis encrasicolus* (Linnaeus 1758) have experienced a prolonged decline in individual size and weight, making them less profitable for fisheries due to the absence of markets for that size. As a result, most pelagic trawlers that normally target sardines and anchovies are now switching to other, more valuable species such as the European hakefish, Merluccius merluccius) or ceasing their activities altogether. As a result, the landings of both species, especially sardines, have decreased insignificantly over the past few years. In conclusion, the significant decline in small pelagic landings in Lion Gulf was due to a decrease in the size and condition of the fish, not a decrease in abundance. Changes in size result from decreased growth (anchovies and sardines) and loss of old individuals (sardines).

SEA SURFACE TEMPERATURE (SST)

Sea Surface Temperature (SST) is one oceanographic parameter closely related to climate change. Sea Surface Temperature (SST) is an oceanographic parameter that characterizes water masses and is related to the condition of the sea layer beneath it so that it can be used to analyze phenomena that occur in waters (Kurniawati et al. 2015). Sea surface temperature is the main environmental factor explaining abundance, but other factors (food availability and water currents) have an additional role in temperature fluctuations (Maynou et al. 2014). Sea surface temperature changes also affect salinity, oxygen concentration, and primary production (Schickele et al. 2020). Higher or lower temperatures than normal can affect the metabolism, reproduction, and distribution of small pelagic fish (Lloret-Lloret et al. 2022). Observations of sea surface temperature can be categorized as the impact of climate change with global SST data sets, then interpolated and anomaly analyzed (Pandey and Liou 2022). The study showed spatial and temporal analysis of temperature changes in 1977-2016 from May to November, average sea surface temperature and anomaly sea surface temperature for a 30 year period with a maximum value of 31.21°C, a minimum of -1.88°C and an average of 13.38°C for the entire global ocean. This affects the catch of small pelagic fish in various countries, considering the habitat tolerance of sea surface temperatures of small pelagic fish, which average 27-30°C. The study from Safruddin et al. (2014) showed that Sea Surface Temperature (SST) positively influences the distribution of anchovies in the Spermonde Islands in the 28.8-29.3°C range.

In the Pacific Ocean, special influences were caused by the ITF, resulting in several Indonesian territorial waters and changes in parameters such as SST and chl-a to the Indian Ocean (Wyrtki 1961; Nababan et al. 2016). Oceanographic conditions in different countries vary greatly. For example, polar environmental conditions are unique to all waters in the hemisphere as low temperatures and seasonal light create one of the most extreme habitats (Lopes et al. 2023). Research from Wassmann (2011) showed that climate change is causing temperatures in the Arctic to increase two to three times the estimated global average temperature of 0.4°C over the past 150 years. The temperature in this sea varies around -2-10°C. This affects the density of pelagic fish species in the world. Rising ocean temperatures are a major cause of vulnerability of European freshwater fish communities, which migrate from colder seas to warmer seas. We analysed changes in the distribution and presence of the six most common species and looked at potential shelters in the North and Baltic Seas. These areas have shifted from cold-water fishing events with Atlantic mackerel and European juvenile fish from the 1960s to 1980s to warmer water fishing events, including Pacific mackerel, Atlantic mackerel, freshwater fish, and anchovies in the northern territory to investigate whether warming oceans are causing these changes. Our model showed that the most important change for these species is sea surface temperature in all cases. These analyses suggest that each species combined response resulted in the ecological diversification of pelagic fish assemblages on the continental shelf (Montero-Serra et al. 2015; Haugen et al. 2021).

Several studies prove the relationship of SST parameters to the distribution of small pelagic fish. Research by Maynou et al (2014) proves the impact of ocean warming on two small pelagic fish (*Engraulis encrasicolus* and *Sardinella aurita*) in the Northwest Mediterranean Sea. In the summer of 2003, there was a decrease in local egg production from anchovies, and in the same period, Sardinella spawning was higher and expanded to a wider area. Several studies prove the relationship of SST parameters to the distribution of small pelagic fish. It same research from Amri et al. (2015) explained that the Sulawesi Sea (Indonesia) is known as a fishing area as well as a potential for pelagic-type spawning (Gerasmio et al. 2015). Then, Puspasari et al. (2016) explains that small pelagic fish are vulnerable to the dynamics of sea surface temperature (SST) ranging from 38.3-30.2°C with salinity between 30.0-37.5 psu (Simon et al. 2020) with thermocline layer is at a depth of 50-250 m in another meaning is that this type of fish is sensitive to changes in temperature (Safruddin et al. 2014; Safruddin 2022). Then, a study by Zainuddin et al. (2013) showed that oceanographic indicators are related to potential fish-feeding areas. This is also driven by the upwelling dynamics in the region, which can create a potential fishing zone during the southeast season. This water area forms high biological productivity in fishing activities due to upwelling. Analyzing the oceanographic conditions of pelagic fish catches is an effort to see the impact of climate change on fishing activities, especially small pelagic fish in Bone Bay (Safruddin et al. 2019). Then, Safruddin et al. (2018b) showed that changes in SST (Sea Surface Temperature) and SSC (Sea Surface Chlorophyll) conditions cause changes in anchovy distribution, which are then validated through a model developed. In addition, proves that Sea Surface Temperature (SST) is the factor that has the most influence on changes in marine ecosystems, including catches and ENSO phenomena. In addition, temperature significantly contributes to the diversity of small pelagic fish stocks and overall fish communities in waters (Zhang et al. 2022).

Figure 3 describes the study of the average sea surface temperature that is optimal for the abundance and distribution of small pelagic fish. The minimum temperature range is 22°C, and the maximum temperature reaches up to 34°C. A study in the Yellow Sea in 1970-2016 with climate using sea surface and sea temperature to look at benthopelagic and pelagic-neritic fish species with low emission scenarios (RCP 2.6) and high emission scenarios (RCP 8.5) showed that even fish with warmer temperaments tended to migrate to higher latitudes and areas to the north (Zhu et al. 2024).

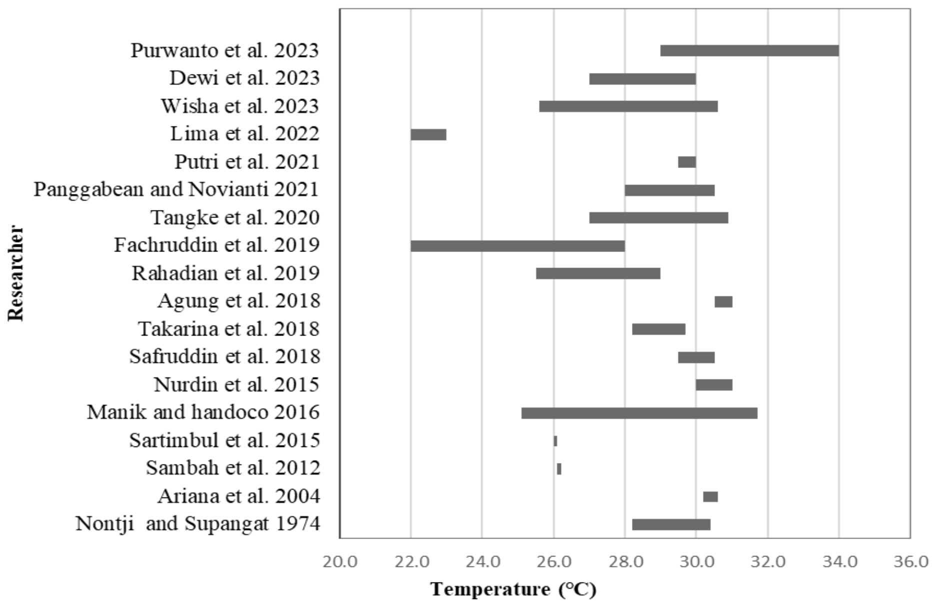

Figure 3. Potential temperature of small pelagic fish during 1974-2023

Oceanographic parameters such as ocean temperature are very important to analyze to find links to the abundance and distribution of small pelagic fish. In addition, anomaly analysis also needs to be done, such as analyzing sea surface temperature anomalies (Wei et al. 2023) to identify unusual temperature changes or shifts from normal or average conditions. It is commonly used to identify phenomena such as El Niño and La Niña that can cause significant changes in global weather patterns based on climate change. Sea surface temperature anomalies can be defined as the result of values from the average SST. A study by Lentini et al. (2001) observed spatial and temporal variability in the South Atlantic Ocean region from 1982 to 1994 (13 years), showing there were 13 cold SST anomalies and 7 warm SST anomalies immediately after the onset of ENSO. Cold SSTA spreads north at speeds of 18 and 14 $m.s^{-1}$. Research by Alheit et al. (2014) showed the AMO (Atlantic Multidecadal Oscillation) phase describes alternating warm and cold periods in the North Atlantic (Mohan et al. 2017). AMO is defined as an anomaly of Sea Surface Temperature (SST) in the North Atlantic that has decreased over the past ten years, lasting for 20-40 years with an extreme phase difference of ~0.5°C. That means climate variability showed that temperature does not directly drive fish dynamics and populations, but through AMO (Atlantic Multidecadal Oscillation), both warm and cold phases affect the dynamics of the abundance of small pelagic fish such as anchovies, sardines, and herring in 1930-2010. In the waters of the Canary Islands (Spain) showed that the average annual SSTA was positive, showing an annual upward trend that affected the dominant catch species (Jurado-Ruzafa et al. 2019). Research using SSTA (Sea Surface Temperature Anomaly) parameters can also be done to predict the global climate system at seasonal scales in many ecosystems, such as Pacific sardines in various cases (Tommasi et al. 2017). Other also showed that environmental variations in ocean temperature, chlorophyll-a, rainfall and sea level can alter the abundance, distribution, and recruitment of small pelagic fish in the Java Sea using PCA analysis (Ma' et al. 2019).

The results of the spatial correlation between environmental factors and the presence of pelagic fish, it is concluded that the density of pelagic fish is spatially correlated and dominant successively with environmental factors salinity, oxygen, chlorophyll, pH, and temperature. In some areas of high-temperature waters, some species of small pelagic fish have low catches, indicating conditions prone to warming waters (Yasumiishi et al. 2020). Research by Zhu et al. (2024) explained the phenomenon of El-Niño warming results in changes in ocean temperatures. Then, the influence of equatorial backflows during El Niño causes shifts in fish species. *S. aurita* was pushed Northward, and S. *Maderensis* became more dominant in Congo Waters when 1964-1999 with sea temperature. Small-scale fisheries in Morocco show significant differences and trends with important socio-economic implications. These changes are usually related to the influence of environmental conditions on the absorption process. The results showed an inversely proportional relationship between variations in the CPUE of sardines and sea surface temperature. The non-linear relationship confirms that temperature is the most important parameter affecting abundance, whereas chlorophyll-a tends to be weakly correlated with CPUE data in monthly and seasonal changes, except annual changes. The analysis also showed a positive trend in chlorophyll-a since 2003 and a negative trend since 2011, indicating annual variability based on changes in fish habitat. Modeling based on the relationship between CPUE and temperature/chlorophyll-a improved predictions of sardine abundance in the Al Hoceima fishing area (southern Alboran Sea) (Abdellaoui et al. 2017).

CHLOROPHYLL-A (CHL-A)

Chlorophyll-a is one of the parameters that support the abundance of small pelagic fish species (Mustapha et al. 2017). This has been proven in various studies. The abundance of chlorophyll-a in the waters indicates the high productivity of the waters and the abundance of food sources for large pelagic fish (Zainuddin et al. 2019; Elvianti et al. 2022). Chlorophyll-a is an indicator of primary productivity and food availability for small pelagic fish (Lloret-Lloret et al. 2022). The results of many studies found that the parameters of pelagic fish become important because of the life cycle of the ecosystem where small pelagic fish eat plankton in the vicinity. Chlorophyll-a is one of the parameters that can be used as an indicator of water fertility levels (Gunarso 1985). The potential presence of pelagic fish can be measured from Sea Surface Temperature (SST) and the abundance of aquatic chlorophyll. On the other hand, environmental parameters also factor in the abundance of pelagic fish, such as climate variability in waters (Sari et al. 2021). Research on climate variability in global waters with chlorophyll-a parameters (Dvoretsky et al. 2023) showed data for 1984-2021. In May, the chl-a concentration was 0.01-8.25 $mg.m^{-3}$, and the highest concentrations were in the northwestern and eastern water areas. Study with the concept of top-down and bottom-up processes on the history of survival of small pelagic fish such as herring. This proves that the abundance of herring increases with the increase in juvenile salmon, which shows that favorable conditions for herring are also favorable for predators. The increasing abundance of herring indicat es an abundance of biomass, which is evidenced by the abundance of predators around it (Boldt et al. 2019). Analysis of environmental variability showed changes in lower chl-a concentrations led to a sharp decline in the population and condition of small pelagic fish (anchovy and sardine) in the Mediterranean Sea (Palomera et al. 2007; Brosset et al. 2017).

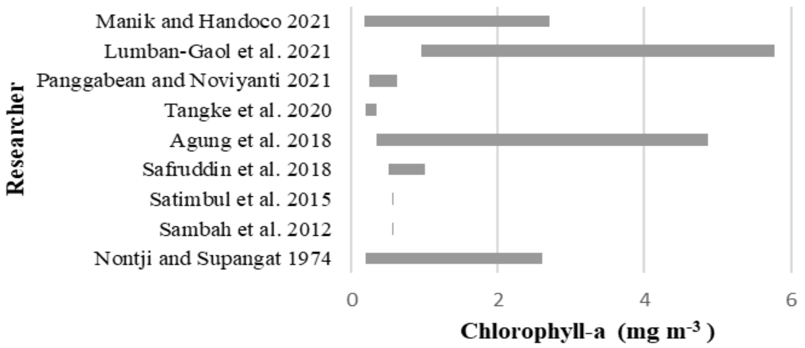

Figure 4. Potential chlorophyll-a on small pelagic fish

It shows the potential parameter chlorophyll-a for small pelagic fish based on several studies, namely the range of 0.1-5.8 mg.m^{-3}. The relation between chlorophyll and the abundance of small pelagic fish was studied to prove that this parameter is one of the factors affecting the abundance of small pelagic fish based on climate change (Figure 4). Except for annual trends, showed that the correlation between chlorophyll-a abundance and sardines is generally weak, and its effect on fish landing fluctuations is insignificant (Kyewalyanga 2022). Chlorophyll-a was positively correlated with anchovy catches, but the correlation was not apparent (r=0.47, df=11, p=0.12). Compared to the southeast monsoon season, phytoplankton species and biomass increase significantly in the northeast monsoon season. The most abundant fish is anchovy, which has the highest production in both seasons, followed by sardines, while mackerel has the lowest production. Chlorophyll a was positively correlated with anchovy catches, but the relationship was not apparent (r=0.47, df=11, p=0.12). Both variables reached their highest peaks in October, while the other group of fish showed a very weak and insignificant positive or negative correlation. These findings suggest that factors other than phytoplankton biomass also contribute to controlling the availability of small pelagic fish. Another study by Hong et al. (2023) showed a higher concentration of chlorophyll-a near the surface during La Niña events that provided better food conditions for small pelagic fish overwintering. In the North Atlantic from 1975 to 2005, climate events in the Northern Hemisphere have been linked to the rise and fall of fishing for Adriatic and Japanese sardines. Sardines and anchovies shifted for about 50 years in two separate periods in recent years. The last period, along with the North Atlantic warming period, caused pelagic species from the South to migrate to Northern California, which accelerated the development of California sardines (Blenckner et al. 2015). The similar research from Lincoln et al. (2023) showed that thse temperature and chl-a influence long-term fluctuations in trends in small pelagic fish populations. The distribution of sardines is found further north, to the North Sea and the Baltic Sea, after 40 years of absence in the region. On the Iberian Peninsula, higher temperatures are associated with lower landings. A similar study was also conducted (Nurdin et al. 2017) to detect the influence of changes in oceanographic conditions with the abundance of small pelagic fish on Spermonde Island with catch data from 2008-2009. It showed that chlorophyll-a and sea surface temperature strongly influenced mackerel catch. In addition, it was also shown that the highest mackerel catch was in April to June 2008 and 2009 with an accuracy rate of 83.34% and a kappa value of 0.70. Other studies related to the effect of chlorophyll have proven in research (Nair et al. 2023) that long-term qualitative changes in phytoplankton can change the abundance of Indian oil sardines and mackerel in recent decades.

SALINITY

Changes in salinity can affect the osmotic balance of fish and the distribution of prey (Lloret-Lloret et al. 2022). Climate events that result in increased salinity of seawater in winter benefit pelagic fish species by increasing habitat availability and providing better food conditions. Analyses using random forest models and GAM models show that climate events are not the best predictor of changes in fish abundance, as most fish stocks show significant year-over-year declines, while fishing pressures increase over time for an overall downward trend. in fisheries resources (Yuan et al. 2011; Hong et al. 2023). The distribution of target species appears to be sensitive to changes in salinity gradients. The results suggest that: (i) The distribution of sthe three dominant small pelagic fish species in Mauritanian Waters may be associated with upwelling intensity; (ii) The coastline may play an important role in the ecology of mackerel, horse mackerel, and round sardines; (iii) Chlorophyll concentration a may be related to the foraging grounds of mackerel; (iv) The distribution of target species is sensitive to changes in the total salinity gradient; (v) Depicted three regions (north, central and south) with different abundances; (vi) The center of gravity is highly concentrated in the central region. This may be due to the strong upwelling of nutrient-rich waters. This study can provide new insights into improving fisheries efficiency and sustainable development management of purse seine vessels in specific areas on the coast of Mauritania (Ebango Ngando et al. 2020). Other things, the abundance of Japanese anchovy *(Engraulis japonicus*) is strongly influenced by environmental factors, with salinity and sea surface temperature closely related to the distribution of catch units in winter. Our results suggest that the abundance of *A. japonicus* is strongly influenced by environmental factors. In particular, salinity and SST highlight a strong relationship with winter CPUE distribution. Based on this model, the results of this study strengthen our hypothesis and suggest that ocean warming will drive significant changes to Japanese anchovy habitats in Chinese waters. SST and CPUE are negatively correlated with the El Niño Southern Oscillation (ENSO) index. The findings reveal the impact of habitat changes in small pelagic fish caused by climate change on regional marine ecosystems in Chinese waters (Liu et al. 2020). Changes in salinity due to climate also affect the abundance and even distribution of small pelagic fish. The spatial distribution of SST, chl-a, and SSS shows variability each season. SST tended to decline from 1984-1988 and then increased until 2016 in the summer. Similarly, chl-a concentrations tend to increase in the Arctic Ocean by 21.5% during 1998-2018 (Dvoretsky et al. 2023). Studies in Malang District show there is a negative correlation between small pelagic fish captures and SST and chl-a parameters. Then, salinity and sea surface temperature explain the influence on the unit catch of both small pelagic fish species during La Niña events and depth sea surface temperatures during El Niño events (Li et al. 2023).

ENSO (EL NINO SOUTHERN OSCILLATION)-IOD (INDIAN OCEAN DIPOLE)

Climate change is also correlated with influencing ENSO events (Montes et al. 2011), global (Mukherjee et al. 2023) weather, and climate. Climate variations associated with El Niño events affect the abundance of coastal areas of pelagic fish, especially small pelagic fish (Yáñez et al. 2001). On other research explains that shifts in fish movement patterns do not occur randomly but are influenced by oceanographic factors and climate variability (Haditiar et al. 2019). This statement was analyzed using GAM (Generalized Additive Model) satellite data. In addition, climate variability such as ENSO and IOD with strong El Niño phenomena and positive IOD are known to influence SST and SSC, thereby influencing variations or fluctuations in fish catch production (Baharuddin et al. 2022; Zhang et al. 2022) conducted research by surveying the period of the year when the La Niña event occurred by describing the years 2006 to 2021 and found that the La Niña event, which had been described previously, only occurred in 2011, 2012, and 2021 but occurred in 2017-2018. However, the intensity is smaller, so the impact on the small pelagic fish ecosystem is also minimal. However, this proves that climate change will impact the ENSO phenomenon, which will occur more frequently and intensely. A study from (Sartimbul et al. 2010) mentioned that pattern monsoon southeast (June-August), transition II (September-November), Northwest Monsoon (December-February), and transition I (March-May) with CPUE more than 15.000 kg unit^{-1} in the Bali Strait influence positive Nino 3.4 and IOD which plays an important role in catching sardinella lemuru fish. Anomaly chlorophyll-a increases in a way significantly reached 1 mg.m^{-3} above normal in line with the upwelling process during the El Nino event at the end of 2006 (Wisha et al. 2023). The influence of ENSO-IOD on SST and chl-a is low. In the northwest monsoon (DJF), chl-a is low, and SST is high, so this is a characteristic of downwelling. Likewise, the opposite tends to happen upwelling occurs (Wijaya et al. 2020). The positive and negative IOD phases greatly affect the concentration of chl-a, either positive or negative anomaly, causing fluctuations in the catch of small pelagic fish (Indian Scad, Mackerel, Sardine) (Lumban-Gaol et al. 2021; Akita et al. 2023). Then, Sartimbul (2017) showed the positive Nino 3.4 and IOD exert a stronger effect on pelagic fish catch than other parameters such as chlorophyll-a. Strong ENSO events, such as La Niña and El Niño events, affect the composition, abundance, and distribution of small pelagic fishes in Beibu Bay, particularly affecting the abundance and distribution of Japanese mackerel (Li et al. 2023). The study from Robinson (2016) focuses on the development of warming in the southern region of the California Current System (CCS) in the western part of Baja California, Mexico. Analysis of Sea Surface Temperature (SST), sea pressure, and wind speed measured by satellite from January 1988 to December 2015 shows that warming occurred within two years. From May 2014 to April 2015, SST warming was caused by weakening non-El Niño onshore winds. This period marked the record for the longest sonic wind in the series, at 15 months. Low air pressure weakens beach upwelling, preventing cold water from rising. The second warming process occurred from September to December 2015, when the El Niño phenomenon was active. One of the most intense El Niño events occurred in 2015-2016, comparable to the events of 1982-1983 and 1997-1998 in terms of Sea Surface Temperature (SST) anomalies, which reached ~2.5°C resulting in a highly abnormal downwelling event north of 36°C, low chl-a levels and low nitrate availability in mixed layers and saltier water in the Baja California region (Dorantes-Gilardi and Rivas 2019).

CURRENT

The current had an important relation to the abundance and distribution of small pelagic fish. Research related to the influence of currents throughout global waters has been widely observed for the effects of climate change. One of the observations made was a small pelagic fish species in northern Humboldt and Kuroshio, namely anchovies and sardines. The change of species from the two currents is caused by a current system that changes biomass conditions due to the environment, which has an impact on fishing (Oozeki et al. 2019). In Indonesia, the optimal current speed for small pelagic fish such as Scads (*Decapterus* spp.*)* is 25.0-42.5 m.s^{-1} (Zainuddin 2011). The link to the impact of climate change is that if the current speed weakens or increases, it certainly affects the distribution and abundance of small pelagic fish in this study, *Decapterus* spp. A study projecting the impact of climate change using California Current System (CCS) parameters using Pacific sardines, swordfish, and albacore tuna shows that all three species are likely to experience distribution shifts that affect the accessibility of fishing fleets and so on (Smith et al. 2023). Changes in climate conditions in Indonesia must be understood through knowledges of the characteristics of the ITF (Purwanto et al. 2023). This is because ocean circulation and processes in Indonesia not only influence the local climate but also influence the global climate through connections with the Pacific Ocean and Indian Ocean (Zainuddin et al. 2023). Data relating to the condition of Indonesian waters is very important for regional forecasts and data assimilation models such as the Indo-Pacific SST anomaly, which influences regional rainfall and drought in many states on the edge of the Indian Ocean. The ITF experiences large interannual variations influenced by Indian and Pacific winds. When Pacific winds weaken or reverse direction during El Niño conditions. This causes the ITF to be reached and vice versa if La Niña conditions occur, although not all pathways are related to the ENSO phenomenon. Therefore, it is very important to study climate variability at interannual scales regarding the ITF (Sprintall et al. 2019). Located on the west coast of South America, Ecuador is characterized by a mix of small and diverse pelagic species, whose variability and productivity are largely determined by the ecosystems of currents opposite to the equator of Humboldt-Marento and Cromwell. Important small pelagic fish species include Mackerel (S. *japonicus*), Pacific herring (*Opisthonema* spp.), Pacific anchovy (*Cetengraulis mysticetus*), and others (Canales et al. 2024).

UPWELLING

One of the phenomena that plays a role in small pelagic fish fisheries is the phenomenon of upwelling. Upwelling is an oceanic phenomenon where cooler, nutrient-rich seawater rises from the ocean floor to the surface (Zuloaga et al. 2018). This process significantly impacts marine ecosystems, including small numbers of pelagic fish stocks. Small pelagic fishes are a key component of marine ecosystems, modulating population dynamics at lower and upper trophic levels, especially in highly productive marine upwelling systems. Scientifically, the impact of upwelling on small pelagic fish can be explained through several mechanisms. At the time of upwelling, the water that rises to the surface carries nutrients such as nitrates, phosphates, and silicates needed by phytoplankton, basic autotrophic organisms in the marine food chain (Bakun et al. 2015). As nutrient concentrations increase, phytoplankton populations experience explosive growth (bloom), which in turn increases primary productivity (Lu et al. 2018). To detect the upwelling area, it is necessary to look at the thermal front event, one of the indicators of upwelling detection (Zainuddin et al. 2020). Small pelagic fish such as sardines and anchovies use zooplankton as their main food source. Zooplankton is the main consumer feed of phytoplankton. As phytoplankton abundance increases, zooplankton populations also increase, which provides a rich food source for small pelagic fish. Upwelling often affects the spatial distribution of small pelagic fish. They tend to congregate in high-growth areas due to the high availability of food. It is often seen in places like the west coast of South America (Peru), the west coast of Africa (Mauritania and Namibia), and the west coast of North America (California) (Brodeur et al. 2019). Similar seasonal events in south-central Chile indicate a significant decline in species growth in winter. This affects the growth rate (after six months) of small pelagic fish and is associated with an increase in the productivity of coastal waters along with upwelling (Cubillos et al. 2001). Such increases are not constant and can vary seasonally or be influenced by climatic phenomena such as El Niño and La Niña. During El Niño, upwelling may decrease in some regions, thereby reducing nutrient availability and thus reducing stocks of small pelagic fish. Conversely, La Niña conditions can strengthen upwelling and increase populations of small pelagic fish (Jiménez-Quiroz et al. 2019). Upwelling can affect fish recruitment and growth performance from a biological aspect (Fuentes et al. 2017). Upwelling conditions are characterized by low seawater temperatures and high availability of nutrients, which is an ideal opportunity to understand how habitats modulate animal performance at different levels of biological complexity. Globally, sardines and anchovy populations are associated with productive upwelling environments along eastern ocean boundaries off the coasts of California, Peru, the Canary Islands, and South Africa (Struck et al. 2002). Then, a study (Aedo et al. 2020) shows that upwelling sustains some small pelagic fish species, such as sardines and anchovies. Research from Hidayat et al. (2022) explains that upwelling events in Bone Bay are not influenced by eddyto increase chlorophyll-a in the waters. Upwelling usually occurs before peak fishing months. The study (Brochier et al. 2018a) used a model to determine the migration and distribution patterns of small pelagic fish. It is explained that the beginning of the upwelling season is marked by the end of rain and the return of weak upwelling. In this situation, fishermen still catch sardinella near the coast, but the number will be higher than during the rainy season. In Portugal, the most important fish species to catch are sardines, mackerel, and flounder. Small pelagic fish account for 62.8% of the total fish biomass and account for 32.7% of the total economic value of the catch. Small pelagic fishes are particularly abundant in areas with high environmental change (coastal upwelling areas and tidal and streamed mixing areas) and exhibit large annual and interdecade fluctuations in abundance (Teixeira et al. 2016). Upwelling ecosystems in the south-central part of Chile show a role in sardines and anchovies as a result of ENSO events, triggering changes in resource availability (Aedo et al. 2020).

ABUNDANCE LEVEL

The abundance of small pelagic fish is strongly influenced by climatic variability affecting the surrounding oceanographic conditions (Tiedemann et al. 2022). The diversity of fish populations is closely related to the fertility of waters that are vulnerable to weather and climate dynamics (Lehodey et al. 2005). Water quality can also be measured through the historical use of small pelagic fisheries in the waters (Brander 2010). Research by Lamine et al. (2023) reveals catches caused by climate change analyze small pelagic fish species and determine which species are most widely caught and valuable based on three periods in the future to 2030. Catch analysis also looks at fishing results. Apart from that, the research results also show this. The EEZ (Exclusive Economic Zone) is most affected by climate change on fishing results, regardless of the fishing gear used. Fish catches are not always influenced by climate change, and there are other factors (Zhang et al. 2022) that are similar to those proven in research by Báez et al. (2022) examine the relationship between the abundance of small pelagic fish and stock dynamics such as abundance, biomass, and pelagic fish fitness. The effect on catches is confirmed by research (Asiedu et al. 2021), which observed a decline in pelagic fish stocks. This stock decline is caused by many factors other than the impact of climate change itself. Research by Alaei et al. (2021) related to the influence of climate change on catches of pelagic fish, in this case, sardines and anchovies in three regions and was measured using a certain model so that a relationship was produced between changes in catch and environmental parameters. Almost the same for both species, and in all models, chlorophyll-a and rainfall are the most influential and significant variables. Then Shannon et al. (2008) shows the correlation of climate with fishing so that the two main impacts of climate are fluctuations and a decline in small pelagic fish stocks so that they have a sustainable impact on the food chain. Research by Nurdin et al. (2017) using GAM analysis shows a strong relationship between chl-a and SST influence distribution. Recently, several variations of the Indian Sardinella longiceps, a small parasitic fish, have been investigated in connection with fisheries and changes in habitat ecology in the southeastern Arabian Sea. Landings reached a record high in 2012, making it the fifth largest sardine fishery in the world, and within three years, catches fell by nearly one-tenth of that level. This study examines factors that depend on fishing, such as intensity, catch, and distribution of fish. Biological changes in fish size, maturation and recruitment; attempts were made to link environmental changes to sardine habitat and food availability. The massive harvest in 2012 was the result of a two-fold increase in fishing gear and mechanization capacity, as well as a 3.7-fold increase in fishing effort. The maturity of females is affected by precipitation, followed by the introduction of nutrient-rich cold water in the house, starting in April, just before the start of the rainy season in June. The lack of air since 2013 and the El Niño Southern Oscillation in 2015 have increased the heating period (by an average of 1.1°C), which has a negative impact on the ripening process. The abundance of jellyfish predators, larvae and juveniles in the habitat has had a negative impact on recruitment since 2013. This also affects the productivity of phytoplankton and sardine larvae in a village on recruitment success. In 2010, these environmental changes, coupled with overfishing and overfishing (in addition to overfishing), resulted in a biological catastrophe that impacted the survival of thousands of small fishermen. Stronger fisheries management that protects fish stocks by limiting overfishing and closing fishing grounds can help reduce impacts (Kripa et al. 2018). A study of small pelagic fish species in the north Atlantic showed migration from spawning areas to nurturing and feeding areas. This involves many environmental factors that exert top-down pressure based on the food web from trophic high to low (Trenkel et al. 2014). The abundance of small pelagic fish is also influenced by various factors such as the fishing gear used (Robertis et al. 2023).

IMPACT OF CLIMATE VARIABILITY ON SMALL PELAGIC FISH SPECIES

Scenarios of the potential impacts of climate change on fish in waters off the coast of the Northeast Pacific that spend a lot of time in the epipelagic zone for at least part of their life cycle. Oceanographic conditions in the epipelagic zone are thought to be highly sensitive to climate change and its variability, leading to relatively rapid changes in the distribution or abundance of small pelagic fish (Cheung et al. 2015).

Based on a review of numerous research findings, explains how different species of small pelagic fish in different parts of the world are impacted by the global cycle of climate change, which is marked by the occurrence of ENSO and IOD (Figure 5). In the Atlantic or Arctic Sea, a phenomenon due to ENSO-IOD affects the presence of small pelagic fish in these waters. Similarly, the same thing happens in subtropical and tropical waters, affecting several oceanographic parameters such as Sea Surface Temperature (SST), chlorophyll-a, currents, and sea temperature. Some studies also show that there are other influences on the consequences of the ENSO-IOD phenomenon (Sambah et al. 2012; Harlyan et al. 2022) showed that monsoon and primary productivity impact the habitat and migration of lemuru fish in the Southern Waters of Malang District depending on oceanographic conditions and primary productivity. Primary productivity increases in the Southeast monsoon, and in the northwest monsoon chlorophyll increases to 3 $mg.m^{-3}$ in July. This was followed by an increase in lemur catches. Similar research shows the influence of seasons on the abundance of small pelagic fish. In the western season, sardines and spotted sardines dominate the species catch, and during the transition of species, the rainy season catch is dominated by sardines, with the highest catch in the eastern season (Wiyono et al. 2024).

The results showed that the abundance of E. *japonicus* was strongly influenced by environmental factors. In particular, salinity and SST show a strong relationship with winter CPUE distribution. The findings are based on models showing that ocean warming will cause significant changes to Japanese anchovy habitats in Chinese waters. SST and CPUE negatively correlate to El Niño Southern Oscillation (ENSO) signals. These findings underlie the impact of habitat change due to climate change on small pelagic fish species in China's marine ecosystems (Liu et al. 2020).

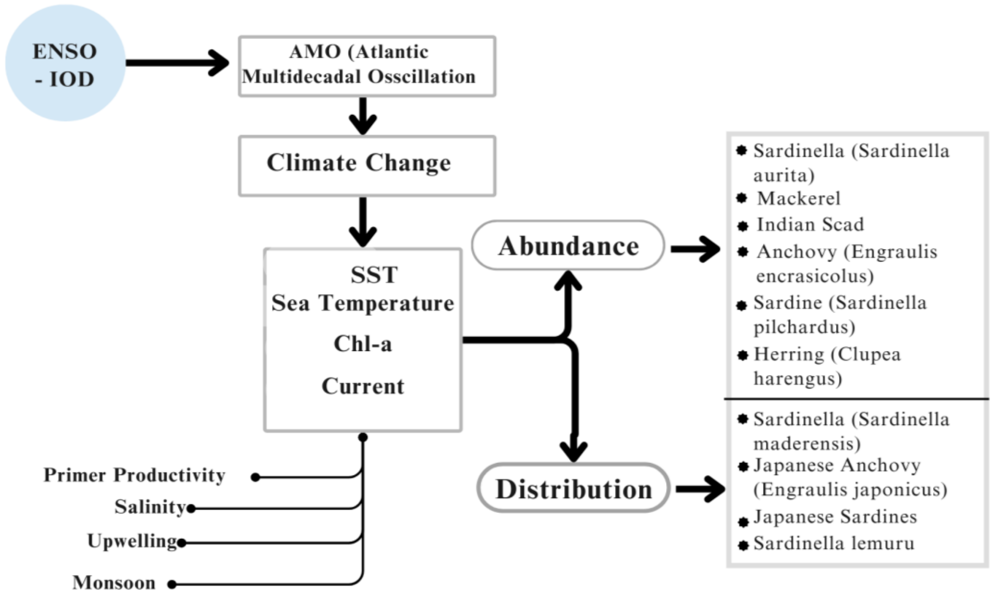

Figure 5. Effects of ENSO-IOD impacts on pelagic fish species in the world

Table 2. Parameter conditions of small pelagic fish in the world

Research	SST (°C)	SSS (psu)	SSC (mg.m^{-3})
Raj et al. (1979)	26.5 -30.0	34.7-36.0	-
Pati (1982)	24.9-29.4	22.4-33.4	-
Zainuddin (2011)	27.5-29.5	-	0.25-0.70
Sambah et al. (2012)	26.1	-	0.55
Sartimbul et al. (2015)	26.4	-	0.55
Nurdin et al. (2017)	30.0-31.0	-	0.30-0.40
Nontji and Supangat (2018)	28.8-30.4	30.0-32.9	0.2-2.6
Takarina et al. (2018)	28.2-29.7	30.0-32	-
Agung et al. (2018)	30.5-31.0	-	0.34-0.86
Sprintall et al. (2019)	30.2-30.6	32.2-33,5	0.16-0.77
Syah et al. (2019)	22.0-28.0	-	-
Lumban-Gaol et al. (2021)	28.2-29.7	30.0-32.9	0.9-2.0
Tangke et al. (2020)	27.0-30.9	-	0.2-0.35
Simon et al. (2020)	27.6-30.1	33.1- 35.4	-
Manik and Handoco (2021)	26.8-30.9	-	0.15-1.56
Lima et al. (2022)	22.0-23.0	17.3-39.6	-
Putri et al. (2022)	29.5-30.0	-	0.5-0.8
Panggabean and Noviyanti (2022)	28.0-30.5	-	0.25-0.62
Wisha et al. (2023)	25.6-30.6	-	-
Dewi et al. (2023)	27.0-30.0	-	-
Purwanto et al. (2023)	29.0-32.0	-	-

The results from research show that productivity is the main factor controlling bluefish abundance, but basic health supply affects anchovy and sardine populations (Salvatteci et al. 2019). During the Ice Age, lower productivity and higher oxygen availability were associated with lower overall fish productivity, whereas during the Holocene, higher productivity was observed, and stronger OMZs produced more fish. These differences between the end members of the ocean reflect favorable environmental conditions for small fish species. There is no evidence in the records of any specific association between anchovies and sardines during the period studied in this study. Other factors, such as seasonality, have an impact that varies on the habitat of small pelagic fish in subtropical waters. SST parameters contribute the most to the distribution of swallowfish in spring, and SSH contributes the most in autumn. In addition, chl-a has little influence on the distribution of flyfish with different levels of contribution (Yang et al. 2024). The results of the study (Safruddin et al. 2016) showed that small pelagic fish require specific oceanographic conditions with a tendency to gather in SST and chl-a with a range of 29.0-29.5°C and 0.45-0.65 mg.m^{-3} in Bone bay. A study conducted on the influence of currents, namely the Kuroshio current system, stated that these currents affect the distribution of small pelagic fish. In addition, sea temperature also affects Japanese sardine and Japanese anchovy species (Yu et al. 2023).

Several studies have elucidated the optimal parameters for the highest catch in each study. So when the effects of climate change cause a decrease in abundance and a shift in distribution, oceanographic conditions change from the optimal point, as in (**Error! Reference source not found.**). The results of the study by Zeeberg et al. (2008) showed the abundance of small pelagic fish *Sardinella aurita* in Mauritanian waters for 20 years associated with environmental dynamics showed an increase in annual sea surface temperature up to 3°C higher than the long-term average of 2002-2003, following climate change in 1995. Fish abundance and increased sardinella populations are associated with intense upwelling, high primary productivity during spring, and water retention during summer and fall. The impact of other aspects sustainably affects feed availability for coastal communities across

Africa. This is because if there is a lack of nutrients in the waters, the abundance of small pelagic fish will also decrease, causing the potential for reduced food availability with its nutritional content (Clarke et al. 2022). Marine environmental conditions strongly influence the distribution of fish populations (Torri et al. 2018). Meanwhile, changes in temperature and other marine conditions due to climate change significantly impact fisheries and aquaculture. In Ghana, sardine species are one of the most important fishery resources. About 60% of the total catch in coastal areas is higher than during the boom. This study investigated the role of marine physiological processes in the capture of Sardinella species (*S. aurita* and *S. maderensis*) arriving in Ghana. An analysis of the relationship between environmental conditions and Sardinella species catches was conducted for seasonal and seasonal variations between 2005. Analysis of the collected data shows that the higher (low) the wind speed, the stronger (weaker) the coastal upwelling. Low (high) SST were found to catch *Sardinella* spp. It is above (below) seasonal and seasonal variations. He has also proven to be able to catch small fish such as *Sardinella* spp. It depends on the upwelling strength of the beach. In addition, the Atlantic Meridional Mode Index (meridional mode index) is now recognized as a driver of seasonal variation in catches of small pelagic fish species (Neokye et al. 2021).

A growing body of evidence suggests that environmental changes in ocean temperature, chlorophyll-a concentrations, precipitation, and sea level can alter the abundance, distribution, and inclusion of small pelagic fish (Brosset et al. 2017). Small pelagic fish have a strong relationship with their environment, especially in the early stages of their life, so they are sensitive to climatic conditions (Brochier et al. 2018b). Small pelagic fishes appear to have a strong response to climate variability, which is seen in climate change over decades or cycles (Alheit et al. 2014). Variability over several years was observed in six small fisheries, with patterns differing between warm and cold-water species. Changes in the catch were observed in six species in every years from 1976-2006 and average changes in the climate index/SPL occurred in 1976-1977 and 1980 in the late to mid-80s. This suggests that small-sized freshwater fish are highly sensitive to climate change, and differences in the responses of warm and cold-water species reflect their survival strategies. The pattern of sea surface temperature variation during 1981-2000 can be explained by the difference in SST phase change between summer and winter and is consistent with seasonal changes in small fish catches (Ma et al. 2019).

In essence, climate change will always have an impact on many things. Research related to climate change in small pelagic fish has been carried out by many countries, as shown in (

Figure 6. *Countries that research related to small pelagic fish in the world* Currently, the highest number of studies related to climate change on small pelagic fish based on oceanographic parameters is carried out in Indonesia and followed by other countries based on color bars in the image. In the future, many studies from different countries will be conducted on various aspects of fisheries resources in world waters.

In conclusion, based on research conducted between 1975 and 2024, the effects of climate change which are typified by the presence of ENSO and IOD have an impact on a number of small pelagic fish species in different global oceans. The presence of small pelagic species is impacted by ENSO-IOD occurrences in the Atlantic and Arctic Seas. Similar to this, they also impact several oceanographic parameters in tropical and subtropical waters, including Sea Surface Temperature (SST), chlorophyll-a, current patterns, and sea temperature. The small pelagic fish ecosystem is thus significantly impacted by the notable variations in oceanographic characteristics, which include captures (CPUE), abundance, dynamic distribution, and migration. Most climate change indicators are based on Sea Surface Temperature (SST), Sea Surface Temperature Anomaly (SSTA), and other variables.

Figure 6. Countries that research related to small pelagic fish in the world (looker.google.com)

ACKNOWLEDGEMENTS

Thank you to the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia for funding us in the PMDSU scholarship program and previous researchers who included similar studies to make it easier to study this literature.

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