Università
Ca'Foscari
Venezia

Corso di Laurea Magistrale in

Scienze Ambientali

Environmental Global Change

"Life traits in the nekton assemblage: a comparison between effects of Climate Change on Adriatic Sea and Barents Sea"

Relatore:

dott. Fabio Pranovi

Supervisori tesi:

dott.ssa Elisabetta Russo, dott. Matteo Zucchetta

Laurenda:

Ylenia Moro

Anno accademico:

2021-2022

INDEX

LIST OF TABLES

LIST OF FIGURES

Abstract

Global environmental changes are impacting marine ecosystems and altering species distributions and interactions. With global warming, species redistribute to more suitable areas, affecting the persistence of resident species, modifying biodiversity and ecosystem functions.

In ecology, trait-based approaches are useful and efficient in order to understand what determines species distributions and the relationship with the environment.

In this thesis, a trait-based study is applied to the Northern Adriatic, using data from the fish market of Chioggia that provide captures of marine community, nektons and benthos, from 1945 to 2019. For every species 11 functional groups are applied, each of them divided in two or more categories. Functional diversity is analysed with R software, in particular with time series, data distribution analysis, community-weighted mean (CWM) and the principal component analysis (PCA).

The study emphasises the trend of the species abundance, through time, in relation with the different functional groups. Traits -based analysis of the marine community of Barents Sea, through the same time period, is compared to study the correlation between two different study areas.

The case studies are analysed comparing the effects of climate change on marine ecosystem functions and marine biodiversity.

1. Introduction

Ecology is the scientific discipline that studies the interactions between living organisms and their environments. It researches vital connections among plants, animals, bacteria and habitats[1]. The word *ecology* was introduced in German by the zoologist Ernst Haeckel, with the meaning of "relation of the animal both to its organic as well as its inorganic environment". Ecology studies both dynamics of communities and energy budgets, with energy flow and nutrient cycling. Modern methods in ecology are focusing on a new subject: systems ecology, such as the structure and function of ecosystems. Evolutionary ecology is a branch that studies the environmental factors that drive species adaptation[2]. Ecology wants to know where the organisms live and why, how many organisms are present in ecosystem and why.

One focal point of the ecology is the study of the biodiversity. Biodiversity, biological diversity, represents the variety of life forms at all levels of organization. It is the richness of life on Earth: plants, animals, microorganisms, and their genes, ecosystems that are part of the biosphere. The diversity refers to the abundance, distribution and interaction between the components of a system[3]. Biodiversity is the variety and variability of living organisms and of the ecosystems where they live, and it includes also genetic diversity, species diversity, ecosystem diversity. The term was first used by Norse and McManus in 1980. Diversity indicated the number of different items and their frequency[4].

As measure of biodiversity, the number of species in an ecosystem has been used.

It refers to taxonomic diversity, but it does not consider the functional variation between taxonomic units. Functional diversity (FD) considers the different types of processes in community that key factor for its structure and dynamic stability. It comprehends the components of biodiversity that effects ecosystem functions. FD is measured by the values of those species traits that influence the functioning of an ecosystem: ecosystem stability, productivity, dynamic, nutrient balance, and so on[5]. Different studies affirm that the functional traits of the organisms affect ecosystem processes, not the taxonomic identification.

Functional diversity can be measured through two indexes: functional richness and functional evenness. Functional richness indicates the amount of an ecological niche occupied by species within a community. When this is low, some of available resources are being unused and the productivity is

---

[1] *The Ecological Society of America*, https://www.esa.org/about/what-does-ecology-have-to-do-with-me.

[2] Smith, R. Leo and Pimm,. Stuart L.. "ecology." *Encyclopedia Britannica*, February 7, 2019. https://www.britannica.com/science/ecology.

[3] *Ispra*, Istituto Superiore per la Protezione e la ricerca Ambientale, "Biodiversity", https://www.isprambiente.gov.it/en/activities/biodiversity.

[4] *EEA*, European Environment Agency, "biological diversity", http://biodiversity-chm.eea.europa.eu/nyglossary_terms/B/biological_diversity.

[5] David Tilman, "Functional Diversity", Editor(s): Simon A Levin, *Encyclopedia of Biodiversity* (Second Edition), https://doi.org/10.1016/B978-0-12-384719-5.00061-7.

lower. Functional evenness is the measure of species trait distributed regularly. It refers to the degree of biomass distribution in niche space, in order to allow effective utilisation of all the range of resources available in an ecosystem.

Species are different in their competitive abilities. According to the sampling effect model, diversity leads to increases in productivity, when the ecosystem diversity is low.

Diversity influences ecosystem processes, considering that more diversifying ecosystems have greater range in those species traits that influence functioning.

Functional diversity can be used to measure the proper functioning of an ecosystem. According to the Niche Complementary Model, functional groups occupy functionally characteristic niches and utilize resources in a complementary way. Therefore, if some functional groups of a niche go extinct, the use of resources decreases, declining ecosystem functions[6].

Dividing species in functional groups is a trait-based approach always more used in ecology. Two important aspects are the species reactions to changes in the environment, according to their functional characteristics, and the effects of community shifts on ecosystem functioning. More studies proved that biodiversity indicators based on functional traits open to a more specific and complete comprehension of ecosystem functions and properties[7].

Trait-based approaches in ecology seem to explain why species are found in such zones and to predict the future location, given the connection between traits, adaptations and inhabitable environments. Traits refer to any characteristic of an individual organism, or a group of organisms, that can be morphological, demographic or physiological. They give more information about community composition, focusing on factors that best represent an organism’s fitness. In order to reduce the complexity of a trait analysis, traits can be combined into particular trait values, such as into functional groups, units of species with same trait attributes[6].

Considering that ecosystems with higher functional diversity are expected to have less species losses, an ecosystem with high functional redundancy is also less sensitive to disturbance. The presence of different functional types of species is a key factor to ensure sufficient adaptability, in the occurrence of environmental perturbations. With new environmental challenges, the ecosystem functioning could experience a transition, with similar species that compensate functionally the loss of others, without showing immediate clear effects, if the FD is high[8].

---

[6] Goswami, M., Bhattacharyya, P., Mukherjee, I. and Tribedi, P. (2017) “Functional Diversity: An Important Measure of Ecosystem Functioning”. *Advances in Microbiology*, doi: 10.4236/aim.2017.71007.

[7] Nock, Charles A; Vogt, Richard J; and Beisner, Beatrix E (February 2016) “Functional Traits”. In: eLS. John Wiley & Sons, Ltd: Chicheste, doi: 10.1002/9780470015902.a0026282.

[8] Aune M, Aschan MM, Greenacre M, Dolgov AV, Fossheim M, Primicerio R (2018), “Functional roles and redundancy of demersal Barents Sea fish: Ecological implications of environmental change”, https://doi.org/10.1371/journal. pone.0207451.

Trait-environmental relationships are fundamental to understand current ecosystems functioning, but they are also crucial for predicting species and community responses to future environmental disturbance or changes.

Our seas and oceans are experiencing, in the last decades, strong environmental changes given by global warming and other effects of human activities. According to the IPCC special report "Global Warming of 1.5°C" of 2018, human activities have caused 1.0°C of global warming, above pre-industrial level. Anthropogenic emissions will persist for centuries to millennia, continuing to cause long-term changes in the climate system[9].

According to the IPCC special report "The Ocean and Cryosphere in a Changing Climate of 2019, Arctic June snow cover extent on land declined by 13.4% from 1967 to 2018, permafrost temperatures are increasing to record high levels, releasing net methane and CO2 with the thaw, Arctic Sea ice is reducing 12.8% per decade with a surface air temperature that is increased by more than the double the global average over the last decades. Global ocean has warmed since 1970 and the rate of warming is doubled from 1993. This rapid change is causing more frequent marine heatwaves, ocean acidification (due to more CO2 absorbed), loss of oxygen. Surface ocean warming and high latitude addition of freshwater (due to faster ice melting) are making surface ocean less dense, inhibiting mixing between surface and deep waters. Hydrological changes are impacting freshwater species and their ecosystems, altering seasonal activities, abundance and distribution of animal species, causing ecological disturbances and changing ecosystem dynamics. Some species of animals establishes in new areas, thanks to the receding of glaciers and the lengthening of snow-free season. Since 1950, many marine species have shifted geographical range and seasonal activities, causing changes in species composition and biomass production of ecosystems. The alteration of interactions between species has led to cascading impacts on ecosystem functioning and structure[10].

According to the IPCC Sixth Assessment report "Climate Change 2021: The Physical Science Basis", many changes due to greenhouse gas emissions are irreversible for centuries to millennia, such as changes in the ocean, ice sheets and global sea level. Rises in sea surface temperature can bring to modifications of the vertical thermal structure of upper ocean, alterations of species distributions, pathogens and invasive species, mass mortalities. From 2011 to 2020 the global surface temperature was 1.09°C higher than the period between 1850 and 1900, over land 1.59°C, over ocean 0.88°C.

---

[9] IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. *World Meteorological Organization, Geneva, Switzerland, 32 pp.*

[10] IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)].

Global upper ocean temperature has increased since 1970s, due to human influence, that caused through large CO_2 emissions surface ocean acidification and oxygen levels decrease in upper ocean. Global sea level has increased since 1900 and ocean warmed faster in the 20th century than from the end of last deglaciation[11].

In this thesis, a trait-based study is applied to the North Adriatic, using data from the fish market of Chioggia that provide captures of marine community, nektons and benthos, from 1945 to 2019.

For every species 11 functional groups are applied, each of them divided in two or more categories. Functional diversity is analysed with R software, in particular with time series, data distribution analysis, community-weighted mean (CWM) and the principal component analysis (PCA). The study emphasises the behaviour of the species abundance, through time, in relation with the different functional groups. Traits -based analysis of the marine community of Barents Sea, through the same time period, is compared to study the correlation (positive, negative or null) between two different study areas. The case studies are analysed comparing the effects of climate change on marine ecosystem functions and marine biodiversity.

This recent ecological approach, functional diversity, is used to show how global warming is acting on ocean and how it is changing ecosystems structures, with future cascade effects.

---

[11] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001

1.1 Ecological principles

An ecological system is the organization and interactions of communities of living things, together with non-living components, such as chemical and physical factors in their environment. It is a dynamic continuum, with changes in time relative to species composition, population abundance, interspecific relationships.

When an ecological system matures, species stabilize and energy is stored.

The stability of an ecosystem depends on three aspects: inertia, ability to resist to disturbance or alteration; constancy, ability to maintain a state; resilience, ability to recover after a disturbance.

Disturbance is a discrete event that arrests ecosystem, community structure, and that alters resources or physical environment. According to intermediate disturbance hypothesis, species diversity is maximized when ecological disturbance is not rare or frequent.

When a disturbance event occurs, the ecological system modifies its states, as it changes. When the perturbation is getting smaller, the system can reach a new equilibrium state or turn back to the initial one. Resistance and resilience are two key factors to describe system response to a perturbation. The first one is the potential energy of a configuration that tends to maintain the structure when an external disturbance occurs. The second one is the capability to absorb a disturbance, maintain functioning.

Ecological succession is a process of change in species structure over time. With succession, three mechanisms can take place: facilitation, when earlier species make environment suitable for later species; inhibition, when one species hinder establishment or growth of another one; tolerance, when later and earlier species do not influence each other. With the maturation of an ecological succession, species diversity increases in time with stratification, while primary productivity decreases. Late succession is characterized by a complex trophic structure, with producers, consumers, decomposers, high biomass, high efficiency of nutrient cycling and energy use, many ecological niches, complex food web.

System dynamics is characterized by adaptive cycle, that describes how a system reorganize after a collapse, into similar or different structures and processes. After a disturbance the recovery of an ecological system depends on the features of the disturbance, the topological feature of the area, and on ecological memory, determined by ecological past and evolutive history of the system[12].

In the context of climate change, the impact pathways start with physical changes in the environment, as seas, oceans. These ones can be heat content and temperature, stratification, upwelling, acidification, sea level rise. The path way continues with impacts on species, physiological processes

---

[12] Pravoni F., (2020), materials from "Ecosystem functioning and climate change". Department of Environmental Science, Computer Science and Statistics, University Ca' Foscari of Venice.

of fishes, primary and secondary production, species distribution, species abundance, species invasion, ecosystems, food web structure.

To better understand how a disturbance event can impact the marine ecosystem, a description of marine structure and processes is introduced.

Marine organisms can be divided into plankton, nekton, and benthos.

Primary producers live in the pelagic zone as phytoplankton, in the benthic zone as microalgae and sea grass. Zooplankton are heterotrophic consumers.

Nekton are mobile organisms, able to swim ore move independently. They comprehend fishes, shrimps, cephalopods, sharks and marine mammals. They usually live in pelagic environment, but some are demersal and live close to the bottom.

Benthos are organisms that live in surface sediments of continental shelf and in deeper waters, they can be deposit feeders, suspension feeder or predators.

Organisms and environment are linked by energy flux and flux of matters. n. Nutrients enter the system through run-off from land or rivers, sediment redistribution and upwelling events.

Primary production moves energy from phytoplankton to other marine species through pelagic and benthic food webs. Food web transfers energy from one trophic level to another: primary producers, primary consumers, secondary consumers, tertiary consumers. Primary producers convert solar energy into biomass, through photosynthesis. The energy is then distributed to the others trophic levels, with partial losses due limited assimilation, to respiration and heat production.

Top-down control is the regulation of lower food-web components by upper-level predators. Predation exceeds fishing in marine species mortality. According to the top-down theory, if top predators decrease in size, there is a reduced predation on prey. The increase in abundance of prey fish leads to a bigger predation on zooplankton, which decrease in abundance. This phenomenon has the result of an increase of phytoplankton population size. Trophic cascade is the reciprocal predator-prey effects that can impact productivity, abundance of a population or food web. It concerns top-down dominance that can cause drastic changes in the system. In a bottom-up control situation, predatory fishes are negatively impact by the collapse of their prey[13].

After habitat change and loss, invasive species are one of the greatest threats to marine biodiversity. They are species that move from their original location to a new one, reproducing and establishing in the new place. They can impact ecosystem, biodiversity, fisheries and human health. Their presence can lead to flora and fauna extinction, a decreased water quality, increased competition and predation and spread of disease[14].

---

[13] P. Cury, L. Shannon, Y.-J. Shin, “The functioning of marine ecosystems”.

[14] Noaa Fisheries, “Invasive and Exotic Marine Species”. https://www.fisheries.noaa.gov/insight/invasive-and-exotic-marine-species.

A regime shift is a consequence of large-scale changes in the trophic level and in ecosystem services. Multiple external drivers can corrode system resilience[15]. They can be the sum of overfishing and climate change. A regime shift brings to reorganizations of ecosystems and the food web, leading to a different state. An ecosystem regime shift is the time-and-space scale change in abundance of components of biological communities, that can be caused by a climate regime shift, connected to different climatic characteristics. Eutrophication, exploitation and climate can cause a regime shift. The change can be linear, abrupt or discontinuous. Trophic cascades are the result of this phenomenon, with evidences of decrease in top-predators abundance and of changes in the trophic control from bottom-up to top-down. Usually, the marine ecosystem presents a bottom-up control, with planktivorous caught by piscivorous. With fishing, the apex predators decrease and macropredators increase in abundance. Planktivorous species grow in response to depletion of piscivorous species, as cod. In this case the system changes to top-down control. Every ecosystem responds in a different way. Warm areas revealed a bottom-up control, with high levels of turnover rate that contrast overfishing. Also, ecosystems with high species richness present bottom-up control. Cold areas, such as Barents Sea, are characterized by top-down control. Temperature can change predator-prey relationships with a phenomenon called trophic amplification.[16]

The disturbance event chosen for this analysis is climate change. Sea temperature is the aspect of environmental changes that more influences marine ecosystems. The alteration of sea temperature is correlated with potential responses by marine organisms' characteristics. Oxygen- and capacity-limited thermal tolerance is a crucial aspect correlated to the climate variability.

Changes in temperature can induce growth variations, with potential dramatic fluctuations in recruitment success. Oxygen consumption rate and organism's scope for activity have temperature-dependent optima. Reproduction and egg production increase with temperature, causing lower age of maturity and faster growth rates. Light and temperature affect phenology in marine environment. Earlier seasonal warming brings to earlier migratory movements. Distribution is the characteristic that mostly shows climate change effect on marine species. Warming induces poleward movement, with the consequence of a distributional shifts. These changes can alter composition of ecosystem assemblages. Invasive species or the disappear of species, due to their thermal tolerance, can provoke the decrease of prey abundance, or the increase of predators and competitors. Adult fish can move to

---

[15] P. S. Levin, C. Möllmann, 01/05/2015, "Marine ecosystem regime shifts: challenges and opportunities for ecosystem-based management". https://doi.org/10.1098/rstb.2013.0275

[16] C. Mollman, M. Casini, G. M. Daskalov, B. de Young, 2011, Virginija KELMELYTE, "Regime shifts in marine ecosystems: how overfishing can provoke sudden ecosystem changes". Directorate-general for internal policies, policy department structural and cohesion policies. https://www.europarl.europa.eu/RegData/etudes/workshop/join/2011/474557/IPOL-PECH_AT(2011)474557_EN.pdf

places with a better thermal range, or to escape from predators or to search prey. The geographical shift results in changes in community structure and in ecosystem function.

Alterations of existing biological interactions can occur in shifts in seasonal phonologies of interacting predator and prey populations. Biogeographic reorganizations change the community composition and biodiversity, with loss of functionally prominent species.

Temperature influences growth rate and larval stage duration, but it can also lead to direct mortality. Thermal shocks and rapid changes are the reason of mass mortality in many cases.

Critical habitat-forming marine benthic species, as corals or oysters, are very sensitive to climate change and CO_2, with the occurring of pathogens. Environmental changes can cause alterations in ocean circulation, affecting organism dispersal and transport of nutrient and organic matter[17].

Climate change impacts also ecosystem services from the sea, with negative repercussions for society's dependence on marine food, recreation, nutrient cycling, waste processing, climate regulation and so on. These services have important social values, such as maintenance of human health and livelihoods, cultural and aesthetic sustenance.

---

[17] K. Drinkwater, G. Hunt, P. Lehodey, S. Lluch-Cota, E. J. Murphy, Y. Sakurai, F. Schwing, G. Beaugrand, S. Sundby, 2010, "Climate forcing on marine ecosystems", Marine Ecosystems and Global Change, Oxford Biology. New York.

2. Materials and Methods

2.1 Study Area

Adriatic Sea is the part of the eastern Mediterranean Sea between Italian Peninsula and the Balkans. It is the northernmost tip of the Mediterranean Sea, from the Strait of Otranto to northwest and Po valley. Adriatic Sea wets the coast of Italy, Slovenia, Croatia, Montenegro, Albania and Bosnia and Herzegovina. The sea is long circa 800 km, large 150 km, and it covers a surface of 132 000 km^2. The mean salinity is 3.8%, considering a less salty north and a saltier south[18].

The Adriatic is divided into three basins: Northern Adriatic, the shallowest, Central Adriatic and Southern Adriatic, the deepest (1 233 meters as maximum depth) (Figure 1).

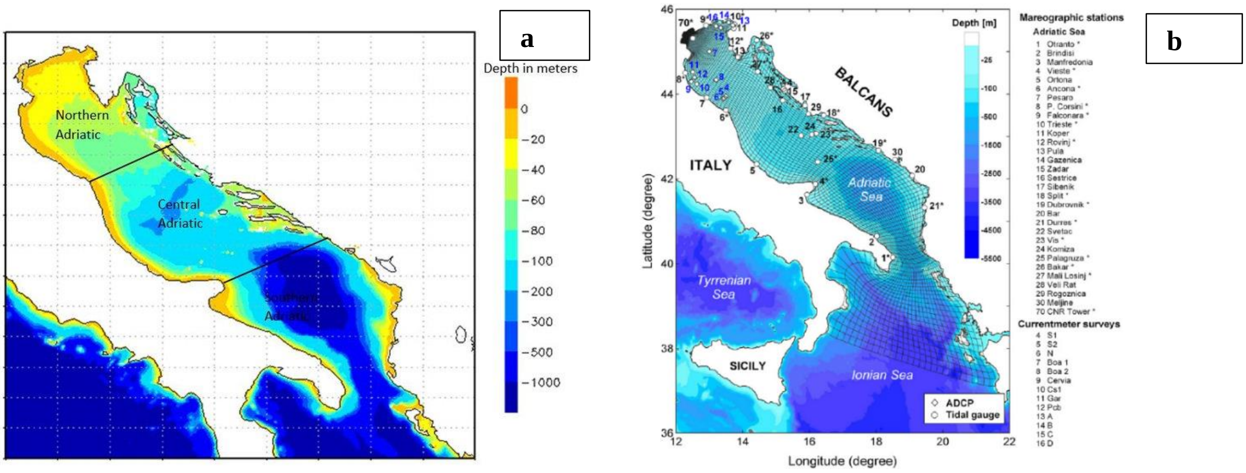


Figure 1. (a) Bottom topography and division of the Ariatic Sea. Source: Oceanlab, 2017; Meteorological and Hydrological Service, 2017. (b) Bathymetric chart of the Adriatic Sea and curvilinear boundary-fitted grid for integrated domain. Source: Continental Shelf Research, researchgate.net.

Northern Adriatic (*Alto Adriatico*) includes coastal areas between north-eastern Italy, Slovenia and Croatia (Figure 2). Its southern limit is monte Conero, Ancona and Zara canal, in Croatia. The Italian coasts are low and sandy, with portions of lagunes, the Slovenian and Croatian coasts are high and jagged, with islands and fiords[19].

The maximum depth is 100 meters; therefore, it is a shallow shell basin that represents an important economic resource area for fisheries and aquaculture, but also for maritime traffic and tourism.

Northern Adriatic Sea represents an area surrounded by land and mountain chains, Dinaric Alps to the east, Alps to the North, Apennines to the West. These conditions together with its shallowness make the sea respond faster to changes in boundary conditions, mostly atmosphere and river runoff[20].

---

[18] Treccani enciclopedia, “Mar Adriatico”. www.treccani.it/enciclopedia/mar-adriatico.

[19] Wikipedia, “Alto Adriatico”. https://it.wikipedia.org/wiki/Alto_Adriatico.

[20] United nations Environment Programme/ Mediterranean Action Plan, 2015, “Adriatic Sea: Ecology, draft report”.

Figure 2. Area of North Adriatic Sea, inside Mediterranean Sea, indicated with a black polygon. Source: Google Maps.

The Po’ river is one of the major drivers of the environmental dynamics of the sea. The circulation is cyclonic moving freshwater from the Po’ and other rivers south-eastward, influencing surface seawater salinity and determining nutrient availability.

Bora winds, from north-east, creates a configuration that push freshwater flux up to Istrian coast and the Gulf of Trieste.

Sea bottoms are defined movable because off non-consolidated sediments and the instability of the substratum. Bivalves and ceriantis live on the sea bottom, thanks to anchoring apparatus. Other species, like crustaceous, use the sea bottom to hide during the hunting. The low levels of the sea bottom determinate a high ecological productivity, given by the rapid nutrient recycle and the high sun exposition of the water column. The Adriatic basin has the highest fishing productivity of the Mediterranean and corresponds to 1/20 of the Mediterranean Sea surface. In the years 2009-2013 the productivity, with fishes and shellfish, was 208 000 t, representing the 53-54% of Italian fish productivity.

Nutrient’s enrichment brings to relevant phytoplankton biomass, determining the density of zooplankton and little pelagic fishes. Organic particles from rivers create an optimal sustenance for mussels, oysters and bivalves, like clams. The food chain goes on with nektobenthos and benthos, like phytobenthos and zoobenthos until fishes and macro-invertebrates. The north Adriatic basin can reach circa 70 meters of depth at maximum, it is composed by movable sediments given by sandy coasts and costal muds, but also by beach rocks, ancient shorelines.

The shallow sea bottom and the extensive slowly descending continental shelf can bring in addition negative aspects, such as rapid algal growth and eutrophication, during summer’s water stratification. Generally, the cyclonic circulation of Adriatic basin is driven by the wind Bora, cold by east/north-east and wind Scirocco, hot by south-east. The circulation influenced strongly the nutrients distribution from rivers, mostly on the occidental coast. Here the water is less salty and richer in organic components. These chemical-physical conditions create optimal environments for the nursery of some marine species[21].

During winter, cold salty waters can slide down, because of their density, mixing surface water with bottom water and bringing oxidation and organic matter enrichment.

The Adriatic Sea is characterized by huge seasonal changes, from hot summers and cold winters (Figure 3). In particular, during winter North Adriatic waters are the coldest, due to the discharge of Po’ waters. The southest part of Adriatic is also influenced by a hot current from Ionian Sea that rises until Istrian Peninsula. In the summer south Adriatic is characterized by costal upwelling and the discharge of Ionian waters that alter sea surface temperature, with a temperature decrease respect to North Adriatic[22].

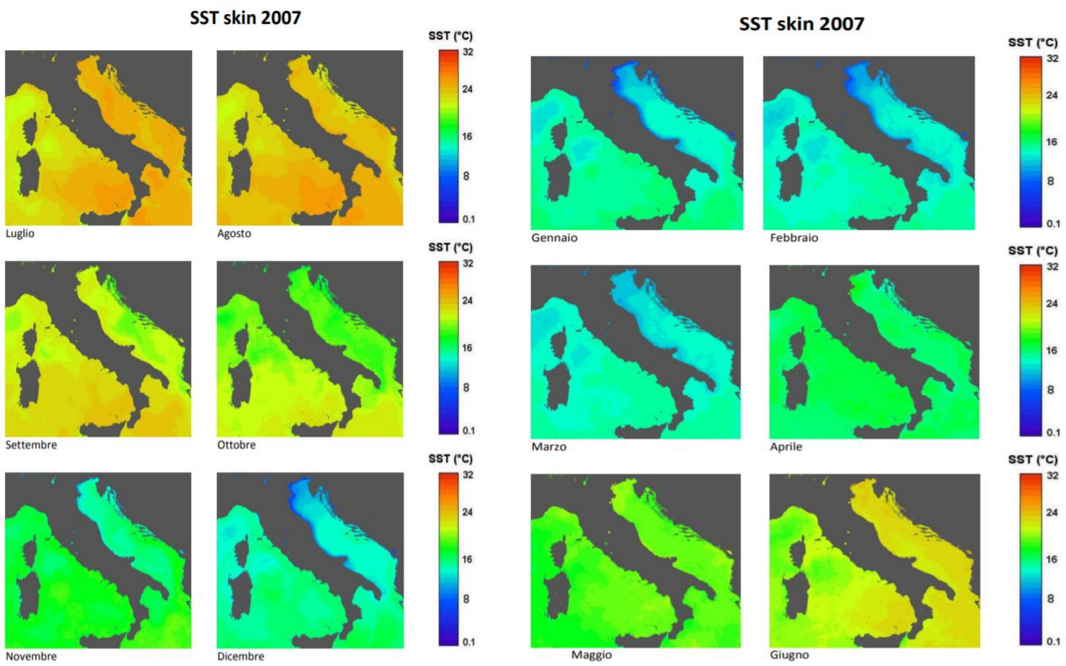


Figure 3. Sea Surface Temperature, SST, skin of 2007 of Adriatic Sea. Source: Research program “MARCOAST”, isprambiente.it

---

[21] M. Marini, G. Bombace, G. Iacobone, 2015, “Il Mare Adriatico e le sue risorse”, Carlo Saladino Editore s.r.l., Il mare Adriatico ambiente, pesca e cultura. www.assonautica.an.it/iniziative/2017/tonno/Il%20Mare%20Adriatico%20e%20le%20sue%20risorse%20-%202017.pdf

[22] Ispra, 2012, “Valutazione iniziale sottoregione Mae Adriatico”, Strategia per l’ambiente Marino, Carattertistiche fisiche. www.strategiamarina.isprambiente.it/consultazioni/consultazione-2012

2.2 Functional traits

In order to reconstruct time series of marine communities, records of fishing activities are used as data source. These data are recognised to be useful to study temporal variations of marine assemblages.

Data from the most important fish market of Northern Adriatic Sea, in Chioggia, were used to analyse marine community composition, focusing on nekton component and benthos. Data can be assumed to be representative of whole Northern Adriatic basin.

The city of Chioggia has a long tradition of fishing and its market, born in the 1960, is nationally recognized, thanks to the location and the multiple techniques of provision. Chioggia has 200 active fishing boats. The fishing can be passive and active: the first one uses gillnetting or longline fishing as technique, the second one uses trawling, hydraulic dredge, mechanical dredge. Gillnetting is for lagoon/costal fishing and consists in blockading net arranged on the sea bottom to block fishes. Longline fishing utilizes a rope, a girder and hooks colligated. Trawling is the most adopted in Chioggia, it needs a net with the form of a funnel, that are towed on the bottom (Bottom Otter Trawl) or in the pelagic zone (Midwater Pair Trawl). Hydraulic dredge and mechanical dredge, the latter used in the lagoon of Venice, are made to catch bivalves[23].

Landing data were collected from 1945 to 2019 and consist in the total annual capture of 104 different marine species, between fishes, molluscs and crustaceans.

For each species, some of the most relevant functional traits were searched and defined, through the biggest database on fishes “FishBase”[24] and the database on other marine species “SeaLifeBase”[25].

Functional traits are morphological, structural, behavioural characteristics of an organism, that determine fitness or performance. They can be applied to investigate community responses to changes in the environment. The measure of functional traits leads to an increase in the understanding of ecological processes. Functional traits can be divided into soft traits and hard traits, in relation to the strength of relationship to species responses or effects[26]. The characteristics are defined as variables in ecology, that have different possible states, with each one representing an element.

The Functional traits chosen are the following: Climatic Zone, Trophic Levels, Diet, Habitat, Offspring Behaviour, Offspring size, Fish Size, Body Shape, Salinity Tolerance Range, Temperature Tolerance Range, Depth Tolerance Range.

---

[23] Chioggia pesca, Mercato ittico di Chioggia. www.chioggiapesca.it

[24] www.fishbase.de

[25] www.sealifebase.ca

[26] Nock, Charles A; Vogt, Richard J; and Beisner, Beatrix E, February 2016, “Functional Traits”. In: eLS. John Wiley & Sons, Ltd: Chichester. DOI: 10.1002/9780470015902.a0026282

Climatic Zones reflect the set of ideal conditions for the survival and wellness of a species. These factors can be temperature ranges, sunlight hours, marine currents and circulation. Climatic zones are divided into: cold, cold-temperate, temperate, temperate-warm, warm.

Trophic level stands for the position of an organism in the food chain. It indicates the feeding behaviour of a species and the feeding relationships between organisms. The studied species belong to one of the following three levels: primary consumers, herbivores that feed on phytoplankton and algae; secondary consumers, carnivores or omnivores; tertiary consumers, higher order of carnivores.

Diet represents what an organism can consume and digest, it can be: planktivours, for planktonic food including zooplankton and phytoplankton; benthivorous, for species that feed on benthic preys; ichtyvorous, piscivorous; omnivorous, for fishes that eat both plants and other meat. In addition, a column specifies if the species is also detritivorous.

Habitat is the area used by a species which includes the resources needed to survive. It is represented by two variables: demersal, for species mostly associates to the bottom, benthic species, benthopelagic fishes; pelagic, for species that spend most of their time in the water column.

The trait Offspring behaviour summarise the main strategy of eggs release: demersal eggs, pelagic eggs, ovoviparous species. Demersal eggs remain on the bottom, free or attached to the substrate. They usually have thick complex chorion, more resistant to mechanical damage. Pelagic eggs float in the water column and are characterized by a thin homogenous chorion. They are subjected to high mortality, because of predators or hostile conditions. Ovoviparous refers to species that develop eggs within the maternal body, that stay there until they hatch.

Offspring size depends on cost of production, genetics and nutrition. It consists of three ranges: small for measure from 0 to 2 mm, medium for the interval 2-8 mm, high for eggs smaller than 8 mm.

Fish size is the standard length of a fish that excludes the caudal fin. The size is important for reproductive potential and stability of population. It includes small organisms, 0-30 cm, medium ones, 30-90 cm and big ones, more than 90 cm.

Body shape of a fish is related to the lifestyle, it can be used as camouflage, to navigate, to feed and survive in open water. It is divided into six categories: normal, flat, eellike, elongated, deep and short, compressiform.

Salinity tolerance range includes small tolerance range, medium tolerance range, high tolerance range, according to the type of water that the species can tolerate.

Temperature tolerance range is a zone where growth rate is positive. It consists of: small range, from 0 to 4 °C between minimum and maximum, medium range, with 4°C to 7°C of difference, high range, with more than 7°C between minimum temperature and maximum tolerated temperature.

Depth tolerance range influences the structure of population and it is caused by light attenuation, resource availability and change in water temperature. It is divided into: small range, between 0- and 150-meters depth, medium range, between 150- and 1 000-meters depth occupied, high range, for species that can reach more than 1 000 meters depth.

The adopted system gives the species the number 0 if a particular characteristic is not present, 10 if it is the prevalent one for that species, and 5 if a species presents a non-unique trait expression.

The following table (Table 1) explains the meaning, the state number and the indicator name of each functional trait, that will be used in the data analysis.

FUNCTIONAL TRAIT	STATE NUMBER: MEANING (INDICATOR NAME)					
Climatic Zone	1-1.5: Cold (Czone1/CZ1-Czone1.5/CZ1.5)	2-2.5: Cold-temperate (Czone2/CZ2-Czone2.5/CZ2.5)	3: Temperate (Czone3/CZ3)	4: Temperate-warm (Czone4/CZ4)	5: Warm (Czone5/CZ5)	
Trophic level	2: Primary consumers (TL2)	3: Secondary consumers (TL3)	4: Tertiary consumers (TL4)			
Diet	1: Planktivorous (D1)	2: Benthivorous (D2)	3: Ichthyvorous (D3)	4: Onnivorous (D4)	5: Detritivorous (D5)	
Habitat	1: Demersal (H1)	2: Pelagic (H2)				
Offspring behaviour	1: Demersal eggs (OB1)	2: Pelagic eggs (OB2)	3: Ovoviparous species (OB3)			
Offspring size	1: Small eggs, 0-2 mm (Small Offspring/OS1)	2: Medium eggs, 2-8 mm (Medium Offspring/OS2)	3: Big eggs, more than 8 mm (High Offspring/OS3)			
Fish size	1: Small organisms, 0-30 cm (Small Size/FS1)	2: Medium organisms, 30-90 cm (Medium Size/FS2)	3: Big organisms, more than 90 cm (Big Size/FS3)			
Body Shape	1: Normal (ShapeN/BS1)	2: Flat (ShapeF/BS2)	3: Eelike (ShapeEe/BS3)	4: Elongated (ShapeEl/BS4)	5: Deep and short (ShapeDS/BS5)	
Salinity tolerance range	1: Small	2: Medium	3: High			
Temperature tolerance range	1: Small, 0-4 °C between minimum and maximum (T1)	2: Medium, 4-7 °C of difference (T2)	3: High, more than 7 °C between minimum and maximum tolerated temperature (T3)			
Depth tolerance range	1: Small, 0-150 meters depth (DE1)	2: medium, 150-1000 meters depth (DE2)	3: high, more than 1000 meters (DE3)			

Table 1. Classification of functional traits. Division of traits with their meaning, state number and indicators. Source: Author.

The next table (Table 2) is the organization of species per functional trait, each one divided into categories. The species are indicated with the scientific name and the English name. The functional traits mean fecundity and salinity tolerance range are not indicated with the numeration 0-10-5 chosen because of lack of information. This table is used to analyse data from 1945 to 2019 crossing the numeration of functional traits with the annual catches.

	English-name	Climatic-Zone	TL2	TL3	TL4	DIET-Planktivorous	DIET-Benthivorous	DIET-Ichthyvorous	DIET-Omnivorous	DIET-Detritivorous	HABITAT-Demersal	HABITAT-Pelagic	OB-Demersaleggs	OB-Pelagiceggs	OB-Ovoviparous	OS-Small	OS-Medium	OS-Large	Mean-fecundity	FS-Small	FS-Medium	FS-Big	BS-Normal	BS-Flat	BS-Eelike	BS-Elongated	BS-Deepandshort	BS-Compressiform	SALINITYRANGE	TEMPR-Small	TEMPR-medium	TEMPR-Large	DEPTHR-Small	DEPTHR-Medium	DEPTHR-Large
Aequipecten opercularis	Queen Scallop	1	10	0	0	10	0	0	0	10	10	0	10	0	0	10	0	0	3-6 million	10	0	0	0	0	0	0	0	0	3	0	0	10	0	10	0
Alloteuthis media	Midsize Squid	1.5	10	0	0	0	5	5	0	0	10	0	10	0	0	10	0	0	1500-2500	10	0	0	0	0	0	0	0	0	3	10	0	0	0	10	0
Alopias vulpinus	Tresher	3	0	0	10	0	0	10	0	0	0	10	0	0	10	0	0	10	3-7 young in a litter	0	0	10	10	0	0	0	0	0	2	0	0	10	0	10	0
Alosa fallax	Twaite shad	1	0	10	0	0	0	10	0	0	0	10	10	0	0	10	0	0	50 000-200 000	0	10	0	10	0	0	0	0	0	2	0	0	10	0	10	0
Anguilla anguilla	European eel	1	0	10	0	0	5	5	0	10	10	0	10	0	0	0	10	0	2 000 000 - 3 000 000	0	0	10	0	0	10	0	0	0	3	0	0	10	0	10	0
Argyrosomus regius	Meagre	2.5	0	0	10	0	5	5	0	0	0	10	0	10	0	10	0	0	800 000	0	0	10	10	0	0	0	0	0	2	0	10	0	0	10	0
Arnoglossus spp	Mediterranea Scaldfish	1	0	10	0	0	5	5	0	0	10	0	10	0	0	0	0	0	0	10	0	0	0	10	0	0	0	0	3	0	0	10	0	10	0
Atherina boyeri	Big-scale sand melt	2	10	0	0	0	5	5	0	10	0	10	10	0	0	10	0	0	447	10	0	0	0	0	0	10	0	0	3	0	0	10	10	0	0
Auxis rochei	Bullet Tuna	3	0	0	10	0	5	5	0	0	0	10	0	10	0	10	0	0	31 000 - 103 000	0	10	0	0	0	0	10	0	0	2	0	0	10	10	0	0
Belone belone	Garfish	1.5	0	0	10	0	0	10	0	0	0	10	10	0	0	0	10	0	53 534	0	0	10	0	0	0	10	0	0	2	0	0	10	10	0	0
Bolinus brandaris	Purple Dye Murex	2	0	10	0	0	10	0	0	0	10	0	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0	1	0	10	0	0	10	0
Boops boops	Bogue	2.5	10	0	0	0	0	0	10	0	10	0	0	10	0	10	0	0	395 000	0	10	0	0	0	0	10	0	0	2	0	0	10	0	10	0
Callista chione	Brown venus	1.5	10	0	0	10	0	0	0	10	10	0	0	10	0	0	0	0	0	10	0	0	0	0	0	0	0	0	1	0	0	10	0	10	0
Callistoctopus macropus	White-spotted octopus	5	0	10	0	0	5	5	0	0	10	0	10	0	0	0	10	0	0	0	0	10	0	0	0	0	0	0	0	0	10	0	10	0	0
Carcinus maenas	Green crab	2	10	0	0	0	0	0	10	10	10	0	0	0	10	10	0	0	185 000	10	0	0	0	0	0	0	0	0	2	0	10	0	0	10	0
Cepola macrophthalma	Red brankfish	4	0	10	0	5	5	0	0	10	10	0	0	10	0	0	10	0	0	0	10	0	0	0	0	10	0	0	1	0	0	10	0	10	0
Chamelea gallina	Striped venus cham	1	10	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	76 835 - 797 424	10	0	0	0	0	0	0	0	0	0	0	0	10	10	0	0
Chelidonichthys lucerna	Tub gurnard	4	0	10	0	0	5	5	0	10	10	0	0	10	0	0	10	0	0	0	10	0	0	0	0	10	0	0	0	0	0	10	0	10	0
Chelon labrosus	Thicklip grey mullet	1.5	10	0	0	0	10	0	0	0	10	0	0	0	10	0	10	0	750	0	10	0	10	0	0	0	0	0	3	0	0	10	10	0	0
Conger conger	european conger	1	0	0	10	0	5	5	0	10	10	0	0	10	0	0	0	0	3 - 8 million	0	0	10	0	0	10	0	0	0	2	0	0	10	0	0	10
Coryphaena hippurus	common delphinfish	3	0	0	10	0	0	0	10	0	0	10	0	10	0	10	0	0	250 000	0	0	10	10	0	0	0	0	0	1	0	0	10	10	0	0
Crangon crangon	Common Shrimp	1	10	0	0	0	5	5	0	0	10	0	10	0	0	10	0	0	2 297	10	0	0	0	0	0	10	0	0	2	0	10	0	10	0	0
Deltentosteus quadrimaculatus	Fow-spotted goby	2	0	10	0	0	10	0	0	0	10	0	10	0	0	10	0	0	0	10	0	0	0	0	0	10	0	0	1	0	10	0	0	10	0
Dentex dentex	common dentex	2	0	0	10	0	5	5	0	0	0	10	0	10	0	0	0	0	0	0	0	10	10	0	0	0	0	0	1	0	0	10	0	10	0
Dicentrarchus labrax	european seabass	1	0	10	0	0	5	5	0	0	10	0	0	10	0	10	0	0	808 581	0	0	10	10	0	0	0	0	0	2	10	0	10	10	0	0
Diplodus spp	seabream	2	0	10	0	0	5	5	0	0	0	10	0	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	10	0	0	0	10	0
Eledone cirrhosa	horned octopus	1	0	10	0	0	10	0	0	0	10	0	0	0	10	0	10	0	6 000	0	10	0	0	0	0	0	0	0	1	10	0	0	0	10	0
Eledone moschata	Musky octopus	2	0	10	0	0	5	5	0	0	10	0	0	0	10	0	0	0	0	0	10	0	0	0	0	0	0	0	1	0	0	0	0	10	0
Engraulis encrasicolus	European anchovy	2.5	0	10	0	10	0	0	0	0	0	10	0	10	0	0	0	0	3 000	10	0	0	0	0	0	10	0	0	3	0	0	10	0	10	0
Epinephelus marginatus	Dusky grouper	3	0	10	0	0	10	0	0	0	10	0	10	0	0	0	0	0	65 000 - 7 900 000	0	0	10	0	0	0	0	0	0	2	0	0	10	0	10	0
Euthynnus alletteratus	Little tunny	3	0	0	10	0	5	5	0	0	0	10	0	10	0	0	0	0	71 000 - 2 200 000	0	0	10	10	0	0	0	0	0	0	0	0	10	10	0	0
Gobius niger	Black goby	1	0	10	0	5	5	0	0	0	10	0	10	0	0	10	0	0	1 000-6 000	10	0	0	0	0	0	10	0	0	3	0	0	10	10	0	0

	English-name	Climatic-Zone	TL2	TL3	TL4	DIET-Planktivorous	DIET-Benthivorous	DIET-Ichthyvorous	DIET-Omnivorous	DIET-Detritivorous	HABITAT-Demersal	HABITAT-Pelagic	OB-Demersaleggs	OB-Pelagic eggs	OB-Ovoviparous	OS-Small	OS-Medium	OS-Large	Mean-fecundity	FS-Small	FS-Medium	FS-Big	BS-Normal	BS-Flat	BS-Eelike	BS-Elongated	BS-Deepandshort	BS-Compressiform	SALINITYRANGE	TEMPR-Small	TEMPR-medium	TEMPR-Large	DEPTHR-Small	DEPTHR-Medium	DEPTHR-Large
Gobius paganellus	Rock goby	1	0	10	0	5	5	0	0	0	10	0	0	0	10	0	10	0	1 054 - 8 978	10	0	0	0	0	0	10	0	0	3	0	0	10	10	0	0
Homarus gammarus	Eropean lobster	1	10	0	0	0	10	0	0	10	10	0	0	0	10	0	0	0	5 431 - 27 725	0	10	0	0	0	0	0	0	0	0	0	10	0	10	0	0
Isurus oxyrinchus	Shortfin mako	3	0	0	10	0	0	0	10	0	0	10	0	0	10	0	0	0	0	0	0	10	10	0	0	0	0	0	0	0	0	10	0	10	0
Lepidopus caudatus	Silver scabbard fish	2	0	10	0	0	5	5	0	0	10	0	0	10	0	0	0	0	0	0	0	10	0	0	10	0	0	0	0	0	10	0	0	10	0
Lichia amia	Leerfish	2.5	0	0	10	0	5	5	0	0	0	10	0	10	0	0	0	0	0	0	0	10	10	0	0	0	0	0	2	0	0	10	10	0	0
Liocarcinus depurator	Blue-leg swimcrab	1	0	10	0	0	10	0	0	10	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	2	0	0	0	0	10	0
Lithognathus mormyrus	Sand steenbras	2	0	10	0	0	0	0	10	0	10	0	10	0	0	0	0	0	0	0	10	0	10	0	0	0	0	0	2	0	0	10	10	0	0
Liza aurata	Golden grey mullet	2	10	0	0	0	0	0	10	10	0	10	0	0	10	0	0	0	100 000- 1 480 000	0	10	0	10	0	0	0	0	0	1	0	0	10	10	0	0
Liza ramada	Thinlip grey mullet	1.5	10	0	0	0	0	0	10	10	0	10	0	0	10	0	0	0	0	0	10	0	10	0	0	0	0	0	3	0	0	10	10	0	0
Liza saliens-> chelon saliens	Leaping mullet	2	10	0	0	10	0	0	0	10	10	0	0	0	10	0	0	0	218 147-555 299	0	10	0	10	0	0	0	0	0	2	0	0	10	10	0	0
Loligo vulgaris	European squid	1.5	0	10	0	0	0	0	10	0	10	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	10	0	10	0
Lophius piscatorius	Angler	4	0	10	0	0	0	10	0	0	10	0	0	10	0	10	0	0	1 000 000	0	0	10	0	0	0	0	10	0	0	0	0	0	0	0	10
Maja squinado	Spinous spider crab	1	10	0	0	0	10	0	0	10	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	10	0	0
Melicertus kerathurus -> penaeus kerathurus	Caramote prawn	2	10	0	0	0	10	0	0	10	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	2	10	10	0	10	0	0
Merlangius merlangus	Whiting	1	0	0	10	0	0	0	10	0	10	0	0	0	10	0	0	0	200 000-600 000	0	0	10	10	0	0	0	0	0	2	0	0	0	0	10	0
Merluccius merluccius	European hake	1.5	0	0	10	0	5	5	0	0	10	0	0	10	0	0	0	0	7 000 000	0	0	10	0	0	0	10	0	0	1	0	0	10	0	0	10
Monochirus hispidus	Wiskered Sole	3	0	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	10	1	0	10	0	10	0	0
Mugil cephalus	Flathead grey mullet	2.5	10	0	0	0	0	0	10	10	10	0	0	10	0	10	0	0	1 600 000	0	0	10	10	0	0	0	0	0	3	10	0	10	10	0	0
Mullus barbatus	Red mullet	1.5	0	10	0	0	10	0	0	10	10	0	0	10	0	0	0	0	12 000 - 76 000	0	10	0	10	0	0	0	0	0	1	0	0	0	0	10	0
Mullus surmuletus	Surmullet	1.5	0	10	0	0	10	0	0	10	10	0	0	10	0	0	0	0	0	0	10	0	10	0	0	0	0	0	1	0	0	10	0	10	0
Mustelus asterias	Starry smooth-hound	2	0	10	0	0	10	0	0	0	10	0	0	0	10	0	0	0	0	0	0	10	10	0	0	0	0	0	1	0	0	10	0	10	0
Myliobatis aquila	Common eagle ray	3	0	10	0	0	5	5	0	0	0	10	0	0	10	0	0	0	0	0	0	10	0	10	0	0	0	0	2	0	0	10	0	10	0
Mytilus galloprovincialis	Mediterranean mussel	2	10	0	0	10	0	0	0	10	10	0	0	10	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	10	0	0
Nephrops norvegicus	Norway lobster	1	0	10	0	0	10	0	0	10	10	0	0	0	10	0	0	0	735.00	10	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0
Octopus vulgaris	Common octopus	2.5	0	0	10	0	5	5	0	0	10	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	1	10	0	10	0	10	0
Ophidion barbatum	Snake blenny	2	0	10	0	0	10	0	0	0	10	0	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	0	1	0	0	0	0	0	10
Ostrea edulis	Edible oyster	1	10	0	0	10	0	0	0	10	10	0	0	0	0	0	0	0	500 000 - 1 000 000	10	0	0	0	0	0	0	0	0	3	0	0	10	10	0	0
Pagellus spp	Axillary seabream (acarne)	2	0	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	85 000	0	10	0	10	0	0	0	0	0	2	0	10	0	0	10	0

	English-name	Climatic-Zone	TL2	TL3	TL4	DIET-Planktivorous	DIET-Benthivorous	DIET-Ichthyvorous	DIET-Omnivorous	DIET-Detritivorous	HABITAT-Demersal	HABITAT-Pelagic	OB-Demersaleggs	OB-Pelagic eggs	OB-Ovoviparous	OS-Small	OS-Medium	OS-Large	Mean-fecundity	FS-Small	FS-Medium	FS-Big	BS-Normal	BS-Flat	BS-Eelike	BS-Elongated	BS-Deepandshort	BS-Compressiform	SALINITYRANGE	TEMPR-Small	TEMPR-medium	TEMPR-Large	DEPTHR-Small	DEPTHR-Medium	DEPTHR-Large
Palinurus elephas	Common Spiny lobster	1	10	0	0	0	10	0	0	10	10	0	0	0	10	0	0	0	23 485 - 201 549	0	10	0	0	0	0	0	0	0	0	0	0	10	0	10	0
Paracentrotus lividus	Stony sea urchin	1.5	10	0	0	10	0	0	0	10	10	0	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	10	0	0
Pecten jacobaeus	Great mediterranean scallop	2	10	0	0	10	0	0	0	10	10	0	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0	0	0	10	0	0	10	0
Pegusa lascaris	Sand sole	2.5	0	10	0	5	5	0	0	0	10	0	0	10	0	0	0	0	0	0	10	0	0	0	0	0	0	10	2	0	0	10	0	10	0
Platichthys flesus - Platichthys flesus	European flounder	1	0	10	0	0	10	0	0	0	10	0	0	10	0	10	0	0	400 000 - 2 000 000	0	10	0	0	0	0	0	0	10	3	0	0	10	10	0	0
Pomatomus saltator -> Pomatomus saltatrix	Bluefish	2.5	0	0	10	0	5	5	0	0	0	10	0	10	0	10	0	0	400 000 - 2 000 000	0	0	10	10	0	0	0	0	0	2	0	0	10	0	10	0
Pomatoschistus minutus	Sand goby	1	0	10	0	5	5	0	0	0	10	0	10	0	0	10	0	0	5 231- 5 603	10	0	0	10	0	0	0	0	0	2	0	0	10	0	10	0
Psetta maxima + Scophtalmus rhombus -> Scophthalmus maximus	Turbot	1	0	10	0	0	10	0	0	0	10	0	0	10	0	10	0	0	5 000 000	0	0	10	0	0	0	0	0	10	2	10	10	0	10	0	0
Raja spp	Mediterranean starry ray (asterias)	4	0	10	0	0	10	0	0	0	10	0	0	0	10	0	10	0	<100	0	10	0	0	0	0	0	0	0	0	0	0	0	0	10	0
Rossia macrosoma	Stout bobtail	1	0	0	10	0	10	0	0	0	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0
Sarda sarda	Atlantic bonito	3	0	0	10	0	5	5	0	0	0	10	0	10	0	0	0	0	0	0	0	10	10	0	0	0	0	0	3	0	0	10	0	10	0
Sardina pilchardus	European pilchard	2	0	10	0	10	0	0	0	10	0	10	0	10	0	10	0	0	50 000-60 000	10	0	0	10	0	0	0	0	0	3	0	0	10	10	0	0
Sardinella aurita	Round sardinella	3	0	10	0	10	0	0	0	10	0	10	0	0	0	10	0	0	9 700-72 000	0	10	0	10	0	0	0	0	0	3	0	0	10	0	10	0
Sarpa salpa	Salema	2	10	0	0	10	0	0	0	10	10	0	0	0	0	0	0	0	0	0	10	0	10	0	0	0	0	0	3	0	0	10	10	0	0
Sciaena umbra	Brown meagre	3	0	10	0	0	10	0	0	0	10	0	0	10	0	0	0	0	0	0	10	0	10	0	0	0	0	0	2	0	0	10	0	10	0
Scomber japonicus	Chub mackerel-atlantic chumb mack(colias)	2.5	0	10	0	0	0	0	10	10	0	10	0	10	0	10	0	0	100 000-400 000	0	10	0	10	0	0	0	0	0	2	0	0	10	0	10	0
Scomber scombrus	Atlantic mackerel	2	0	10	0	0	0	0	10	0	0	10	0	10	0	10	0	0	200 000	0	10	0	10	0	0	0	0	0	2	0	0	10	0	0	10
Scorpaena spp	Red scorpion fish	2.5	0	0	10	0	5	5	0	0	10	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	10	0	2	0	0	10	0	10	0
Scyliorhinus canicula	Lesser spotted dogfish	1	0	10	0	0	5	5	0	0	10	0	0	0	10	0	10	0	29-62	0	0	10	0	0	0	10	0	0	0	0	0	10	0	10	0
Sepia elegans	Elegant cuttlefish	1	0	10	0	0	5	5	0	0	10	0	10	0	0	0	10	0	0	10	0	0	0	0	0	0	0	0	2	0	10	0	0	10	0
Sepia officinalis	Common cuttlefish	1	0	10	0	0	5	5	0	0	10	0	10	0	0	0	0	10	0	0	10	0	0	0	0	0	0	0	0	0	0	10	0	10	0
Seriola dumerili	Greater amberjack	3	0	0	10	0	5	5	0	0	0	10	0	10	0	10	0	0	0	0	0	10	10	0	0	0	0	0	1	0	0	10	0	10	0
Serranus hepatus	Brown comber	2	0	10	0	0	5	5	0	0	10	0	0	0	0	0	0	0	0	10	0	0	10	0	0	0	0	0	1	0	0	10	10	0	0
Solea solea	Common sole	1	0	10	0	0	10	0	0	10	10	0	0	10	0	0	10	0	100 000	0	10	0	0	0	0	0	0	10	1	0	0	10	10	0	0
Solen marginatus	Europam razor clam	1.5	10	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0

	English-name	Climatic-Zone	TL2	TL3	TL4	DIET-Planktivorous	DIET-Benthivorous	DIET-Ichthyvorous	DIET-Omnivorous	DIET-Detritivorous	HABITAT-Demersal	HABITAT-Pelagic	OB-Demersaleggs	OB-Pelagic eggs	OB-Ovoviparous	OS-Small	OS-Medium	OS-Large	Mean-fecundity	FS-Small	FS-Medium	FS-Big	BS-Normal	BS-Flat	BS-Eelike	BS-Elongated	BS-Deepandshort	BS-Compressiform	SALINITYRANGE	TEMPR-Small	TEMPR-medium	TEMPR-Large	DEPTHR-Small	DEPTHR-Medium	DEPTHR-Large
Solenocera membranacea	Atlantic mud shrimp	1	10	0	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0
Sparus aurata	Gilthead seabream	2	0	10	0	0	10	0	0	0	10	0	10	0	0	10	0	0	0	0	10	0	10	0	0	0	0	0	3	0	0	10	10	0	0
Spicara spp	Blotched picarel (maena)	2	0	10	0	10	0	0	0	0	10	0	10	0	0	0	0	0	0	10	0	0	10	0	0	0	0	0	1	0	10	0	10	0	0
Sprattus sprattus	European sprat	1	0	10	0	10	0	0	0	0	0	10	0	10	0	10	0	0	6 000-14 000	10	0	0	0	0	0	10	0	0	1	0	0	10	10	0	0
Squalus acanthias	Picked dogfish	2	0	0	10	0	5	5	0	10	10	0	0	0	10	0	0	10	0	0	0	10	10	0	0	0	0	0	2	0	0	10	0	0	10
Squilla mantis	Spottail mantis shrimps	2	10	0	0	0	10	0	0	0	10	0	0	10	0	0	0	0	50 000	10	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0
Synapturichthys kleinii	Klein's Sole	2	0	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	10	2	0	0	10	0	10	0
Thunnus thinnus .> thynnus	Atlantic bluefish tuna (thynnus)	2	0	10	0	0	5	5	0	0	0	10	0	10	0	10	0	0	13-15 million	0	0	10	10	0	0	0	0	0	2	0	0	10	0	10	0
Todarodes sagittatus	European flying squid	1.5	0	10	0	0	5	5	0	0	10	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	10	0	0	10
Trachinus draco	Greater weever	1.5	0	0	10	0	5	5	0	0	10	0	0	0	10	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0	0	10	10	0	0
Trachurus spp	Mediterranean horse mackerel	2	0	10	0	0	5	5	0	0	10	0	0	10	0	0	0	0	0	0	10	0	10	0	0	0	0	0	2	0	0	10	0	10	0
Trisopterus minutus capelanus .> Trisopterus capelanus	COD?	1	0	10	0	0	0	0	10	0	10	0	0	0	10	0	0	0	0	0	10	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Umbrina cirrosa	Shi drum	3	0	10	0	0	10	0	0	0	10	0	0	10	0	0	0	0	0	0	10	0	10	0	0	0	0	0	1	0	0	0	10	0	0
Uranoscopus scaber	Stargazer	2	0	0	10	0	5	5	0	0	10	0	0	0	10	0	0	0	0	0	10	0	0	0	0	0	10	0	1	0	10	0	0	10	0
Venerupis philippinarum -> Ruditapes philippinarum	Japanese carpet shell	1.5	10	0	0	10	0	0	0	10	10	0	0	0	0	0	0	0	432 000 - 2 350 000	10	0	0	0	0	0	0	0	0	2	0	0	10	10	0	0
Venus verrucosa	Warty venus	1.5	10	0	0	10	0	0	0	10	10	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	1	0	0	10	10	0	0
Xiphias gladius	Swordfish	2.5	0	0	10	0	5	5	0	0	0	10	0	10	0	10	0	0	2 million	0	0	10	10	0	0	0	0	0	1	0	0	10	0	0	10
Zeus faber	John dory	4	0	0	10	0	5	5	0	0	10	0	0	10	0	0	0	0		0	0	10	0	0	0	0	0	10	2	0	0	10	0	10	0
Zosterisessor ophiocephalus	Grass goby	2	0	10	0	0	10	0	0	0	10	0	0	0	0	0	0	0	5000-26000	10	0	0	10	0	0	0	0	0	2	0	10	0	10	0	0

Table 2 Organization of species per functional trait. Each trait is divided into different categories. Each category is classified with a numeration. The first two columns indicate the name of the species, the scientific name and the English common name. Source: Author.

R software[27] was used to analyse and elaborate the dataset. The sum values of the catches were calculated for each state of the characteristic and represented in terms of distribution over time, considering both functional groups and the catching values, expressed in tonnes[28].

The total catches for each trait were represented in boxplots[29]. This data representation shows how the values changed in time and how the values are distributed, comparing the states of the characteristics. For example, the quantity of species that belong to the climatic zone 1 is compared to the ones belonging to the other climatic zones, in time and in distribution.

The relative values were calculated and transformed into time series, identifying a trend for each state of the variables[30]. To the resultant time series were applied a linear filter for obtaining the trend, with the smoothing method. The filter was a symmetric one with equal weights $w= 1/(2p+1)$[31].

Subsequently, the community-weighted mean (CWM) approach was used to analyse the relationship between traits and sample abundance, via community matrix[32]. The aim was to understand how functional traits of the species were related with their abundance in years. Community-weighted mean can explain most of the variation in community biomass and biodiversity effects. The CWM was calculated as the mean trait value weighted by catches biomass. CWM trait values were standardized through zero-mean approach. The CWM of traits was aggregated in PCA axes, focusing on PC1 and PC2, that mainly represented the variation in the community.

PCA is the principal component analysis[33]. It calculates the covariance, deviation from the mean, of the matrix, looking for directions or vectors that contain most information. PCA is a type of linear transformation on a dataset with values for a number of variables for an amount of space. This transformation fits the dataset to a new coordinate system, with the most significant variance on the first coordinate, and the subsequent is orthogonal to the last, with less variance. A set of x correlated variables over y samples are transformed into a set of p uncorrelated components over the same samples. If the initial variables are strongly correlated, most of the complexity of dataset can be approximated with two principal components. Relevant aspects of the PCA are eigenvectors and eigenvalues. Eigenvector can be described as a direction and eigenvalue is the number that indicates how much variance there is in the data in that direction. The first principal component is the eigenvector with the highest eigenvalue, the direction of greatest variability, otherwise covariance. The number of eigenvectors and eigenvalues corresponds to the number of dimensions of the dataset.

---

[27] R software for statistical computing and graphic. www.r-project.org. www.rstudio.com.

[28] Apply command in R. https://r-coder.com/apply-r. www.datacamp.com/tutorial/r-tutorial-apply-family. www.rdocumentation.org/packages/base/versions/3.6.2/topics/tapply.

[29] Plot and Boxplot in R. https://r-coder.com/plot-r/. https://r-graph-gallery.com/boxplot.html.

[30] Matrix and time series in R. www.datamentor.io/r-programming/matrix/. www.rdocumentation.org/packages/stats/versions/3.6.2/topics/ts.

[31] Linear filter https://search.r-project.org/CRAN/refmans/tis/html/tisFilter.html.

[32] CWM analysis. https://monashbioinformaticsplatform.github.io/r-more/topics/tidyverse.html

[33] PCA analysis www.datacamp.com/tutorial/pca-analysis-r.

GIS, geographic information system, is a software that uses georeferential data to solve problems with specific procedures. Database with a geographic position can be obtained, elaborated, analysed and represented. GIS associates topologic and geometric information of a chart with relational management of descriptors[34]. GIS is used to analysed change of species in the Northern Adriatic during the last years.

---

[34] Treccani Enciclopedia. www.treccani.it/enciclopedia/gis_%28Enciclopedia-Italiana%29.

3. Results

104 different marine species, between fishes, molluscs and crustaceans, are classified into 11 different functional group, each of them divided into 2 or more categories. Catches in tonnes between 1945 and 2019 are associated with annual quantity for each species.

Functional traits are described separately to underline the behaviour of species abundance in time, in correlation with the species belonging to different functional group, the functional diversity.

Climatic zone analysis shows a higher abundance of species belonging to the climatic zone 2, followed by the zone 2.5 and the zone 1. Cold-temperate and cold are the climates to which most of the species belong to. The plots reporting the absolute (Figure 4.a) and the relative (Figure 4.b) values are very similar and indicate the abundance of species with the different thermal affinity as characteristic in time, from 1945 to 2019 (Figure 4). Results reported in Figure 4 and the relative to the distribution of the absolute value, underline the superiority of species belonging to the first four zones[35].

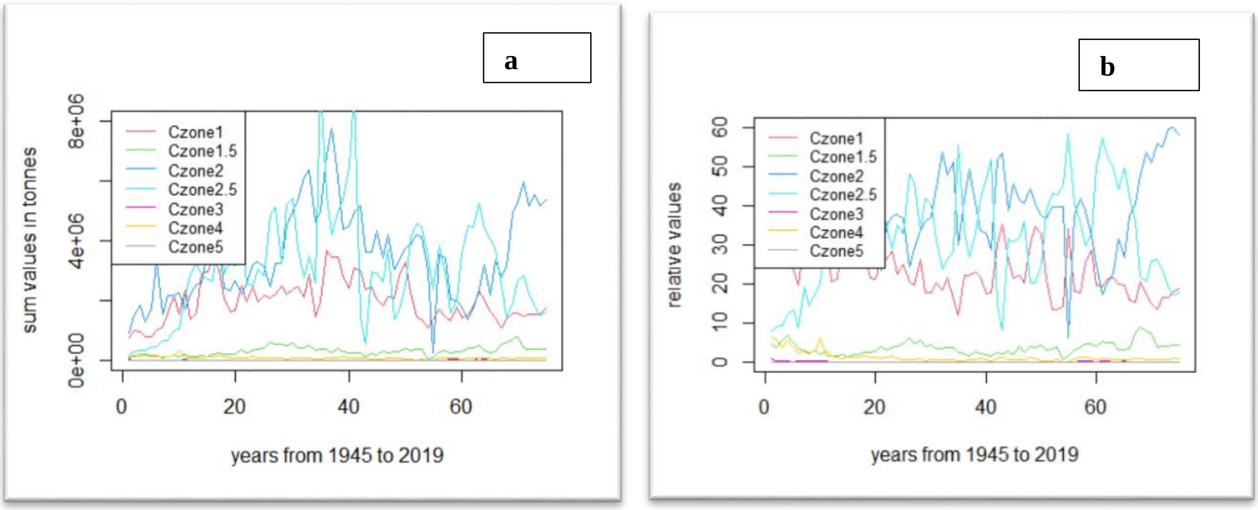


Figure 4. Abundance of species discriminated on basis of their thermal affinity. a. absolute values, b. relative values. Source: Author.

Community-weighted mean analysis illustrates the trend of each climatic zone in time (Figure 5). The climatic zone 1 (Figure 5.a), the colder, demonstrates a rapid decreasing in time. The zones 1.5 (Figure 5.b) and 2 (Figure 5.c) doesn’t show relevant changes in time. The zones 2.5 (Figure 5.d), 3 (Figure 5.e) and 4 (Figure 5.f) decrease in time. The most curious thing is the appearance in the last

---

[35] See Appendix A.

years of the climatic zone 5 (Figure 5.g), the warmer, not found previously in the Northern Adriatic Sea.

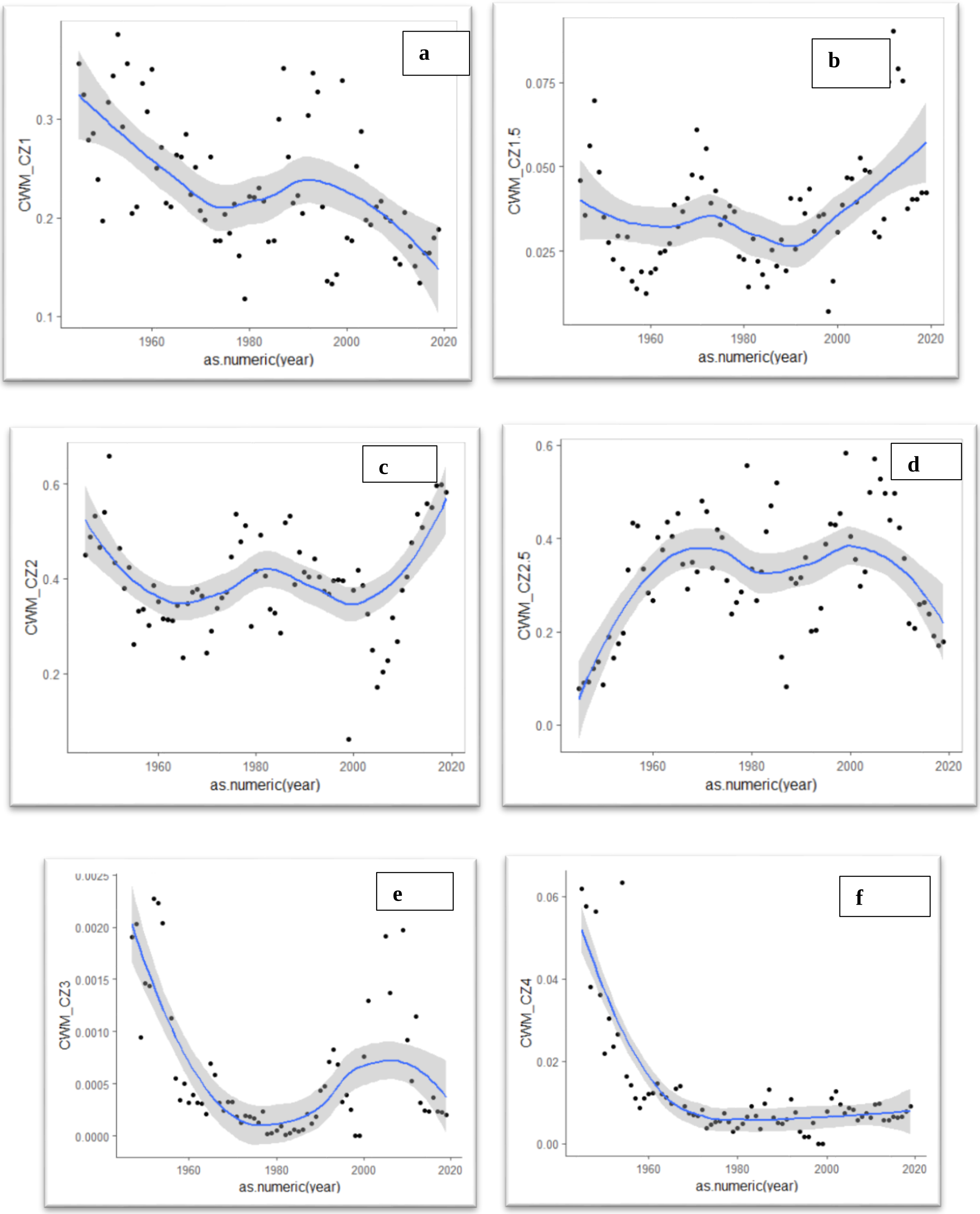


Figure 5. Community-weighted mean analysis illustrating the trend of each climatic zone in time. Source: Author.

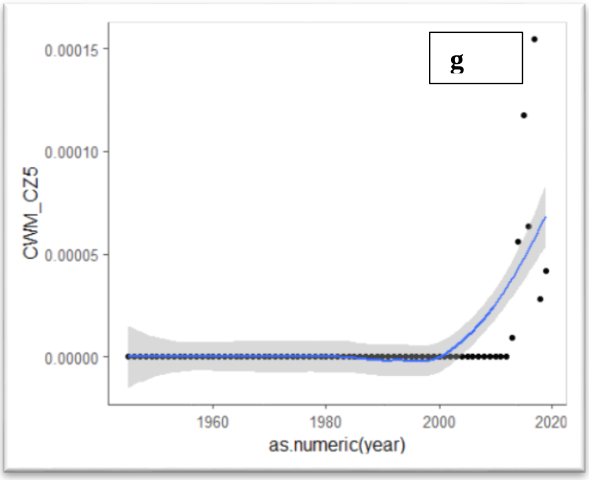


Figure 5. Community-weighted mean analysis illustrating the trend of each climatic zone in time, from 1945 to 2019, in Northern Adriatic Sea: climatic zone 1 (a), climatic zone 1.5 (b), climatic zone 2 (c), climatic zone 2.5 (d), climatic zone 3 (e), climatic zone 4 (f), climatic zone 5 (g). Source: Author.

The analysis of the trophic level highlights that the higher abundance of species belongs to the level 3, which is represented by secondary consumers, such as medium carnivorous fishes, squids, crabs, eels and octopus[36]. Trophic level 4 is the less abundant, with bigger carnivorous fishes, as sharks or bigger fishes (Figure 6). The analysis of abundance of absolute values doesn't show a clear trend in time, only the majority of species belonging to the trophic level 2.

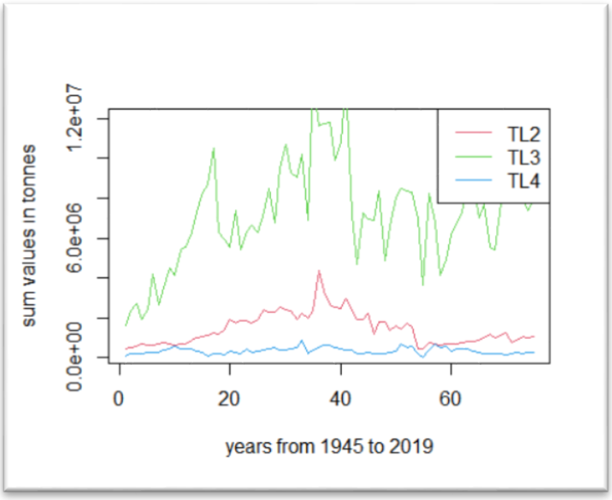


Figure 6. Performance of abundance of species classified per trophic level, trophic level 2, level 3 and level 4. Source: Author.

---

[36] See Appendix A.

Community-weighted mean analysis illustrates that, in the last years, species belonging to the trophic level 3 has continued to grow in quantity, instead of the species of the other trophic levels. In the 1980 there is a decrease of quantity of trophic level 3 and 4, opposite to the growth of the lower trophic level, maybe due to a change in temperature (Figure 7).

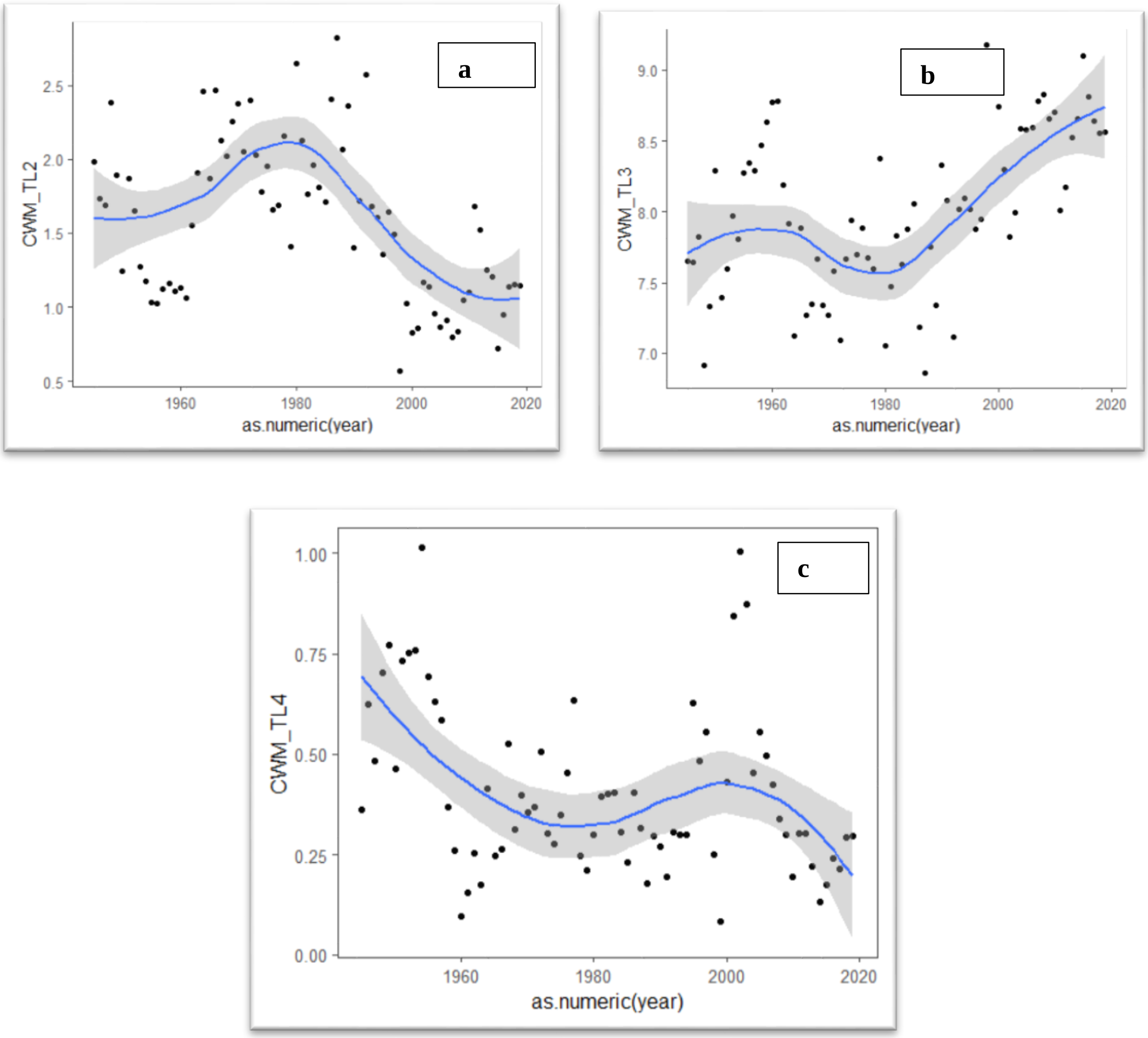


Figure 7. Community-weighted mean analysis illustrating the trend of trophic levels, from 1945 to 2019, in Northern Adriatic Sea: trophic level 2 (a), trophic level 3 (b), trophic level 4 (c). Source: Author.

The analysis of the diet, as functional trait of marine species in the Northern Adriatic Sea, demonstrates the major abundance of species with a planktivorous diet, followed by benthivorous diet, ichthyvorous diet and, in the end, omnivorous diet. Even though some species are both benthivorous and ichthyvorous, the values are summed for each state. Planktivorous diet is a characteristic of most of samples, as it can be seen in Figure 8[37].

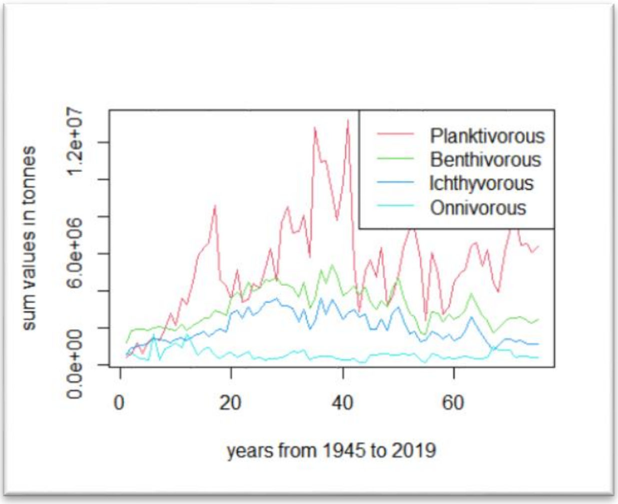
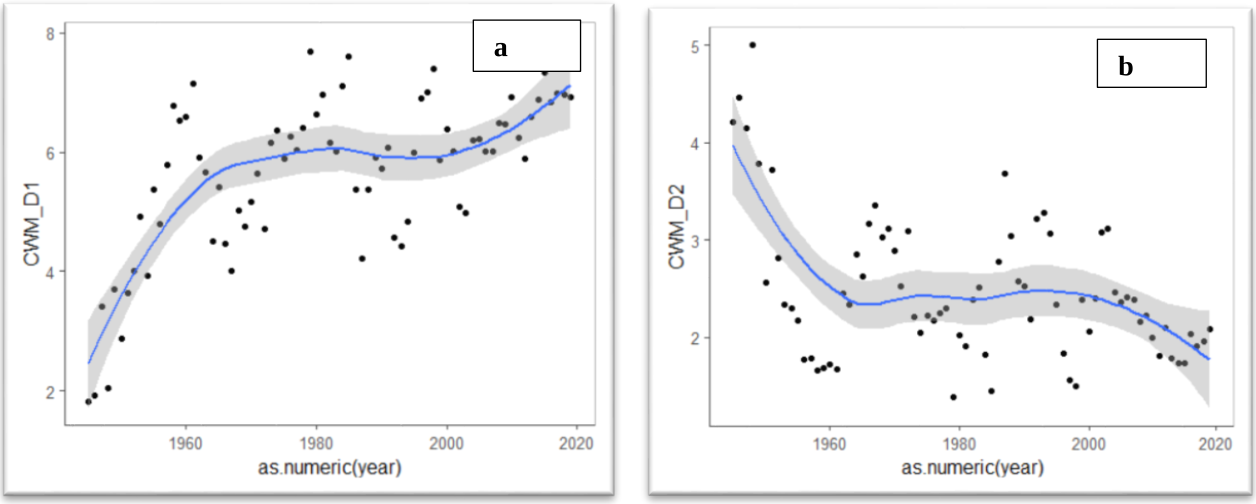


Figure 8. The behaviour of species abundance in the Northern Adriatic Sea between the year 1945 and the year 2019, in terms of diet. Source: Author.

According to the community-weighted mean analysis, planktivorous diet is the only variable that it is increasing in time, remaining the bost diffuse diet of the marine samples of Northern Adriatic Sea (Figure 9).



---

[37] See Appendix A.

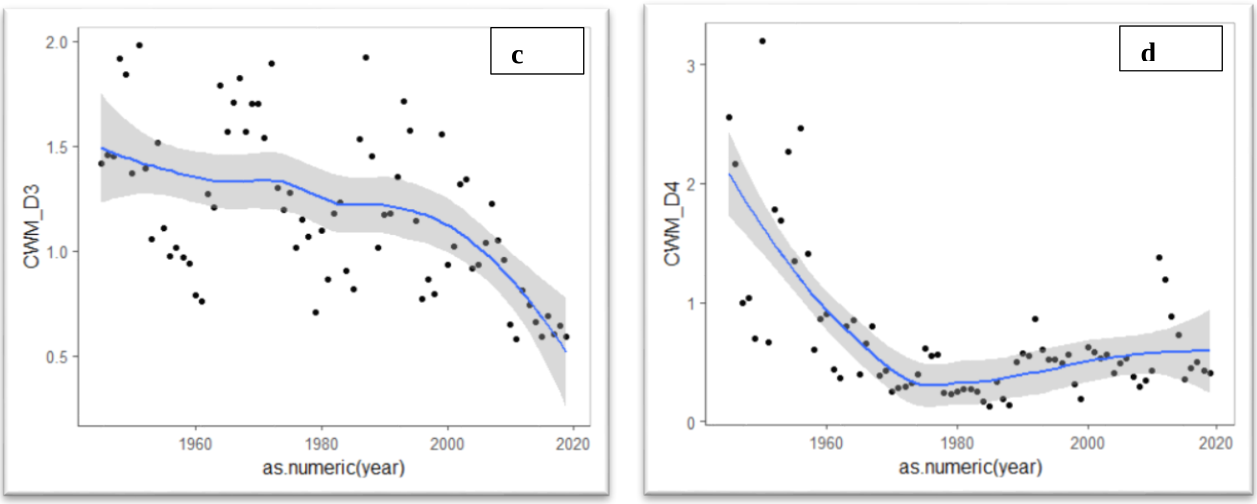


Figure 9. Community-weighted mean analysis illustrating the trend of diets related to sample abundance, from 1945 to 2019, in Northern Adriatic Sea: planktivorous diet (a), benthivorous (b), ichthyvorous (c), omnivorous (d). Source: Author.

Functional trait habitat analysis illustrates the presence of more pelagic species in the sample of Northern Adriatic Sea, differently from demersal species, without big differences between each other. Figure 10 doesn't show a defined trend in time[38].

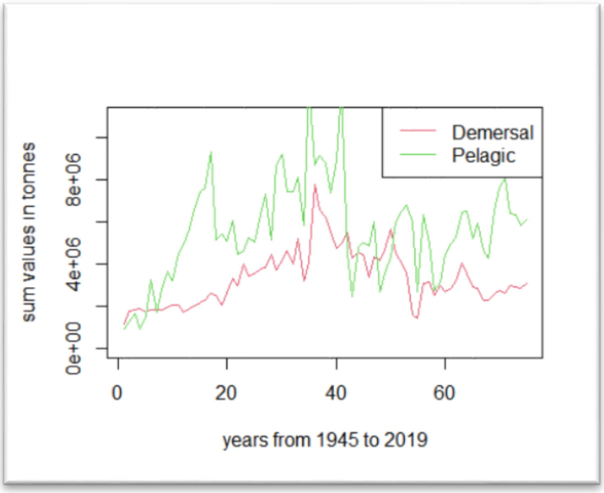


Figure 10. Performance of species classified for their habitat, demersal and pelagic, between 1945 and 2019. Source: Author.

Pelagic habitat shows a tendendcy in time opposite to the trend of demersal habitat. Around 1960 demersal species started an increase in contrast with the decrease of pelagic species, around 1990 their performances changed again, with a majority of pelagic species (Figure 11).

---

[38] See Appendix A.

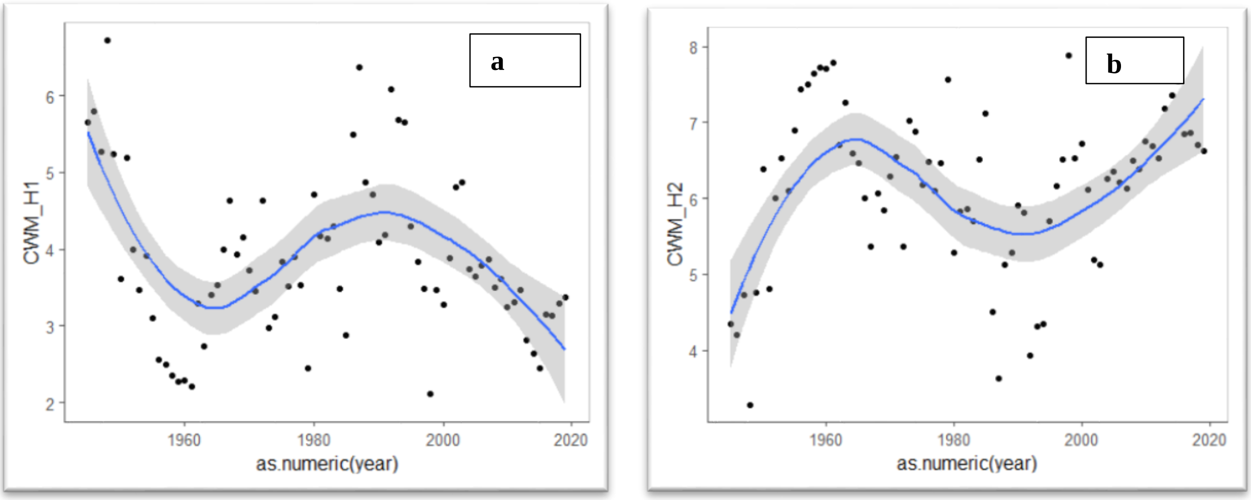


Figure 11. The community-weighted mean analysis demonstrates the performance of habitats related to sample abundance, from 1945 to 2019, in Northern Adriatic Sea; demersal species (a), pelagic species (b). Source: Author.

The analysis of data related to the functional trait offspring behaviour shows the superiority of species having pelagic eggs. Only a little portion of sample organisms are ovoviparous (Figure 12)[39].

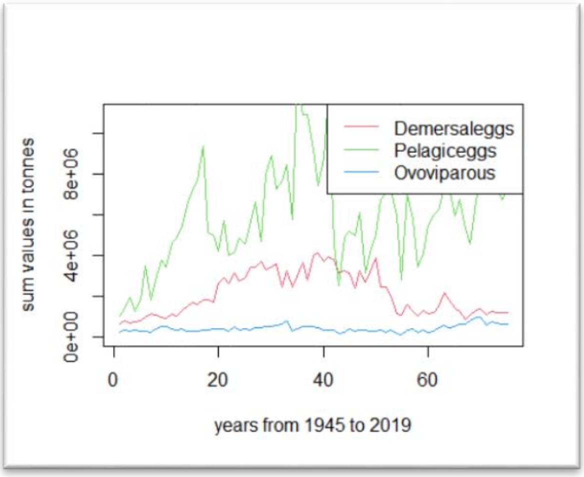


Figure 12. Performance of data between 1945 and 2019 in the Northern Adriatic Sea. Sample species were divided per offspring behaviour: demersal eggs, pelagic eggs, ovoviparous species. Source: Author.

---

[39] See Appendix A.

Between 1945 and 2019, species characterized by pelagic eggs stays almost the same, only from 1990 the abundance starts increasing. Species with demersal eggs are decreasing during the last years. Ovoviparous species shows a particular behaviour: around 1945 abundance starts decreasing, but around 1990 it grows up, turning back to initial values (Figure 13).

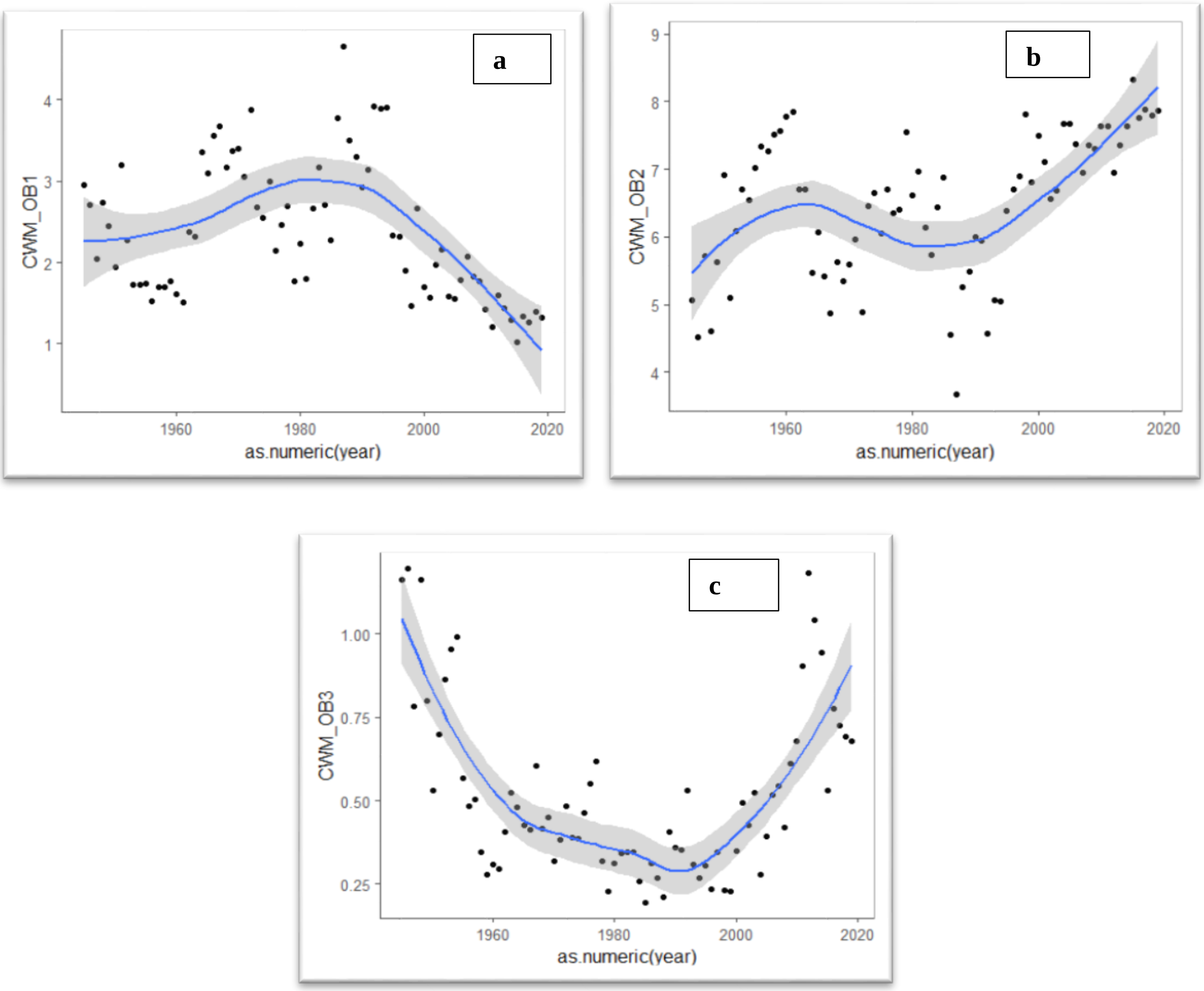


Figure 13. The community-weighted mean analysis demonstrates the performance of offspring behaviour related to sample abundance, from 1945 to 2019, in Northern Adriatic Sea; demersal eggs (a), pelagic eggs (b), ovoviparous (c). Source: Author.

Functional trait offspring size analysis demonstrates the superiority of small eggs species, with a strong degrowth only around 2000. Species with medium or large eggs are not very abundant (Figure 14)[40].

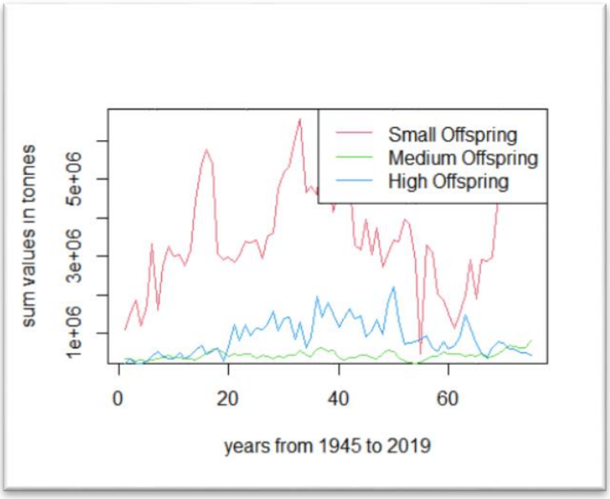
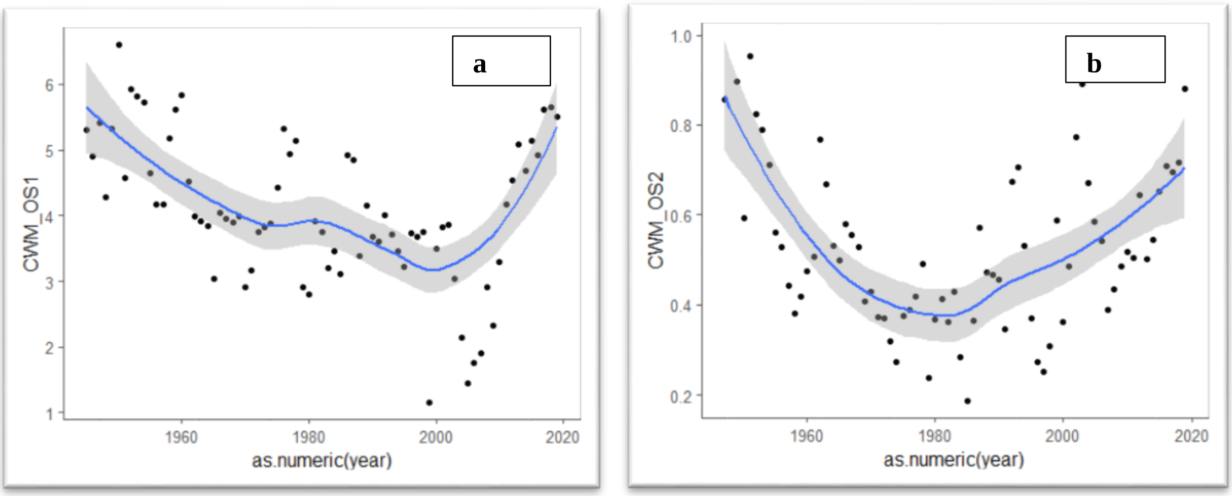


Figure 14. Performance of sample data divided per egg size between 1945 and 2019. Source: Author.

According to the community-weighted mean analysis, species with small eggs decreases in abundance around 2000, in contrast to species with big eggs that shows a peak. Species with medium eggs decreases particularly around 1980 (Figure 15). Small eggs keep the majority.



---

[40] See Appendix A.

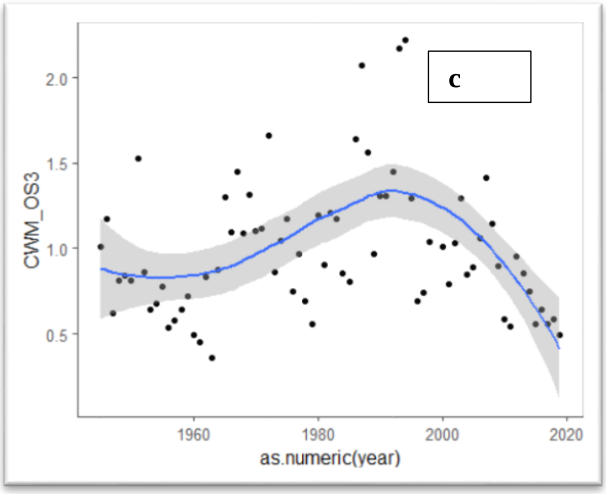


Figure 15. Community-weighted mean analysis showing the trend of functional trait offspring size, eggs size, in Northern Adriatic Sea from 1945 to 2019: small size (a). medium size (b), big size (c). Source: Author.

The analysis of the functional trait body size proves the abundance of species with small body size, like little fishes, crabs, shellfish (Figure 16). Big size species such as sharks are the less abundant in the Northern Adriatic Sea[41]. This can be caused by the shallowness of the Northern Adriatic basin.

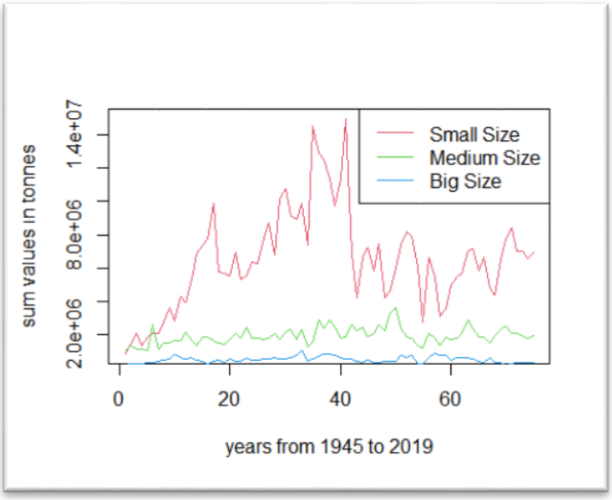


Figure 16. Performance of species of sample data divided per body size. Source: Author.

Small organisms increase in abundance from 1945, instead medium organisms and big organisms decreases in time, except for the year 2000 that shows a little change for each body size, as proved by the community-weighted mean analysis (Figure17).

---

[41] See Appendix A.

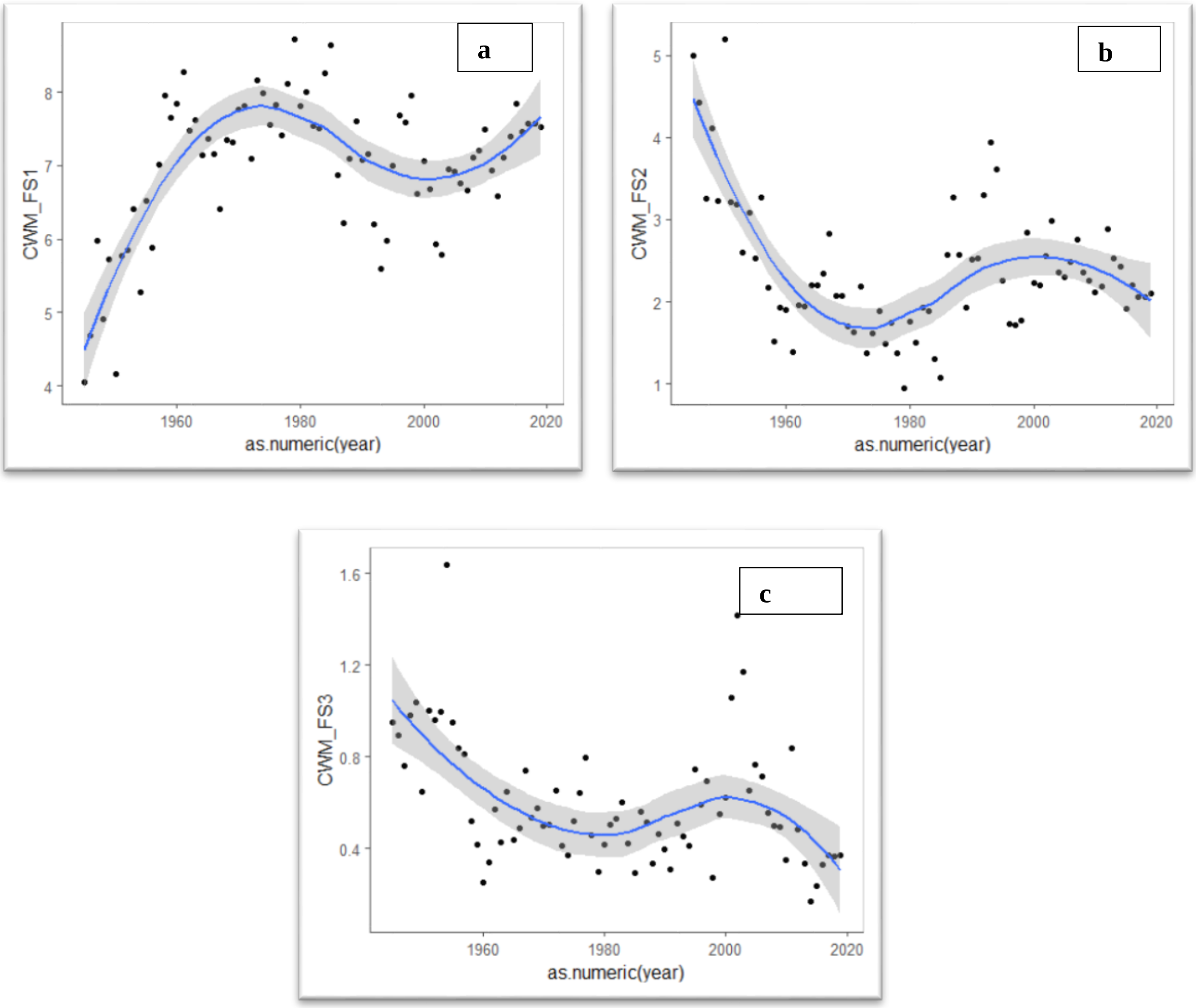


Figure 17. Community-weighted mean analysis of body size of sample data between 1945 and 2019: small size species (a), medium size species (b), big size species (c). Source: Author.

Functional trait body shape analysis draws attention to the elongated shape and the normal shape, the most common ones from the sample species. Body shape is considered for fishes, not for shellfish, octopus, or crabs (Figure 18[42]).

---

[42] See Appendix A.

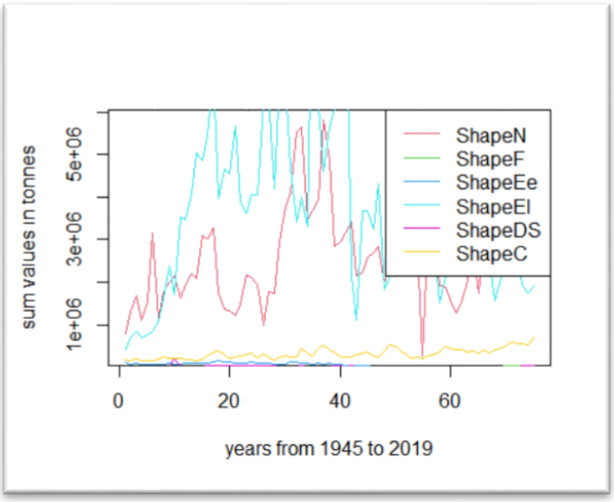
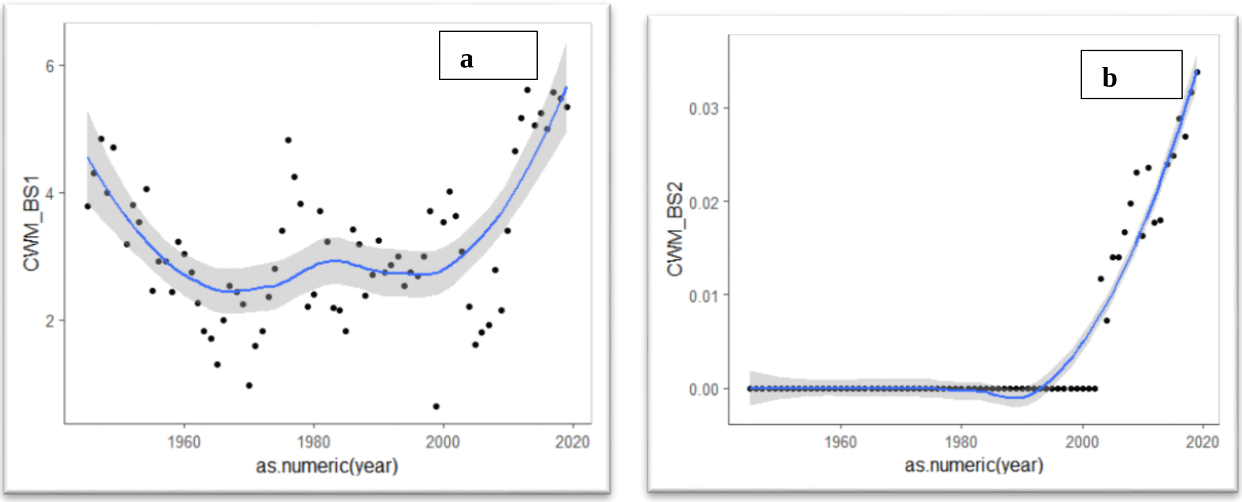


Figure 18. Performance of fishes divided into 6 categories, representing body shape between 1945 and 2019. Source: Author.

The CWM analysis shows an opposite trend between normal shape and elongated shape, the first one is increasing in the last years, the second one is decreasing. Flat shape species appears after the 1990, with an exponential growth. Eellike shape species are decreasing in time. Deep and short shape species abundance follows a sinusoidal behaviour. Compressiform shape species abundance trend is similar to the one of normal shape species, but in a lower scale (Figure 19).



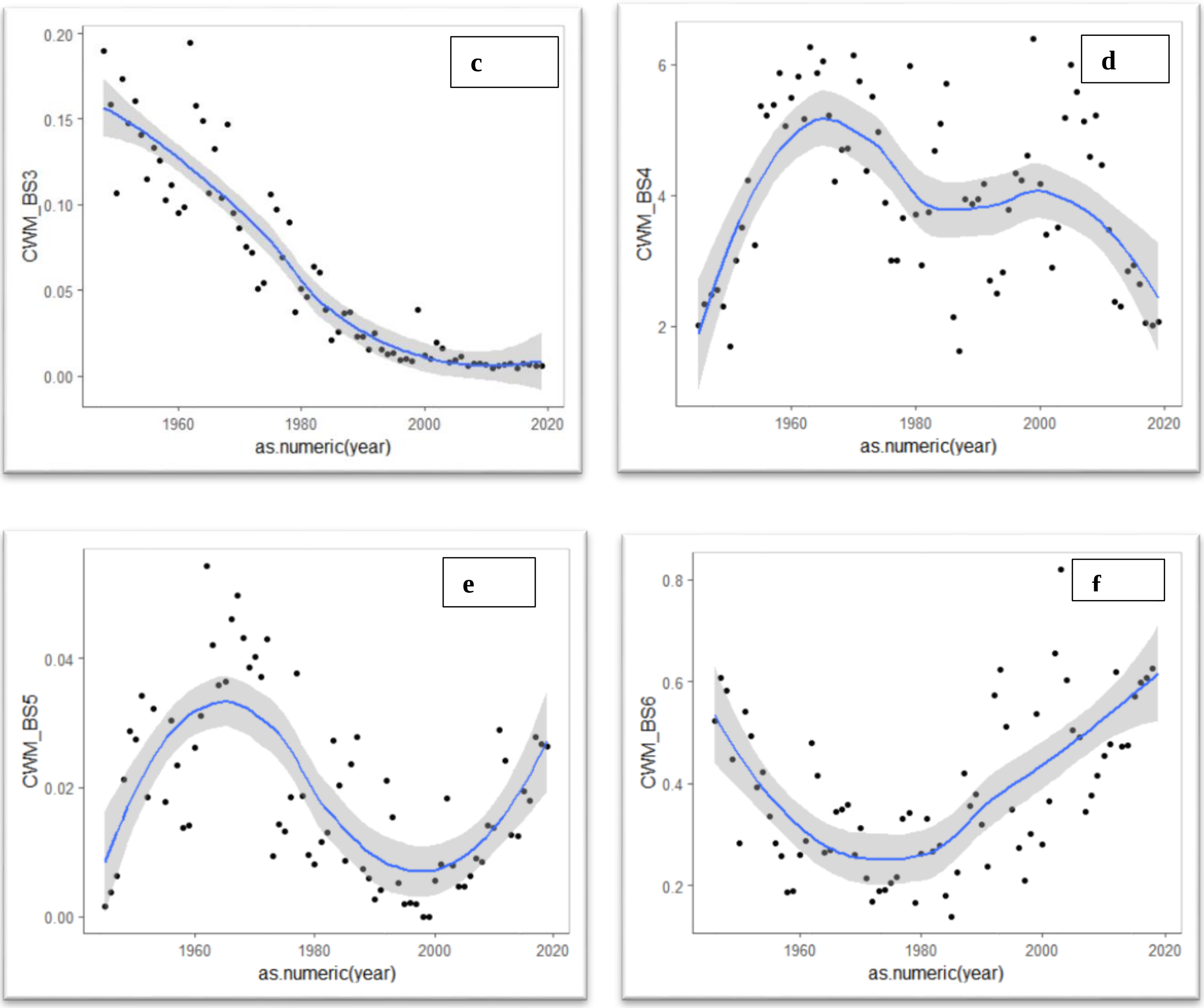


Figure 19. Community-weighted mean analysis of sample data, divided for body shape. Trend of species of the Northern Adriatic Sea between 1945 and 2019. Normal shape (a), flat shape (b), eellike (c), elongated (d), deep and short (e), compressiform (f). Source: Author.

The analysis of the functional trait temperature tolerance range shows a clearly high presence of species that tolerate large temperature range. The species that afford only small temperature range are the less abundant (Figure 20)[43].

---

[43] See Appendix A.

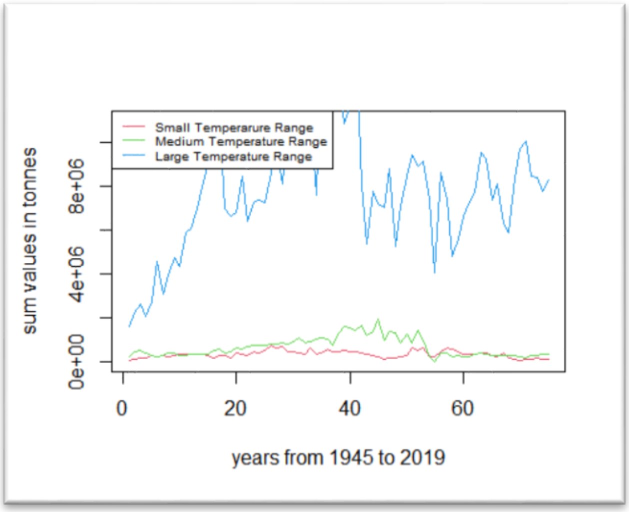
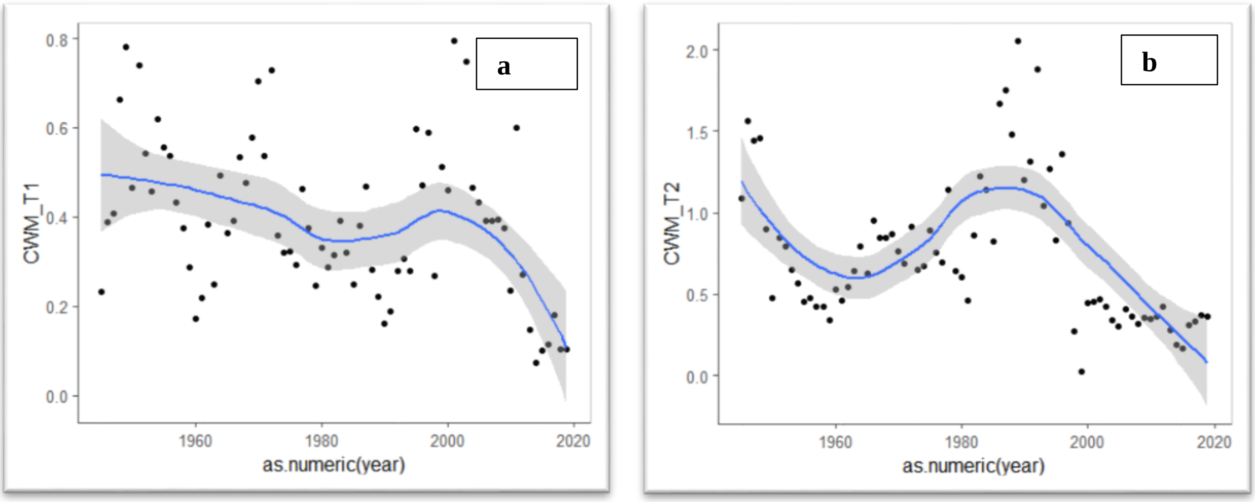


Figure 20. Performance of sample data regarding their temperature tolerance, between 1945 and 2019. Source: Author.

According to the CWM analysis, both species with a small temperature range and species with a medium temperature range decrease in abundance in time, with an exception around the year 2000 for the first one, around the year 1990 for the second one. Species with a large temperature range increase in abundance in time, except for the years around the 1980 and 1990 (Figure 21).



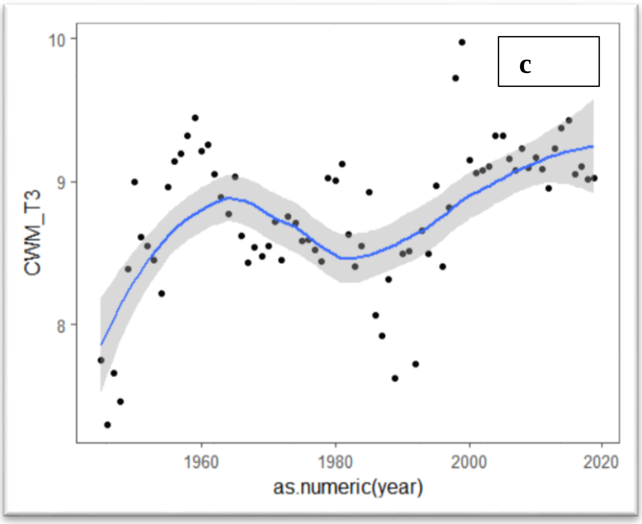


Figure 21. The community-weighted mean analysis of sample data divided per temperature tolerance, between 1945 and 2019. Species with small temperature (a), species with medium range (b), species with large temperature tolerance range (c). Source: Author.

Functional trait depth tolerance range analysis demonstrates that most species have medium depth range, between 150 and 1 000 m. A decent number of species belongs to small depth range, and only few species use to go deeper, with large depth range, due to the shallowest of the study area (Figure 22)[44].

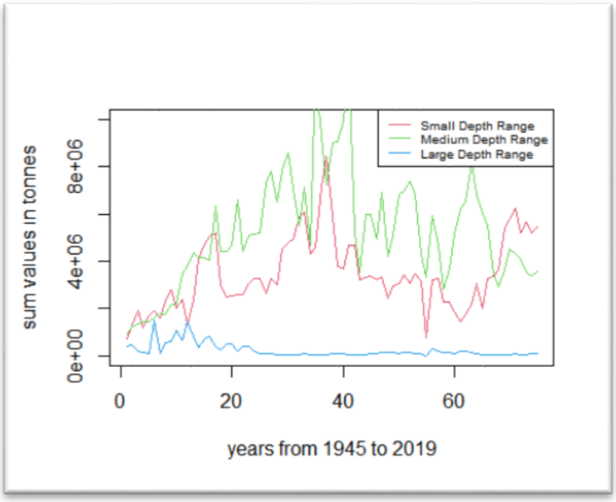


Figure 22. Performance of sample data divided per depth tolerance. Behaviour between 1945 and 2019 in the Northern Adriatic Sea. Source: Author

---

[44] See Appendix A.

Considering CWM analysis, both medium depth range species and big depth range species decrease in abundance in time. Only species belonging to a smaller range of depth, in the first meters of water, increase in time (Figure 23).

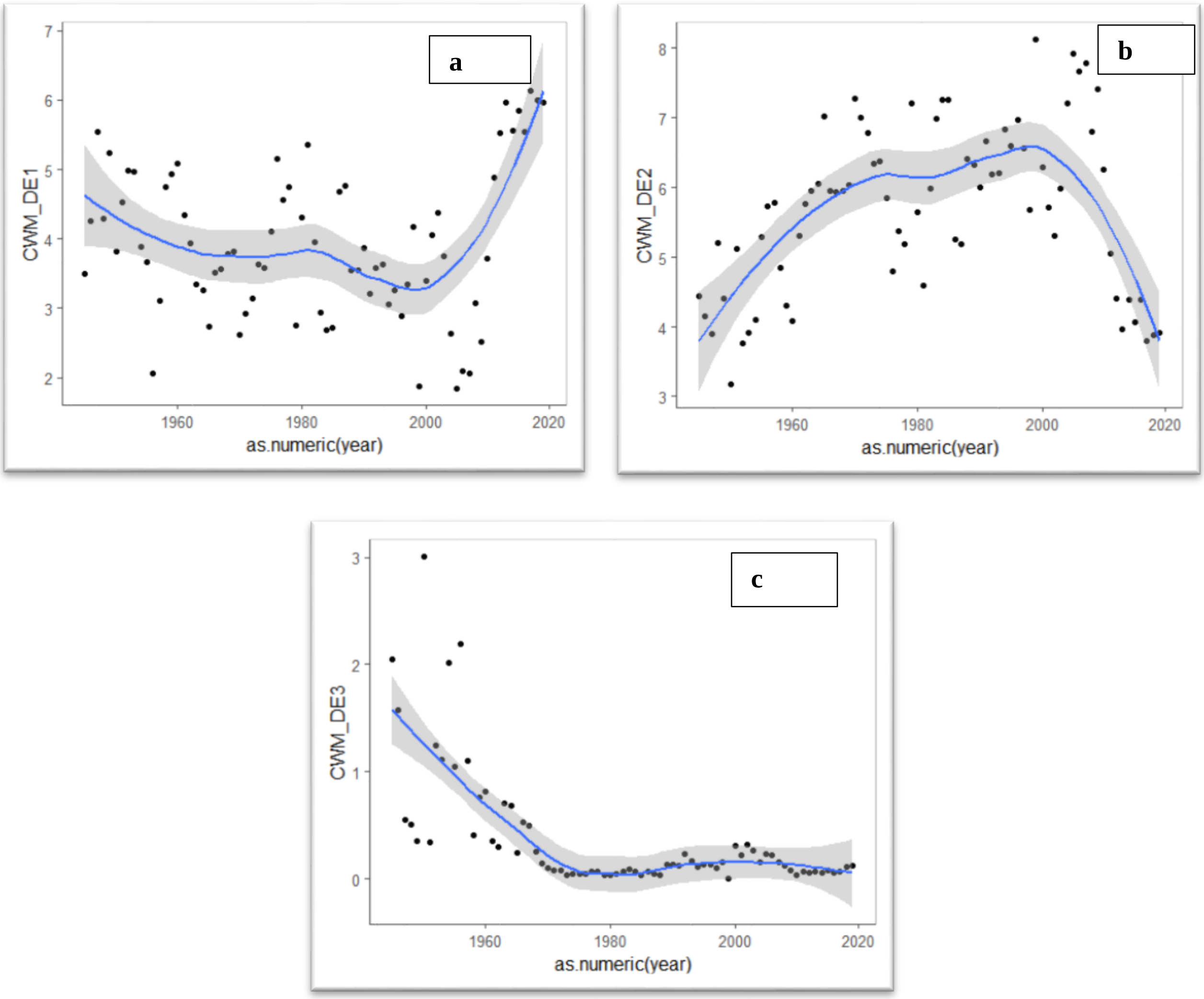


Figure 23. The community-weighted mean analysis of sample data organized per depth tolerance range. The trend of species abundance between 1945 and 2019 in the Northern Adriatic Sea. Species with small depth tolerance range (a), species with medium depth tolerance range (b), species with large depth tolerance range (c). Source: Author.

PCA analysis on the community matrix of functional traits shows the percentage of variance explained by each principal component, through the scree plot, the plot of eigenvalues, ordered from largest to smallest. The first component represented the 34.1%, the second one 21.6%, the third one 13%, the fourth one 7,7% and so on. The variances of the first 6 components are greater than 1, the eigenvalue. The first 4 principal components represented the 76.4% of the variance of sample data (Figure 24). Principal components show the amount of variation they cover. PC1 covers the most variation, followed by PC2, PC3 and PC4. They bring information of dataset.

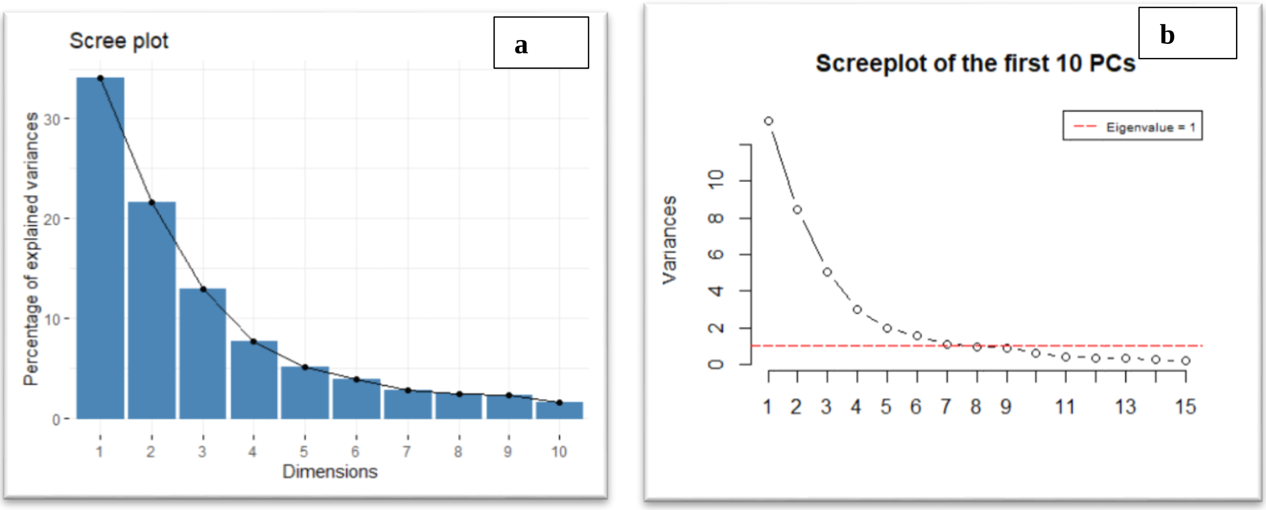


Figure 24. Scree plot of the dimension of the first 10 principal components considering the percentage of variance (a). The x axis is the number of principal components. The ideal curve is signed in black. If the first components represent in a good way the data, the ideal curve bends quickly. In the figure 24.b the y axis represents the variance; the red line corresponds to the value 1 of eigenvalue (b). source: Author.

PCA analysis represents the data in a x-y coordinate system. The directions with largest variances are the most principal. PCA reduces original variables into smaller number of new variables, the principal components. Variables are scaled with mean zero and standard deviation equal to one. The first principal components include the major amount of variation in the dataset. The correlation cycle shows the relationships between the variables (Figure 25). If they are grouped together, they are correlated. If the variables are on opposite sides of the plot origin, they are negatively correlated. The length of the arrows represents the distance between the variable and the origin. If it is long, the variable is well represented on the factor map. This is true also if the cos2 of the variable is high. It indicates the quality of representation. Cos2 is high if the variable is closed to the circle of correlation. Variables are grouped together with the same colour, using kmean clustering algorithm. It is an algorithm that assigns *i* attributes to the variable, transforming them into spatial vectors *i* dimensional. It divides variables in *k* groups according to the attributes.

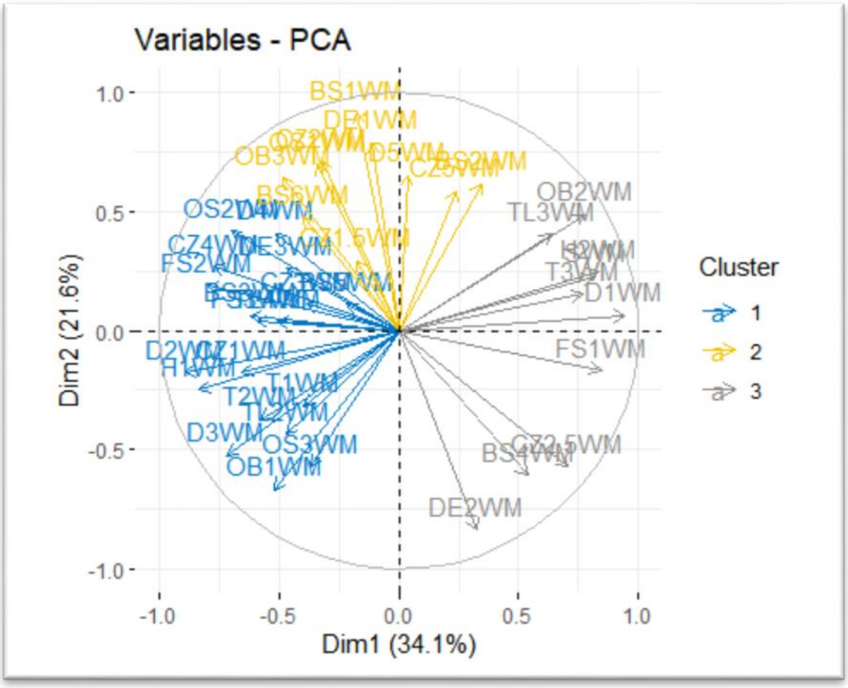


Figure 25. PCA analysis. The correlation circle representing the first 2 principal components. X axis is the first principal component. The y axis is the second principal component. Variables grouped together are positively correlated. The length of the arrow indicates the quality of representation. Source: Author.

The quality of representation is indicated with the cos2 (squared coordinates) and it is shown on all dimensions in the corrplot (Figure 26). The variables with a higher cos2, a bigger and darker circle, most determine the principal component.

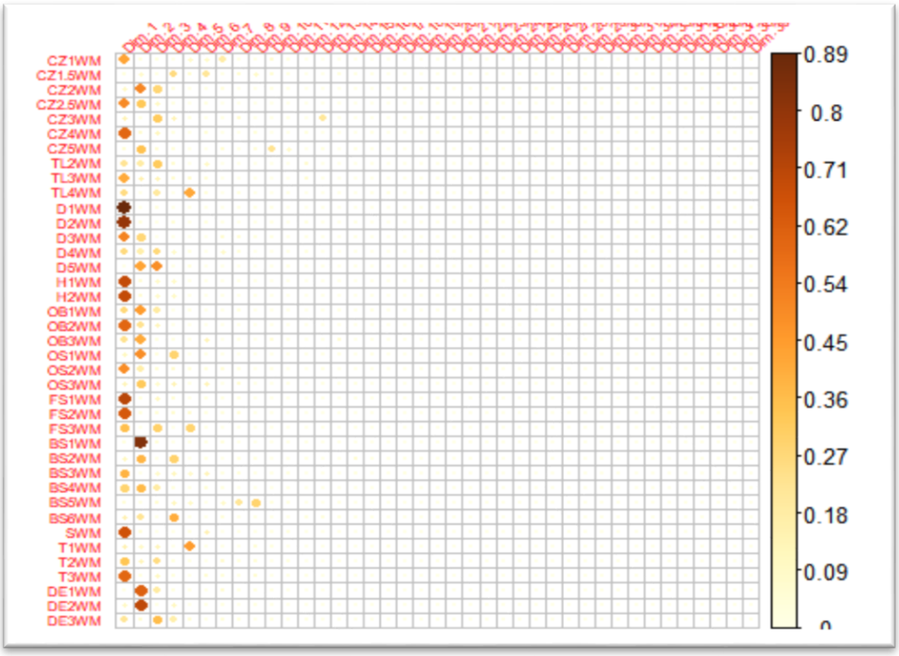


Figure 26. The corrplot of cos2 of variables. It indicates the quality of PCA representation. The x axis is the dimensions, the PCs, created in the PCA analysis and their number correspond to the number of variables. Y axis is the variables. Source: Author.

According to the corrplot, climatic zone 4, diet 1 (planktivorous), diet 2 (benthivorous), habitats, offspring behaviour 2 (pelagic eggs), fish size small and medium, salinity and large temperature range demonstrate high values of cos2 on the first component. Normal body shape and small and medium depth range have high cos2 values on the second component.

The Variables-PCA graph (Figure 27) indicates the variables with cos2 higher than or equal to 0.6. The graph shows offspring behaviour 2, trophic level 3, habitat 2, diet 1, fish size 1, temperature range 3, salinity, climatic zone 2.5 as relevant for the principal component 1 and as correlated between each other. In the opposite direction, uncorrelated with the others, there are diet 2, habitat 1, diet 3, offspring behaviour 1, fish size 2, climatic zone 4, offspring size 2. The principal component 2 in the graph is determined by body shape 1, offspring behaviour 3, offspring size 1, fish size 2, climatic zone 2, correlated with one another, uncorrelated with depth range.

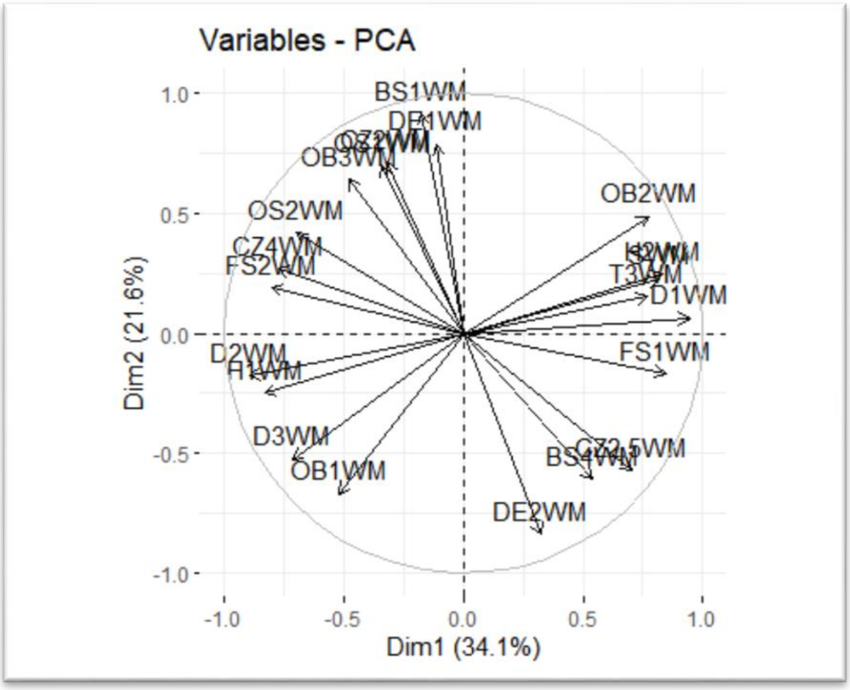


Figure 27. PCA analysis. The variables. PCA graph showing the correlation circle for only the variables with a cos2 equal or higher than 0.6. The characteristics of functional traits represented in the graph are the most contributing to the first 2 principal components and to the variance of 55.7% of dataset. Source: Author.

The top five active variables, with the highest cos2 are: offspring behaviour 2, pelagic eggs, diet 1, planktivorous, climatic zone 2.5, diet 2, benthivorous, body shape 1, normal. They have the higher cos2, so they are the best represented in the correlation circle. They are represented in the biplot. it is used only for the most important variables. If a variable is opposite to a year, that year has a low value because of that functional trait. If year and variable are on the same side, they are positively correlated[45].

The correlation test proves the levels of correlation between variable showed on the PCA graph.

The graphs of variable contributions explain clearly the contributions of variables to the principal components (Figure 28).

---

[45] See Appendix B.

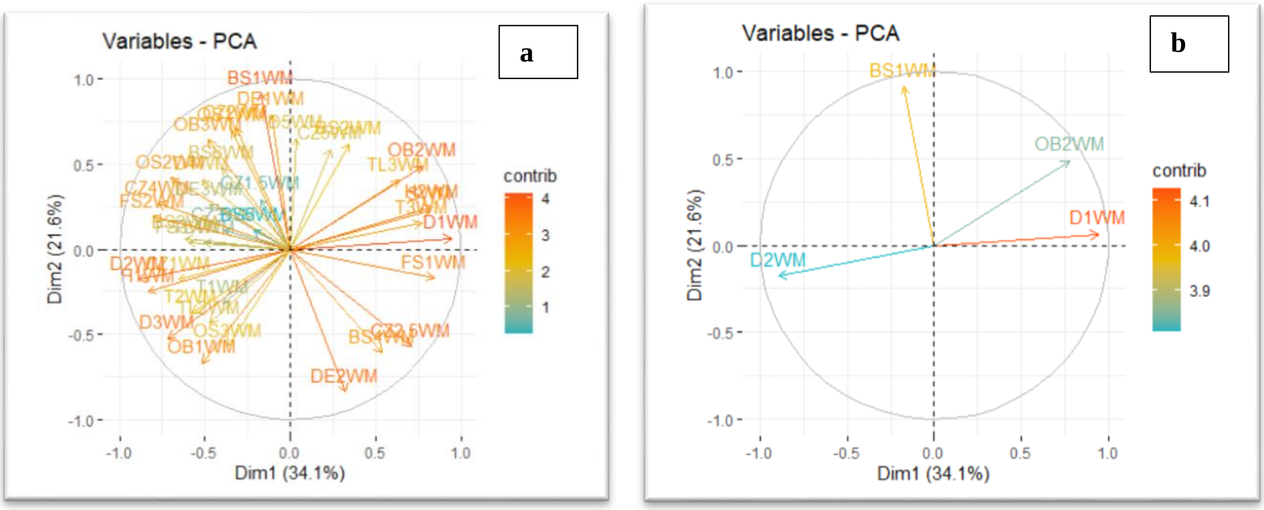


Figure 28. PCA analysis. The graph of variable contributions (a) to the first 2 principal components. The graph showing the first 4 variable that contributes to the principal components (b). They are the same of the previous analysis of cos2 of variables. Source: Author.

In order to not loose information, the plot of principal component 3 vs principal component 4 is performed (Figure 29). They represented 20.7% of data variation. Most significant variables for the PC3 and PC4 are depth range 3, diet 4, climatic zone 3, body shape 6, offspring size 1, trophic level 2, climatic zone 2, diet 5.

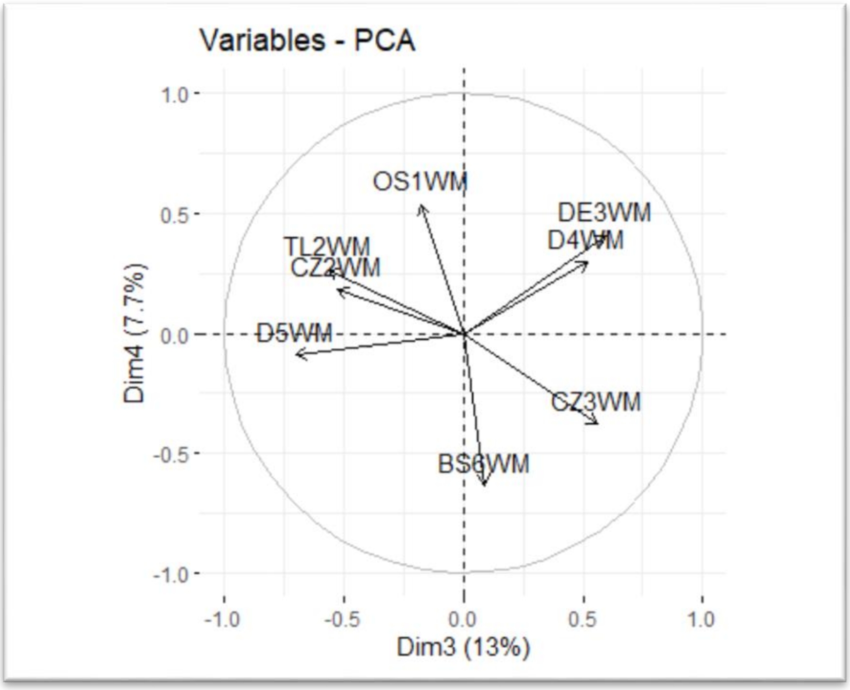


Figure 29. Graph of correlation circle reporting the most contributing variables, functional traits, to principal components 3 and 4, representing 20.7% of variance of data. Source: Author.

GIS analysis is performed. GIS is a system that analyses georeferential data. The distribution of sample species is represented geographically from 2016 to 2019, according to the abundance in tonnes of species organised per trophic level. They are presented in 10x10 km cells (Figure 30).

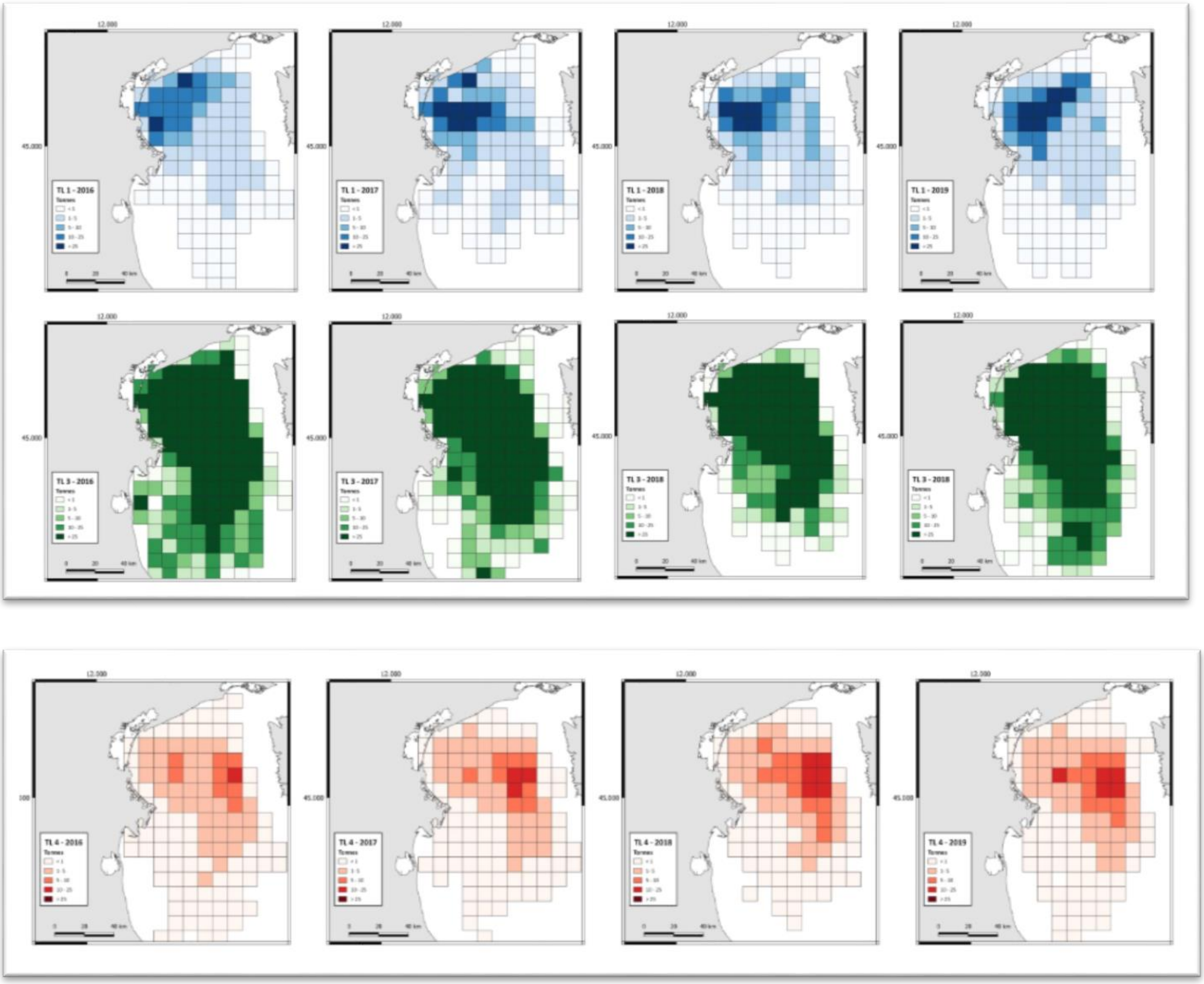


Figure 30. GIS representation of Northern Adriatic Sea. Sample species are visualized in cells of 10x10 km. The colour range represents the abundance in tonnes. The species are divided per trophic level: trophic level 2 in blue, trophic level 3 in green, trophic level 4 in red. The analysis goes from 2016 to 2019. Source: GIS, E. Russo.

The GIS analysis shows the majority of species with trophic level 3, but also the small change of spatial distribution northward of all trophic levels.

This study considers climate change as one of the main drivers of the changes in the ecosystem functioning and structure. Global warming as disturbance event is proved in the following analysis. The temperature between 1946 and 2015 are represented in the Adriatic Sea (Figure 31). The plot of near surface temperature from 1946 to 2015, in Northern Adriatic Sea, that elaborates data taken by sensors of the Gulf of Trieste, shows an increase in the last years[46].

The correlation test shows the variables, the functional traits, correlated with the temperature values, considering the same time interval (Figure 32). Climatic zones 1, 2.5 and 4 shows a negative correlation with near sea surface temperature, while climatic zones 1.5, 2, 3 and 5 are a bit correlated positively. Trophic level 3 has a positive correlation, such as diet 5, offspring size 3, body shape 1 and 2, fish size 2, body shape 6 and temperature range 3. The variables most positively correlated with the increase of temperature are: climatic zone 1.5, trophic level 3, diet 5, body shape 2. These variables are all increase in time in value, such as the temperature.

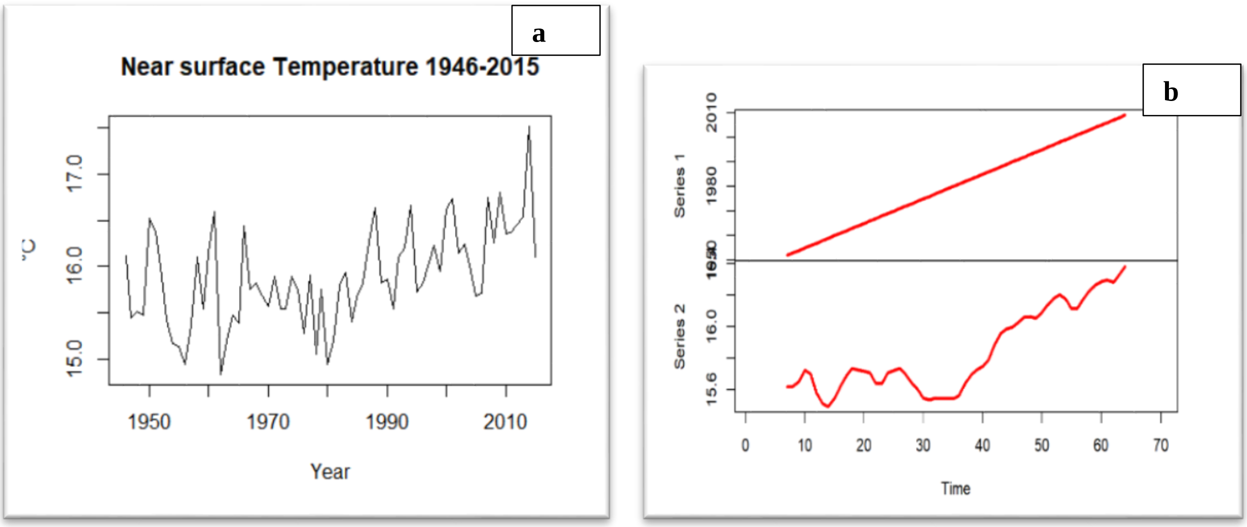


Figure 31. Timeseries plot of near surface temperature of Northern Adriatic Sea between 1946 and 2015 (a). The x axis represents the years, the y axis expresses the temperature in degree Celsius. The representation of the trend in time of data set (b). The isolation of the trend in the analysis shows a direct increase of temperature in the Adriatic basin in the last years. Source: Author.

---

[46] Raicich Fabio, Colucci Renato R. (2021). Trieste 1899-2015 near-surface sea temperature. SEANOE. https://doi.org/10.17882/58728. Raicich Fabio, Colucci Renato R. (2019). A near-surface sea temperature time series from Trieste, northern Adriatic Sea (1899-2015). *Earth System Science Data*, 11, 761-768. https://doi.org/10.5194/essd-11-761-2019.

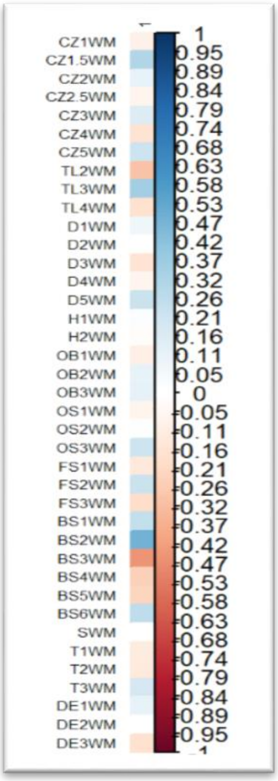


Figure 32. Correlation test between dataset organized in a community matrix and timeseries of temperature in the Northern Adriatic Sea in the same period, 1946-2015. Source: Author.

4. Discussion

The use of functional traits of species, instead of species richness, for the study of biodiversity, is increasing in the last years. Their role in the exploration of ecosystem functioning is getting more and more recognized.

Time series analysis of each state of each trait found validation in the community-weighted mean analysis. The study underlined the succession of the species abundancy, according to the type of characteristic of the trait. Each functional trait showed trends in time, with positive and negative effects among the characteristics.

The climatic zones were peculiar to the acknowledgement of a changing climate and a warmer Northern Adriatic Sea. Marine species belonging to the colder zone are decreasing in abundancy, even though they represent the third major category of the functional trait. Species from temperate zone are not changing definitely in time, instead of the species belonging to the climatic zone 5, the warmer, that appeared in the year 2000 in the Northern Adriatic, as white-spotted octopus (*Callistoctopus Macropus*).

Species with different trophic levels changed in time in opposite ways: trophic level 3 maintained its superiority and increased clearly from the year 1980, the other trophic levels, present in the study area, decreased in time.

Species with a planktivorous diet are growing in abundancy, possibly due to higher temperatures. The shift from benthic-based food to pelagic-based food shows a “pelagification” of the ecosystem, such as an increase in small pelagic fishes, that can be connected to the higher abundancy of small size fishes found in the analysis. Consequently, also the trait demersal eggs is decreasing, instead of the trait pelagic eggs and the trait small size eggs. Also, the depth range is changing in time, with more species living in the first 150 meters of depth.

Additional connections to global warming can be found looking at the functional trait temperature tolerance range. Species with small or medium temperature range are decreasing in abundancy, while species that can tolerate large variance of temperatures are always more abundant. With different global environmental changes, the organisms able in the adaption have more possibility to survive and flourish.

PCA analysis showed the correlation among functional traits and the variance of data. Summarizing the data in a smaller set of data, the PCA demonstrated the trends and cluster of variables. The analysis visualized data maximizing variance of projection coordinates. The first 4 principal components best approximated data in the least squares sense. The first principal component represented the maximum variance direction in the data. The analysis identified the variables that were more responsible for patterns seen among observation. For the first 2 principal component, the most influencing variables were normal body shape, pelagic eggs, planktivorous diet, climatic zone 2.5 and benthivorous diet. For principal component 3 and 4, the most important variables were large depth tolerance range, omnivorous diet, climatic zone 3, compressiform body shape, detritivorous diet, climatic zone 2 and trophic level 2. The correlation circle and the correlation test presented the relationship among variables, functional traits. When two variables are positively correlated, the numerical value of one variable changes similarly to the other.

The analysis of temperature data in the Northern Adriatic Sea demonstrated the warming that the Adriatic Sea is experiencing in the last years, with a defined trend. The faster increase in temperature in the study area can be classified as a strong disturbance event, that alters ecosystem functioning and structure.

The timeseries correlated to the functional traits is part of a Cnr-Ismar study, which declares that between the 1946 and the 2015 the near sea surface temperature of Northern Adriatic Sea is increased of 1.3°C per century[47]. Other studies confirmed the Mediterranean basin as a hot spot for climate change. From 1982 to 2016 total sea surface temperature increased in the range 0.32-2.0 °C across Mediterranean basin, during these 35 years, with a mean value of 1.27°C, statistically significant at 99% confidence level[48].

Adriatic Sea is affected by other environmental issues, such as negative trends of precipitation and reduced inflow of fresh water because off decreasing inflow of Po' river. The increase of sea surface temperature has influences on global energy transfer, precipitation, atmospheric processes, hydrological cycle and so on. It can bring to changes in marine currents, in the physical parameters of water, such as primary production, pH, salinity. These variations may go over the threshold of ecosystem tolerance and degrade marine ecosystems. A study on regional risk assessment analysed the potential effects of climate change on water quality of Northern Adriatic Sea. PH is expected to decrease, while the extreme values of dissolved oxygen will increase in winter. The concentration of phytoplankton will generally increase. Dissolved inorganic nitrogen and reactive phosphorous will increase. The results of the study showed an increment of nutrients in autumn, that can cause transfer of water mass from boundary level. These consequences are expected to degrade water quality, causing hazards to the coastal area[49].

---

[47] F. Raicich,m R. R. Colucci, 2019, "A near-surface sea temperature time series from Trieste, north Adriatic Sea (1899-2015)". Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2019-15.

[48] Pastor, F., Valiente, J.A. & Palau, J.L. "Sea Surface Temperature in the Mediterranean: Trends and Spatial Patterns (1982–2016)". *Pure Appl. Geophys.* 4029 (2018). https://doi.org/10.1007/s00024-017-1739-z.

[49] Rizzi, J., S. Torresan, A. Critto, A. Zabeo, D. Brigolin, S. Carniel, R. Pastres, and A. Marcomini. "Climate Change Impacts on Marine Water Quality: The Case Study of the Northern Adriatic Sea." Marine Pollution Bulletin 102, no. 2 (2016): 271–82. doi:10.1016/J.MARPOLBUL.2015.06.037.

Temperature effects the growth, reproduction, behaviour, and physiology of organisms like fishes. Global warming affects fitness of marine biota in the Mediterranean Sea, with changes in abundance, survival, fertility, and species migration. As showed in this study, the abundance of smaller-bodied species is expected to increase with a shift in the vertical distribution. These changes will cause relevant modifications in the food web, as predator-prey interactions are dependent on body size. Smaller body size leads to smaller size at first maturity, causing higher mortal rates.

In the Mediterranean Sea two phenomena due to global warming are taking place. The first one refers to the northward extension and the increase of native thermophilic species, the meridionalization. The second one is the introduction of non-indigenous species, tropicalization. Thermophilic species enlarged their distribution range, moving northward. The non-indigenous species present in the Mediterranean Sea are thermophilic and come from tropical indo-pacific region. Usually, the February surface isotherms of 14 and 15° C divided warmer biota from colder one, the first one was a limit for native warm-water species, the latter for tropical species. From 1980 many species started cross these divides in the Mediterranean Sea, reaching in particular the Adriatic Sea, hotspot of endemism[50]. In 2012 more than 900 alien species were recorded in the Mediterranean Sea. Tropicalization initially leads to an increase in species richness, but in time aquatic invasions and warming are expected to cause decline and collapse of several marine populations. This will cause significant loss in the biodiversity and cascade effect on food web.

An example is given by the endemic *Gobius geniporus*. A study showed the projections of future thermals habitat versus the observed distribution area of the fish in 1980. By 2041-2060 the species is expected to strongly contract, together with other 44 species[51].

Ocean acidification is considered another relevant issue for marine ecosystems. Calcifying organisms can be affected, with reduced growth of calcareous skeletons. Changing water chemistry affect species sensitive to acidity and the organisms that feed on these. Coralline algae that are habitat-forming species can decrease in biodiversity. Environmental changes can decrease the density of seagrass meadows, an essential habitat for some species and for coastal protection from erosion.

---

[50] Bianchi, C., Caroli, F., Guidetti, P., & Morri, C. (2018). Seawater warming at the northern reach for southern species: Gulf of Genoa, NW Mediterranean. *Journal of the Marine Biological Association of the United Kingdom, 98*(1), 1-12. doi:10.1017/S0025315417000819.

[51] J.-P. Moatti, S. Thièbault, 2016, “The Mediterranean region under climate change”, IRD E’ditoìions, DOI:10.4000/book.irdeditions.22908.

5. Comparison between the Adriatic Sea and the Barents Sea

In this part, the study compares two different study areas, the Adriatic Sea and the Barents Sea, analysing data on climate change effects on functional traits for the same time period.

Before performing the data analysis, a complete description of both ecosystems is given, to better understand initial ecological conditions.

5.1 Adriatic Sea

Mediterranean Sea is a semi-closed sea, connected to Atlantic Ocean through the Strait of Gibraltar, to Red Sea through man-made Suez Canal, to Black Sea through Bosphorus Strait. Water enters from Atlantic Ocean and circulates in the basins, with processes of nutrient cycle, depletion of nutrients and evaporation. Water then returns to Atlantic salty and nutrient poor. The basin is divided into western basin and eastern one, connected by Strait of Sicily. The inflow of warm water from Atlantic circulates in a counter-clockwise direction, cyclonic, and exits the Mediterranean after 80-100 years. The nutrients move eastward, decreasing west-to-east in productivity.

The Mediterranean Sea is an area of 2 536 000 km^2, horizontally long 3860 km. Main rivers that enters the sea are Nile, Po, Rhone and Ebro. The western basin is characterized by a mean depth of 1 612 m and a maximum depth of 3 733 m. The eastern basin presents a maximum depth of 5 150 m. The basin has a total volume of 3 750 000 km^3.

The mean surface temperature is 21°C in eastern basin and 15.5°C in western basin. The temperature at 200 m of depth goes from 15.5°C to 12.7°C, below it is uniform, around 13°C. The salinity increases eastwards in surface waters[52].

The Adriatic Sea is a shallow basin between Italy and the Balkan peninsulas. It is long 800 km and wide 150-200 km. The northern part has mean depth of 35 m. The central section is wide 50 km and has an average depth of 130-150 km, considering the Meso-Adriatic Trench, a depression until 207 m of depth. This area is relevant for cetaceans, sea turtles and birds, for its high productivity. The southern Adriatic is deep 1 218 – 1 225 m and has a large bathyal basin.

Around river mouths, muddy-sandy bottoms present a benthic fauna dominated by bivalves and polychaetes, species of unstable sea bottoms with high sedimentation, anoxic condition and organic enrichment, especially around Po River Delta. In open sea, in the Northern Adriatic Sea, benthic assemblages present deposit-feeding endobenthic bivalves, polychaetes and gastropods. Gastropod

---

[52] Würtz, M. (2010). Mediterranean Pelagic Habitat: Oceano graphic and Biological Processes, An Overview. Gland, Switzerland and Malaga, Spain: IUCN.

shell, after the death of the organism, is used as substratum and favourites crab assemblage. The eastern coast are rocky shores with calcareous substrates for mussels.

Northern Adriatic Sea is an important habitat for sea turtles, such as the *Caretta caretta,* even though the hazard of fishing activities. The Adriatic Sea presents cetaceans, such as dolphins, *Delphinus delphis*, whales, monk seals, *Monachus monachus*. Also, marine mammals are in dangerous because of human impact and shift of ecosystem functioning.

The Adriatic Sea has large occurrence of demersal and small pelagic species. The main small pelagic organisms are sardine, *Sardina Pilchardus*, anchovy, *Engraulis encrasicolus*, mackerel, *Scomber spp.*. The Northern Adriatic Sea is characterized by cod, *Trisopterus minutus*, red muller, *M. barbatus*, flatfishes, *Solea solea*, gobies and pandoras.

The invertebrate fauna is composed by mollusks and crustaceans. The fauna presents bivalves, such as scallops, *Chlamys opercularis*, cephalopods, such as cuttlefish, *Sepia officinalis*, octopuses, *Octopus vulgaris*, squids, *Alloteuthis media*, Norway lobster, *Nephrops novergicus*, shrimps, *Solenocera membranacea*. In the Adriatic there are sharks and rays.

In the Northern Adriatic Sea, eastern areas are oligotrophic, western areas are mesotrophic, and eutrophic near Po River Delta. Nutrient enriched northern section abundance and distribution of direct and indirect consumers. is dominated by diatoms as microplankton, especially in winter with high river discharge. Planktonic availability influences abundance and distribution of consumers. Around Po River Delta there are zooplankton proliferations, due to high presence of phytoplankton and nutrients[53].

---

[53] United Nation environment programme Mediterranean action plan, 2015, “Adriatic Sea: Ecology”. http://rac-spa.org/nfp12/documents/information/wg.408_inf14_eng.pdf.

5.2 Barents Sea

Arctic marine ecosystem is composed by habitats that host 5 000 animal species, including birds and mammals, 2 000 species of algae and tens of thousands of microbes. Arctic Ocean influences Earth climate and the North Atlantic. Sea ice cover started 3-5 million years ago, but season with ice free periods began 10 000 years ago. Ecosystem structure and functioning are connected to the influence of Pacific Ocean and Atlantic Ocean with Arctic Ocean. Freshwater availability and stratification are other variables that together with the presence of sea ice most determine Arctic marine ecosystem. The biodiversity is influenced by seasonal extremes, temperature, salinity, irradiance, and by the occurrence of large continental shelves. They host most of biological production in Arctic Ocean, thanks to the permanent presence of ice cover on the central basins. The dynamic of the environments is associated with the wide range of physical characteristics, due to annual formation and melt of sea ice, that alters biogeochemical cycling of elements.

Biodiversity is influenced by the circulation of Atlantic and Pacific water masses. In Norwegian Sea, Greenland Sea and Barents Sea, warm Atlantic waters host shrimps, *P. boreali*, herring, *C. harengus*, and Atlantic cod, *Gadus morhua*. These waters enter plankton species and planktonic larvae of benthic species. Pacific benthic species occur in the Chukchi Sea, in the Beaufort Sea and in the East Siberian Sea, where Pacific waters pass through Bering Strait. Pacific zooplankton can be present but not reproduce successfully, instead of Atlantic zooplankton. Pacific benthos are part of Arctic biodiversity near pacific gateway.

Arctic Ocean is characterized by a low salinity surface layer, the polar mixed layer, given by water stratification due to the occurrence of Pacific and Atlantic waters, and inflow of freshwater from melting of ice and from rivers. The stratification determines the availability of light and nutrients for primary producers. Where nutrients are continuously replaced by water mixing and upwelling, diatoms flourish. Where nutrients availability is not guaranteed, due to strong stratification, small cells with higher surface/volume ratios grow fast. There are different protists able to live in extreme conditions. Ice algae are fundamental in the food web, in particular for a key zooplankton species. Sea ice gives habitats for seals and polar bears. Ringed seals are crucial prey for polar bears and humans.

The low Arctic temperature determine low metabolic rates for invertebrates, slower growth, higher longevity. The thermal tolerance range of a species is an important variable that decides the capacity to respond and adapt to environmental changes. Sessile species cannot afford rapid changes, in contrast with mobile organisms that can change their geographic distribution.

Temperatures are stable in the central Arctic basin and in deep waters, but they change seasonally and spatially on the shelves[54].

Barents Sea is one of the Arctic Sea, surrounded by the Norwegian Sea, the Arctic Ocean, the Kara Sea, on the east, and Norwegian and Russian coasts, on the south (Figure 33). The Barents Sea is a basin of 1.6 million km^2, 230 m deep in average, 500 m deep at maximum. It has both troughs and shallow bank areas. The troughs are 300 m deep and are in the centre, on the north and on the west. Atlantic waters enter through western trough, causing bottom temperature between 3.5°C and 7.5°c and a salinity of 35. The warm Atlantic inflow influences the climate of the region. Cold Arctic water enters from the north, north-east, determining temperatures below 0°C and salinity of 32-34.8. Sea ice cover is maximum in spring, especially in the north of the polar front, then until September it retreats northwards and eastwards. Polar front is a zone of transition between cold Arctic northern section and warm boreal south section. The ice cover changes inter-annually and seasonally[55].

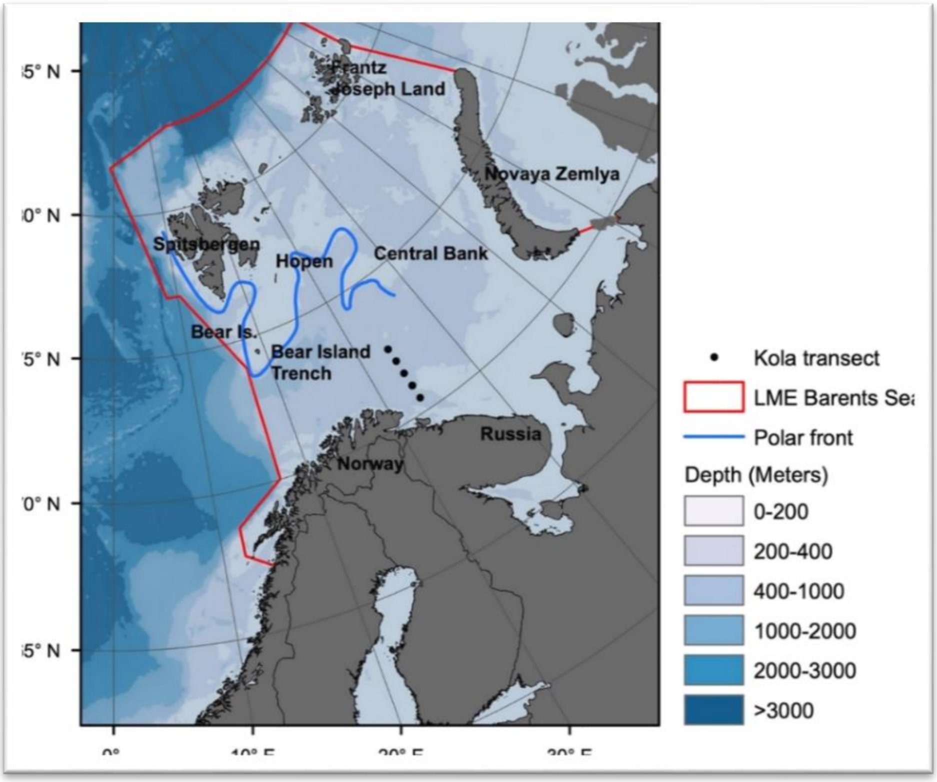


Figure 33. Map of the Barents Sea marine ecosystem. The borders are shown by red lines. Kola transect is the station for hydrographic monitoring. The polar front is indicated by the blue line, Source: Frontiers | Overexploitation, Recovery, and Warming of the Barents Sea Ecosystem During 1950–2013 | Marine Science (frontiersin.org).

---

[54] : C. Michel, B. Bluhm, V. Gallucci, A.J. Gaston, F.J.L. Gordillo, R. Gradinger, R. Hopcroft, N. Jensen, T. Mustonen, A. Niemi & T.G. Nielsen (2012): “Biodiversity of Arctic marine ecosystems and responses to climate change”, Biodiversity, 13:3-4, 200-214.

[55] ICES. 2019. Barents Sea Ecoregion – Ecosystem overview. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, Section 5.1, https://doi.org/10.17895/ices.advice.5747.

The carbon flow goes from microbial food web to higher trophic level organisms. Microzooplanktons and phytoplankton are food for copepods, prey for planktivorous fishes and pelagic carnivorous invertebrates, and also first fish stages. Krill are predators and competitors for zooplanktons, in the last year they are becoming more important for the food web. Crustacean copepods, *Calanus*, are very present. Carbon is transported from detritivorous benthic invertebrates to benthos, demersal and benthic fishes, birds, mammals. Cods, capelins and whales are diffuse. Seals, polar bears and seabirds have a lower amount of biomass. Phytoplankton biomass changes during the year, depending on the timing of first stabilisation of upper layer in ice-free water and on the timing of ice melting in spring and summer. In fish community, cods, lycodids and cottids are present. There are flatfishes and salmonids. Commercial fishes are cod, *Gadus morhua*, capelin, *Mallotus villosus*, haddock, *Melanogrammus aeglefinus*, red fishes, *Sebastes*, Greenland halibut, *Reinharditius hippoglossoides*. Commercial invertebrates are prawns, *Pandalus borealis* and red king crabs, *Paralithodes camtschaticus*. Many seabirds are present, 16 million individuals, between boreal species and Arctic species. Marine mammals are composed by polar bear, *Ursus maritimus*, seals, walrus, whales, narwhals, dolphins, porpoises[56].

From 1997 phytoplankton abundance is increasing, due to climate changes that cause a higher duration of open water. Mesozooplankton are decreasing in abundance in western Barents Sea. The northeastern Barents Sea does not present such a decrease. Barents Sea is also experiencing a decline in krill biomass. In 2014 jellyfish biomass is increased radically, especially the species *Cyanea capillata*. Shrimps expanded their distribution in the last years. Red king crab is decreasing in time in abundance due to fishing mortality. Snow crab biomass is increasing in central and eastern Barents Sea. Fishery harvest is beginning also for this species. The haddock biomass is rapidly increasing. Polar cod is experiencing a decrease. Halibut stock is increasing in the western coast in Barents Sea. Cods stock remains abundant and has moved northward in last years. Red fish stock has gone through a strong decrease[57].

---

[56] Pedersen T, Mikkelsen N, Lindstrøm U, Renaud PE, Nascimento MC, Blanchet M-A, Ellingsen IH, Jørgensen LL and Blanchet H (2021) Overexploitation, Recovery, and Warming of the Barents Sea Ecosystem During 1950–2013. *Front. Mar. Sci.* 8:732637. doi: 10.3389/fmars.2021.732637.

[57] ICES. 2019. Barents Sea Ecoregion – Ecosystem overview. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, Section 5.1, https://doi.org/10.17895/ices.advice.5747.

5.3 Climate change effects on Adriatic Sea and Barents Sea comparing functional traits analysis

The Mediterranean Sea is expected to change faster than the open ocean, with global warming, because of its relatively small volume. 20% of entire basin and 60-99% of territorial waters of EU member states are experiencing heavy effects of global change, because of several stressors: increasing temperature and UV, ocean and sea acidification, overfishing, ship traffic and pollution.

From 1983 in the Mediterranean Sea, mass mortalities of cold-water affinity species and establishment of species of tropical affinity have been reported, with an increase in frequency since 1992.

The increase of sea water temperature is leading to a meridionalization of the Mediterranean Sea, with northward shifts of species. Global warming is causing the increase of eurythermal species, such as species with wide thermal range tolerance, and the decrease of cold stenothermal species, narrow thermal range tolerant[58].

The Mediterranean Sea is affected by a general eastward increase in surface water temperature, salinity, total carbon and total alkalinity. Seasonal pH amplitudes are very large, in particular in North Adriatic Sea. In the Adriatic Sea, the survival and growth of two marine bivalves (*Chamelea gallina and Mytilus galloprovincialis*) has been reduced by a large decrease in pH. Studies in the Adriatic Sea show that acidification causes alterations in immunological parameters of adult bivalves. Adult fishes are motile species, therefore, in contrast with shellfish, the acidification can be overcome changing the geographic and depth ranges of distributions.

There are not sufficient studies to make an evaluation of long-term consequences of higher energy cost for acid-base compensation. Direct effects can be seen on early-life stages of fish, because of their low acclimation capacities. Ocean acidification can cause also shifts in microalgae and seaweed communities, with the loss of some of these, which form important habitats for shellfishes and fishes.

Climate change will also impact negatively social and economic services that provides human communities in the region of the Mediterranean Sea, such as shellfish aquaculture, tourism and fisheries[59].

In particular, the coastal area of the Northern Adriatic Sea, will be impacted by inundation of low-lying areas, erosion of beaches, increased flooding, because of extreme weather events. In areas with coastal subsidence, sea level rise could cause inland migration of beaches, increase of potential damage from storm surges. Coastal ecosystem could be impact by climate change with variations in

---

[58] I. Rivetti, S. Fraschetti, P. Lionello, E. Zambianchi, F. Boero, 2014, “Global Warming and mass mortalities of benthic invertebrates in the Mediterranean Sea”. https://doi.org/10.1371/journal.pone.0115655.

[59] T. Lacoue-Labarthe, P. A.L.D. Nunes, P. Ziveri, M. Cinar, F. Gazeau, et al.. “Impacts of ocean acidification in a warming Mediterranean Sea”: An overview. Regional Studies in Marine Science, Elsevier, 2016, ff10.1016/j.rsma.2015.12.005ff. ffhal-01253944f.

water biogeochemical and physic-chemical parameters, and aquatic ecosystem degradation. Temperature will be a relevant driver of changes, together with macronutrients, in particular in the area of Po' river delta[60].

According to several studies, maximum and minimum temperature trends since 1980 are increasing in Italy and annual and seasonal precipitation are decreasing. In coastal areas, sea level rise, coastal erosion, modification of sea temperature, salinity, eutrophication, anoxia and alien species are occurring as climate change effects, affecting coastal and marine ecosystems. Northern Adriatic Sea is surrounded by land and mountainous chains, causing a faster and more intensely responds to changes in boundary conditions[61]. Some important changes can be seen in the reduction of the phytoplankton biomass, in the trend toward small-size species, in the increase in number and biomass of mesozooplankton, in the spreading of nonindigenous species. The environmental changes could have strong impact on community composition, on modification of nursery areas, on modification of juvenile survival. Some studies have shown an increase of thermophilic species, some of them allochthonous, going northward, and a decrease of cold-water fish species. Another trend that has been recorded is the decrease of demersal fishes[62]. Northern Adriatic Sea is one of the most productive areas of the Mediterranean Sea, therefore changes in its chemical and physical characteristics, that are altering marine biota, could bring to relevant consequences also on human activities. Regional climate changes could result in agricultural issues, social droughts, fishery yield reduction, coastal desertification, harmful algal blooms, spread of new diseases. This is the spectrum of the multidisciplinary dimension of climate changes, but also the domino effect of environmental changes[63].

Global warming affects the Artic with double intensity, respect to the global average. Ice melting, given by the increase of temperature, generates a higher amount of dark water, that absorbs more solar radiation. This system feeds itself, accelerating climate change effects on the environment.

The consequences on marine species are incoming species increasing in abundance and more extended distribution ranges. Climate warming is expected to cause the largest species turnover, between local species extinction and high invasion intensity. The observed community-wide distributional shift changes the ecological interactions by Arctic fish species. Boreal fish communities are moving northward, as shellfish community that moves towards deeper areas. Marine species that

---

[60] S. Torresan, A. Critto, J. Rizzi, A. Marcomini, 2012, "Assessment of coastal vulnerability to climate change hazards at the regional scale: the case study of the North Adriatic Sea", Natural hazards and Earth system sciences. doi:10.5194/nhess-12-2347-2012.

[61] Appiotti, Federica & Krzelj, Maja & Russo, Aniello & Ferretti, M. & Bastianini, Mauro & Marincioni, Fausto. (2014). A multidisciplinary study on the effects of climate change in the northern Adriatic Sea and the Marche region (central Italy). Regional Environmental Change. 10.1007/s10113-013-0451-5.

[62] CIESM, 2008. Climate warming and related changes in Mediterranean marine biota. N° 35 in CIESM Workshop Monographs [F. Briand, Ed.], 152 pages, Monaco.

[63] Appiotti, Federica & Krzelj, Maja & Russo, Aniello & Ferretti, M. & Bastianini, Mauro & Marincioni, Fausto. (2014). A multidisciplinary study on the effects of climate change in the northern Adriatic Sea and the Marche region (central Italy). Regional Environmental Change. 10.1007/s10113-013-0451-5.

do not have limits to dispersion, contrast climate warming changing depth, geographic location and abundancy[64].

In particular, Barents Sea is a shelf sea part of Arctic Ocean that faces to a zoogeographical divide. Where Arctic and Atlantic water masses meet there was the separation between boreal and arctic fishes, different from each other for thermal affinities. The study of 65 km of Barents Sea between 2004 and 2012 showed a shift from the lowest water temperature and most ice, to the warmest water temperature and least ice. This change was caused by a stronger inflow of Atlantic water that reduced sea ice and led many fish species to expand their distributions northwards and eastwards. Arctic shelf species retraced and was confined northernmost. With the increasing of temperature and of sea loss, arctic species are expected to run out completely of their habitat and move to other Russian shelf seas. The rapid borealization of northern Barents Sea caused an effect of habitat loss for Arctic species, together with an increased competition and predation from boreal fishes. Arctic benthivore species are expected to encounter the consequences of a shift in energy pathways from benthic to pelagic, also thanks to sea ice retreat. Sea ice decrease influences ice algae, the supply for benthic production. Biodiversity is changing rapidly in the Barents Sea, with the increased presence of large boreal piscivorous and small planktivorous, and the higher importance of pelagic food web[65].

In the study "Increased functional diversity warns of ecological transition in the Arctic" of 2021, 15 functional traits are elaborated to estimate functional diversity of fish species in the Barents Sea.

The traits provide information on species characteristics, as life history, habitat affinity and feeding ecology, and on ecosystem functions, as food web (Table 3). The community-weighted variance analysis and the community-weighted mean analysis are performed to identify the traits responsible for changes in functional diversity (Figure 33). The variance of each trait is weighted by abundance of species, characterized by that trait. PCA is implemented for assessing magnitude and character of functional variance. Temporal development of functional traits and biodiversity are analysed in two regions of Barents Sea: northeastern Arctic and southwestern boreal region (Figure 34). Functional traits describing trophic links and temperature affinity result associated with PC1, that describes 56% of variation.

---

[64] Bindoff, N.L., W.W.L. Cheung, J.G. Kairo, J. Arístegui, V.A. Guinder, R. Hallberg, N. Hilmi, N. Jiao, M.S. Karim, L. Levin, S. O'Donoghue, S.R. Purca Cuicapusa, B. Rinkevich, T. Suga, A. Tagliabue, and P. Williamson, 2019: Changing Ocean, Marine Ecosystems, and Dependent Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 447-587. https://doi.org/10.1017/9781009157964.007.

[65] M. Fossheim, R. primicerio, E. Johannesen, R. B Ingvaldsen, M. M. Aschan, A.V. Dolgov. 18/05/2015. "Recent warming leads to a rapid borealization of fish communities in the Arctic". Nature climate change. Doi: 10.1038/NCLIMATE2647.

	Habitat affinity					**Life history**						**Body size**	**Feeding ecology**										
Trait number ->	**1**		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**			**13**				**14**			**15**
Fish species	**dem**	**pel**	**sal**	**temp**	**depth**	**fecundity**	**Egg size**	**Longe**	**Age mat**	**Length mat**	**Growth rate**	**ML**	**benth**	**ichty**	**plankt**	**Res Det**	**Res Zoo**	**Res Benth**	**Res Fish**	**Pred Fish**	**Pred Bird**	**Pred Mam**	**omni**
Amblyraja hyperborea	10	0	1	2	3	30	102.5	24	11	45	4.1	89	5	5	0	0	4	4	21	1	0	0	0.41
Amblyraja radiata	10	0	3	3	3	26.5	55	16	11	35	3.2	68	5	5	0	0	8	18	34	2	0	0	0.48
Anarhichas denticulatus	10	0	2	2	3	46500	6	16	6	80	13.3	162	3	3	3	0	9	8	4	5	0	1	0.43
Anarhichas lupus	10	0	2	3	3	12740	6	20	6	50	8.3	104	10	0	0	0	7	18	2	7	0	2	0.45
Anarhichas minor	10	0	3	3	3	19700	3.35	40	7	70	10	138.4	10	0	0	0	7	10	4	6	0	1	0.54
Anisarchus medius	10	0	3	2	2	700	2	13	6	9.5	1.6	13.2	10	0	0	0	4	0	0	1	0	2	0.25
Argentina silus	0	10	1	3	3	10381	3.25	35	8	26.0	3.2	49	0	0	10	0	2	2	0	5	1	1	0.46
Artediellus atlanticus	10	0	3	3	3	117.5	2.25	10	3.5	5.1	1.5	14.3	5	5	0	0	2	3	1	4	0	1	0.47
Aspidophoroides olrikii	10	0	3	3	1	180	1.125	4	2	6	3.0	8.6	10	0	0	0	0	3	0	1	0	0	0.29
Bathyraja spinicauda	10	0	1	2	3	47	130	50	12	118	9.8	165	5	5	0	0	2	3	10	1	0	0	0.51
Brosme brosme	10	0	2	3	3	2300000	1.35	20	9	53	5.9	69	10	0	0	0	0	4	5	4	0	0	0.66
Cottunculus microps	10	0	1	2	3	375	1.85	25	3	24	8	19	10	0	0	0	0	4	0	4	0	0	0.51
Cyclopterus lumpus	5	5	2	3	3	194112	2.6	15	3	29	9.7	55	0	0	10	0	5	3	0	1	0	0	0.47
Enchelyopus cimbrius	10	0	1	2	1	500000	0.82	9	3	12.7	4.2	36	5	0	5	0	0	2	0	2	0	0	0.68
Eumicrotremus spinosus	10	0	3	2	3	1187	3	3	1	5.6	5.6	14	0	0	10	0	5	2	0	0	0	1	0.36
Gadiculus argenteus	0	10	1	2	1	2763809	1	4	2	12.6	6.3	22	0	0	10	0	9	0	1	3	0	2	0.46
Gadus morhua	5	5	3	3	3	5900000	1.4	25	9	69.7	7.7	123	0	5	5	0	19	32	52	18	6	11	0.52
Gaidropsarus argentatus	10	0	1	2	3	500000	1.3	10	4	25	6.2	42	5	0	5	0	6	2	1	1	0	0	0.40
Glyptocephalus cynoglossus	10	0	1	2	2	100000	1.2	18	4.5	30.4	6.8	62	10	0	0	0	0	4	0	2	0	3	0.55
Gymnocanthus tricuspis	10	0	3	3	2	4710	1.5	8	4	11.8	2.9	21	10	0	0	0	4	6	0	1	0	0	0.30
Hippoglossus hippoglossus	10	0	1	1	2	3750000	3.4	50	12	105	8.7	220	0	10	0	0	0	11	7	3	0	1	0.66
Hippoglossoides platessoides	10	0	3	3	3	380000	2.4	19	2.6	35.2	13.5	54	5	5	0	0	2	10	7	13	1	5	0.47
Icelus spp.	10	0	2	2	2	457.5	1.7	9	2	5.5	2.7	13.8	5	0	5	0	5	3	0	1	0	0	0.37
Leptagonus decagonus	10	0	3	2	3	627	2	11	3	11.6	3.9	21.1	5	0	5	0	8	3	0	4	0	0	0.41

Leptoclinus maculatus	10	0	3	3	3	920	1.5	10	6	8.9	1.5	17.6	10	0	0	0	0	2	0	1	0	1	0
Limanda limanda	10	0	3	3	1	141000	1.2	13	5	22	4.4	43	10	0	0	0	0	14	1	4	1	1	0.52
Liparidae	10	0	3	2	2	4150	1.6	7	2.6	8.5	3.2	26.4	10	0	0	0	2.7	0.3	0.3	3	0	2.7	0.34
Lumpenus fabricii	10	0	2	2	2	490	3	7	3	14	4.7	23	10	0	0	0	0	1	1	2	0	1	0.25
Lumpenus lampretaeformis	10	0	3	3	2	700	0.8	16	8	14.5	1.8	50	10	0	0	1	5	3	0	6	0	3	0.58
Macrourus berglax	10	0	1	3	3	36500	2.2	25	15	28.5	1.9	82.5	5	5	0	0	5	13	5	4	0	0	0.55
Melanogrammus aeglefinus	5	5	3	3	3	9085000	1.43	20	5.5	37	6.7	110	5	5	0	0	17	45	22	16	3	7	0.56
Merlangius merlangus	5	5	2	2	1	120535	1.1	20	2	25	12.5	42.4	5	5	0	0	4	8	16	4	1	2	0.42
Microstomus kitt	10	0	2	2	1	95000	1.3	10	5	25	5	60	10	0	0	0	0	2	0	1	0	1	0.35
Micromesistius poutassou	0	10	1	3	3	122000	1.16	20	4.5	25.1	5.6	37.1	0	5	5	0	17	4	19	16	1	4	0.35
Molva molva	10	0	1	1	1	40000000000	0.55	30	6	74	12.3	119	5	5	0	0	1	5	4	1	0	1	0.45
Myoxocephalus scorpius	10	0	3	3	2	2742	2.51	10	3.5	10	2.9	38	5	5	0	0	1	2	1	4	0	2	0.58
Pleuronectes platessa	10	0	3	2	2	552000	2.17	36	10	26.6	2.7	86	10	0	0	0	5	21	4	3	0	3	0.47
Pollachius virens	0	10	3	3	3	6630000	1.125	30	5.5	55.4	10.1	177.1	0	10	0	0	13	4	16	6	2	8	0.48
Rajella fyllae	10	0	1	3	3	47	42	14	5	36	7.2	57	10	0	0	0	3	3	1	1	0	0	0.16
Reinhardtius hippoglossoides	5	5	3	3	3	28100	4.25	30	7	55	7.9	111.7	0	5	5	0	2	8	17	10	0	5	0.48
Sebastes mentella	5	5	2	3	3	83900	6	70	11	30.7	2.8	58	0	5	5	0	30	15	14	9	3	5	0.56
Sebastes spp.	5	5	1	3	3	85750	6.8	60	11	39.6	3.6	50.2	5	5	0	0	11	3	2	11	2	6	0.53
Sebastes norvegicus	5	5	1	3	3	85750	6.8	60	11	39.6	3.6	50.2	5	5	0	0	11	3	2	11	2	6	0.53
Sebastes viviparus	10	0	1	3	3	15450	5.8	40	12.5	15	1.2	340	5	5	0	0	4	3	0	3	0	0	0.37
Triglops murrayi	10	0	2	3	3	450	2	10.00	4	7.6	1.9	17.2	5	0	5	0	5	1	1	4	0	0	0.31
Triglops nybelini	10	0	2	2	3	800	1.875	7.00	3	5.6	1.9	14.5	0	0	10	0	3	1	0	3	0	0	0.49
Triglops pingelii	10	0	3	3	2	430	2.25	9	4	8.7	2.2	17.5	5	0	5	0	6	3	0	3	0	0	0.41
Trisopterus esmarkii	0	10	2	3	2	222938	1.1	8	2	15	7.5	25	5	0	5	0	17	9	0	9	2	2	0.38
Zoarcidae	10	0	1	2	2	194.2	4.83	13.9	3.4	16.2	4.8	39.7	10	0	0	0.17	3.8	3.5	0.17	2	0	1	0.29

Table 3. List of 15 functional traits used in the study of Barents Sea. Division of 49 species per functional trait. Source: Results on FD, CWV, and CWM from 2004 to 2017 in the Barents Sea from Increased functional diversity warns of ecological transition in the Arctic (figshare.com).

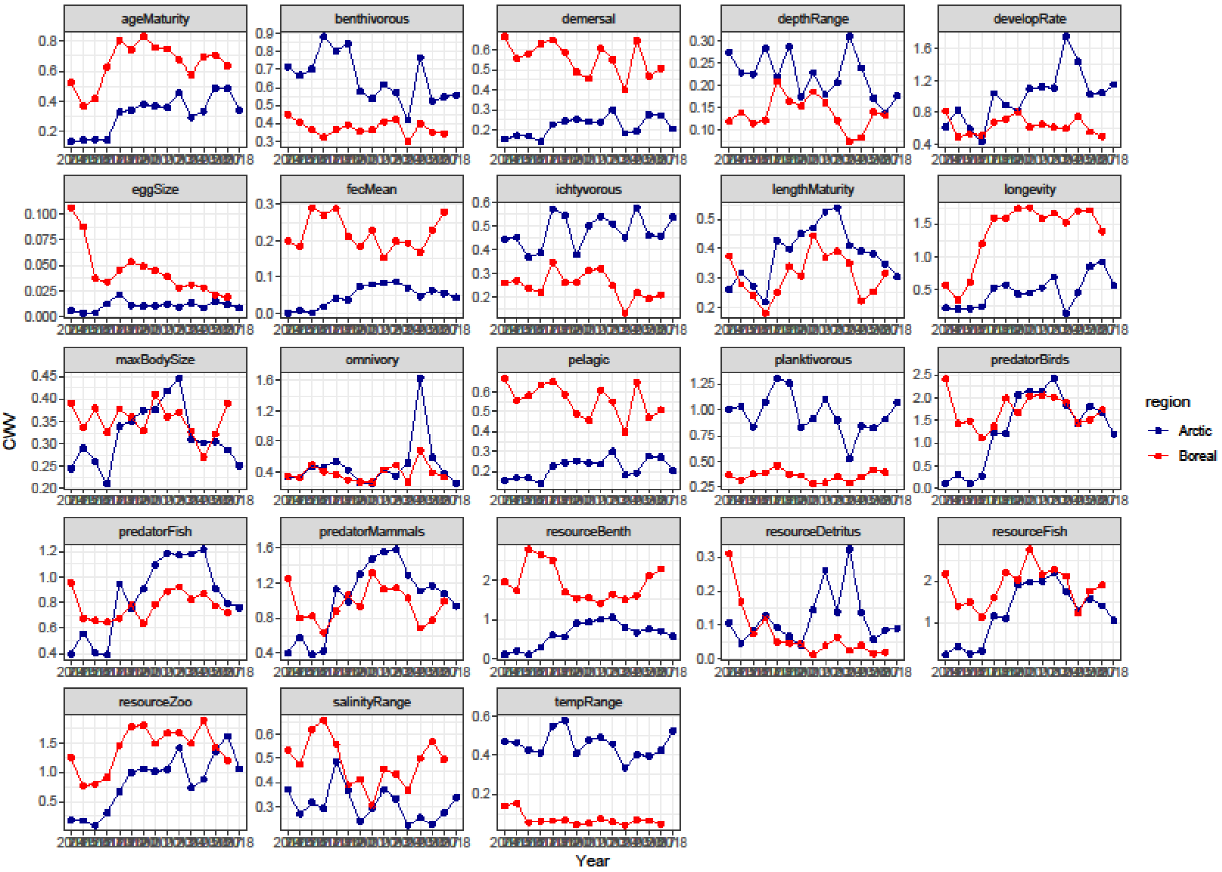


Figure 34. Variation in community-weighted trait variance of 49 species and 15 functional traits analysed in the Barents Sea study, from 2004 to 2017. Source: Results on FD, CWV, and CWM from 2004 to 2017 in the Barents Sea from Increased functional diversity warns of ecological transition in the Arctic (figshare.com).

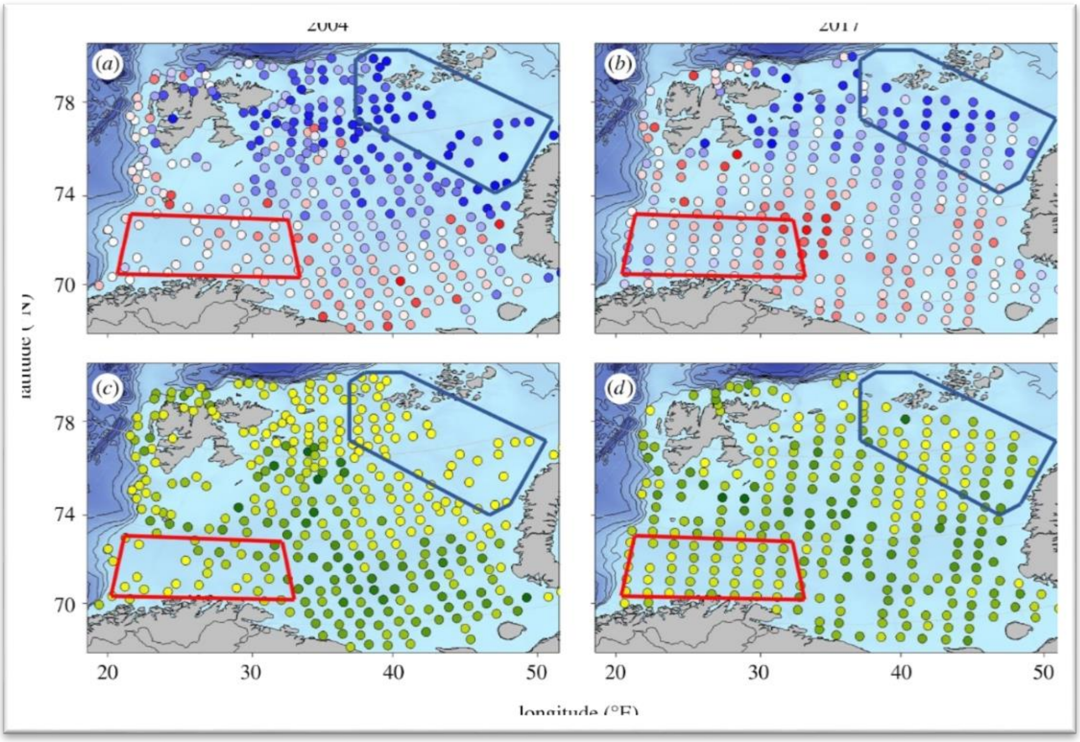


Figure 35. Variation of species abundance in the Barents Sea between 2004 and 2017. CWM trait values (a, b) and CWV trait variance (c, d) from data on demersal fishes in the two subregions of Barents Sea: arctic region in blue, boreal region in red. The sampled sites are delimited with colour gradients. For CWV colours from yellow to green indicate trait variance, from low heterogeneity to high heterogeneity. Source: Increased functional diversity warns of ecological transition in the Arctic | Proceedings of the Royal Society B: Biological Sciences (royalsocietypublishing.org).

The study reveals a strong increase in functional variance of Arctic Barents Sea region, driven by migrated boreal species. According to figure 34, in the Arctic region, the age of maturity is increasing in time, in terms of variance, following boreal trend. Benthivorous species variance is decreasing in time, together with depth range variance, maximum body size variance, length of maturity, omnivorous variance. The variances of Arctic region that maintain the same range are the ones of demersal species, egg size, mean fecundity, pelagic species. The functional traits with increasing variances in the Arctic region are ichtyvorous, temperature range, mean fecundity, pelagic. In the boreal region the variances that are increasing in time belong to the functional trait age of maturity, depth range, mean fecundity, longevity. The functional traits of species in the boreal region with a decreasing variance are demersal, benthivorous, egg size, temperature range, pelagic. In figure 35, the CWM analysis shows a different spatial distribution of species in the Barents Sea from 2004 to 2017. The northward trend is more evident in the last year, with an increase of red points, representing boreal species. Arctic species are disappearing or changing habitat, concentrating in the north region of Barents Sea. The CWV analysis expresses the variance, showing the majority of green points in the last year, that indicate high trait variance. In fact, the increase of boreal species in the Barents Sea, brings to a high heterogeneity of functional traits.

The presence of motile large piscivorous and of small pelagic fish increases functional variance and adaptive capacity. But the persistence of the increasing temperature trend can bring to future biodiversity loss, benthivorous fish component loss and reduction on adaptive capacity[66].

The study “Climate-driven changes in functional biogeography of Arctic marine fish communities” of 2017, demonstrates the poleward shifts in species distribution, analysing 52 fish species and 15 functional traits from 2004 to 2012. The study area is the Barents Sea, as the area of the Arctic that is most affected by borealization. The multivariate analysis of species functional traits shows in the left part of the graph species with boreal-like traits that have the higher variance (Figure 36). The right part of the PCA graph represents less abundant species with Arctic-like traits. Piscivorous species with pelagic behaviour and higher growth rate are the most abundant in southwestern and central regions of Barents Sea. In the northernmost region of Barents Sea are more abundant species that are benthivorous, demersal behaviour, small body size and slow growth rate.

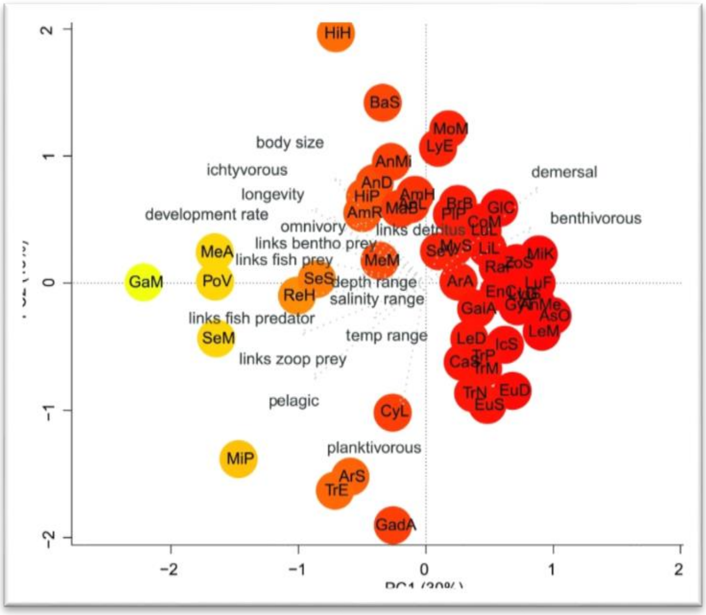


Figure 36. PCA analysis of species functional traits. Representation of PC1 and PC2 that are 45% of data variation. The colour refers to the position of species in the functional multivariate space, from yellow to red. Source: Climate-driven changes in functional biogeography of Arctic marine fish communities. - Abstract - Europe PMC.

According to this study, in 2004 the Arctic-like traits were dominant, for 50% of Barents Sea. In 2012 they were representtaive of only 20% of Barents Sea. The CWM analysis shows the interaction between time and region, with convergence or divergence between Arctic and boreal regions (figure 37).

---

[66] A. Frainer, R. Primicerio, A. Dolgov, M. Fossheim, E. Johannesen, S. Lind, M. Aschan, 07/04/2021, “Increased functional diversity warns ecological transition in the Arctic”, Proceedings of the Royal Society b. https://doi.org/10.1098/rspb.2021.0054.

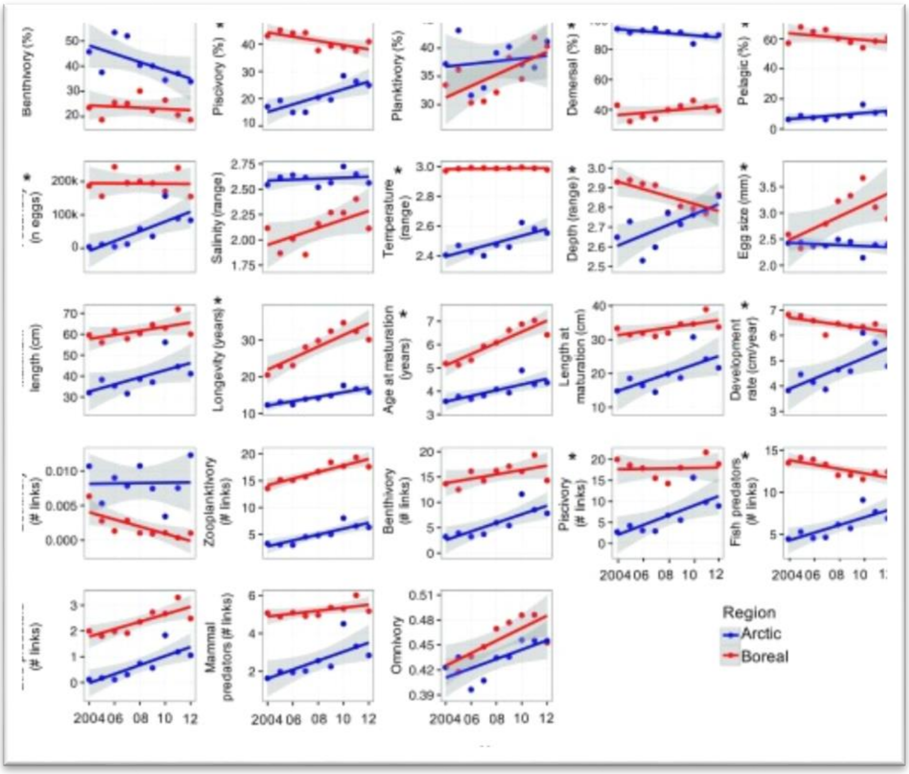


Figure 37. Variation of community-weighted mean trait values, from 2004 to 2012 in the boreal region, red, and arctic region, in blue. Source: Europe PMC.

In the Arctic region, benthivorous species are decreasing in time, together with demersal species. Piscivorous, planktivorous, omnivorous and pelagic species are increasing in time. The number of eggs per individual is increasing, with temperature range, depth range, maximum length and longevity. In boreal region the functional traits that are increasing are planktivorous, salinity range, agg size, longevity, mmaximum length, omnivorous.

Observed species in the Barents Sea are increasing in body size, generalist diet, consumption rate, energy flow. Large omnivorous species are decreasing smaller Arctic organisms biomass, with negative consequences of winter production and with changes on ecosystem structure and functioning[67].

The increase of water temperature facilitates the inflow of boreal species, cod, haddock and red fishes. The new species use different resource, they compete with Arctic species or feed on them. They are advantaged by the increase of pelagic productivity, caused by climate conditions, thanks to poleward movement of Atlantic waters. Non indigenous species are causing top-down effects, with the reduction of of secondary consumers and the release of their prey from pressures. Arctic fish species

---

[67] Frainer A, Primicerio R, Kortsch S, et al. Climate-driven changes in functional biogeography of Arctic marine fish communities. Proceedings of the National Academy of Sciences of the United States of America. 2017 Nov;114(46):12202-12207. DOI: 10.1073/pnas.1706080114. PMID: 29087943; PMCID: PMC5699037.

depend on the sea-ice cover and on benthic production, and global warming are threatening this equilibrium.

Both study areas, Northern Adriatic Sea and Barents Sea are experiencing a rapid sea surface tempearature increase. From the year 1965 to the year 2015, Barents Sea temperature increased by 1.74°C on average (Figure 38), with a strong shift since 2004 given by reduction of mean and variance of winter sea ice concentration[68].

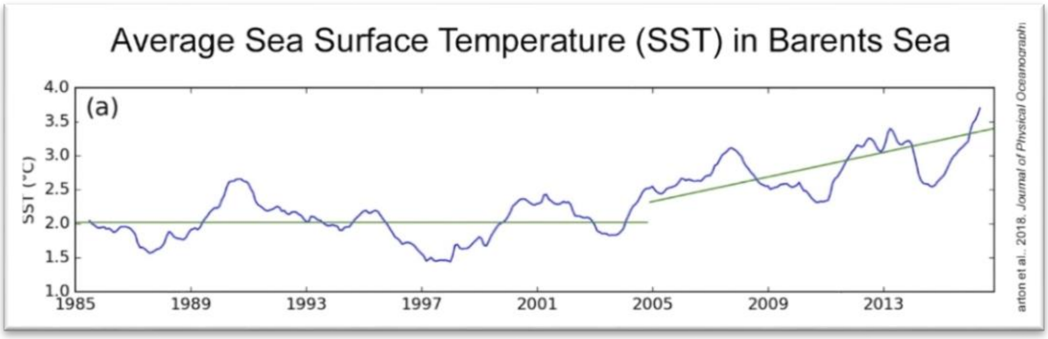


Figure 38. Average Sea surface temperature trend in Barents Sea, from 1985 to 2016, with 12-month running mean in blue and linear trend in green. Source: Observed Atlantification of the Barents Sea Causes the Polar Front to Limit the Expansion of Winter Sea Ice in: Journal of Physical Oceanography Volume 48 Issue 8 (2018) (ametsoc.org).

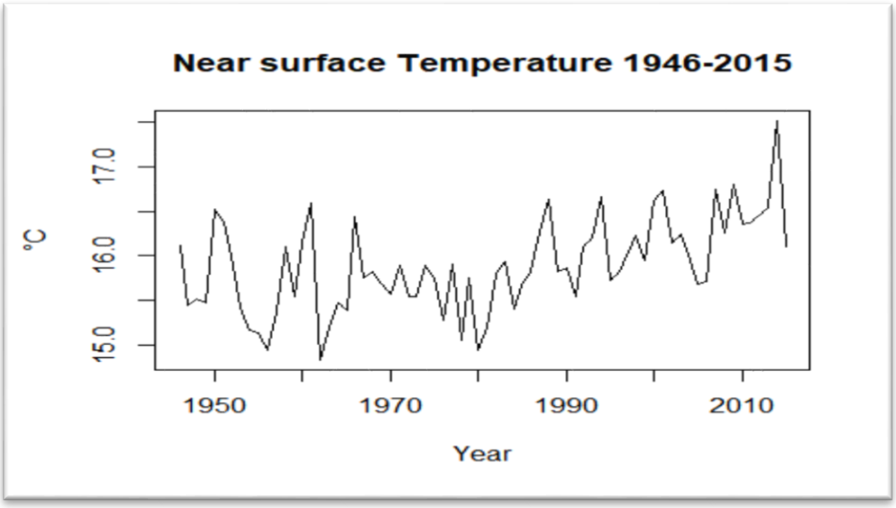


Figure 39. Timeseries plot of near surface temperature of Northern Adriatic Sea between 1946 and 2015. Source: Author.

---

[68] Barton, B. I., Lenn, Y., & Lique, C. (2018). Observed Atlantification of the Barents Sea Causes the Polar Front to Limit the Expansion of Winter Sea Ice, *Journal of Physical Oceanography*, *48*(8), 1849-1866. Retrieved Jun 23, 2022, https://journals.ametsoc.org/view/journals/phoc/48/8/jpo-d-18-0003.1.xml.

The consequences of Climate Change are modifying strongly both habitats and ecosystems structures. In the Northern Adriatic, global warming and sea acidification are decreasing water quality, degrading coastal area, coralline algae and seagrass meadows. In the Barents Sea warming are causing a rapid sea ice loss, accelerating climate change effects and altering the environment.

With different weigths, both study areas are facing changes in marine species abundance, biodiversity, in fishes physiology, trophic levels and species distributions.

Sea warming is causing a shift from demersal and benthivorous species to pelagic and planktivorous species in both areas, event though in Barents Sea it is also recorded the migration of large pescivorous. Except for some Arctic species that are reaching deeper waters to contrast increase in temperature, both studies proved the shift to pelagic habitats and less deep waters. In the Northern Adriatic Sea species with small body size and small eggs are increasing in abundance. In the Barents Sea bigger fishes with bigger eggs are dominating.

The functional trait temperature tolerance range is quite similar, but with some differences. Northern Adriatic Sea is experiencing a decrease of marine species with small or medium temperature range, and species with a large range are increasing in abundance. In the Barents Sea temperature tolerance is divided into two categories: from one side Arctic species that cannot tolerate warmer water are decreasing in abundance, moving northwards and eastwards; from the other side boreal species are migrating into the study area, increasing the samples of high temperature tolerance fishes.

The main difference in the responses to sea warming between Northern Adriatic Sea and Barents Sea can be found in the geographical component. Even though Barents Sea is experiencing an higher temperature trend increase, species loss can be moderated with shift in spatial distribution, as seen towards deeper waters or northwards. Northern Adriatic Sea is a shallow closed basin, where endemic species cannot move towards better habitat. The intensive fishering activies in the Adriatic is also increasing the threat of local species, worsening environmental change effects.

6. Conclusions

Marine ecosystems and services are under multiple threats. Information and scientifical studies are needed to understand the dimension and relevance of these negative phenomena, to analyse their interactions with the ecosystems and mostly to know how management can adapt to future challenges. This study aimed to investigate climate change effects on two different study areas, both hotspots of environmental changes.

The first step was the description of ecosystem structure, functioning and dynamics, to understand when an ecosystem is in equilibrium and what happens when a disturbance event occurs. Fishery was taken into account, but climate change was defined as main driver of changing in the ecosystem.

The first part of the thesis was experimental, with the organization, processing and analysis of sample data in the first study area, the Northern Adriatic Sea. Time series analysis, CWM and PCA analyses were used to underline how global warming and ocean acidification are changing an entire ecosystem. Climate change is altering the equilibrium of the entire Mediterranean Sea, with strong consequences on water quality, coastal areas, marine organisms, ecosystems, natural resources and human activities. The increase of sea surface temperature in recent years was proved both in the Northern Adriatic Sea and in the Barents Sea.

The data for the analysis of the second hotspot of climate change were taken by scientific articles made by researchers that study the Arctic basin. Global warming and sea ice loss are changing definitively Arctic marine ecosystem. CMV, CWM and PCA analyses were used to study the effects of disturbance events on ecosystem structure, composition, dynamic and on marine organisms' spatial distribution.

The two study areas were compared to describe the dimension of climate change effects. Both areas presented similar trends of functional traits of the sample marine species. Sea warming is causing in the Northern Adriatic Sea, as in all the Mediterranean Sea, two phenomena: meriditionalization and tropicalization. In the Barents Sea, as in all the Arctic basin, increase of sea surface temperature are causing the phenomenon of borealization. These phenomena refer to a change in marine species' spatial distribution, with northward migration of local species and northward intrusion of non-indigenous species, with consequential changes of ecosystem structure, functioning and dynamics.

The thesis is based on functional traits analysis, a recent ecological method to study the biodiversity. The trends of species abundances are studied on the basis of their functional roles.

Climate change effects on biodiversity were analysed and compared in the two study areas.

The main difference between Northern Adriatic Sea and Barents Sea is the ecosystem response.

Both areas presented a “pelagification” of the system, ecological shifts, invasive species and biodiversity loss. But the northward species migration has a huge limit in the Adriatic Sea, because it is a shallow semi-closed basin. Marine organisms cannot change habitat in terms of depth distribution or horizontal distribution, with biodiversity loss as consequence. The Barents Sea is an open sea that allows some species to move northward and to change their spatial distribution, to escape from climate and ecological hazards. Increasing temperatures are, anyway, causing habitat loss, not only biodiversity loss.

The use of functional traits analysis should be intensified to understand better how climate change is altering ecosystems, to study their equilibrium points, their disturbance events, their ecological shifts, their ecosystems vulnerabilities. Studies and researches on climate change effects are crucial to visualize future scenarios and to stabilize the right adaptation and mitigation plan of global environmental changes effects.

Appendix A.

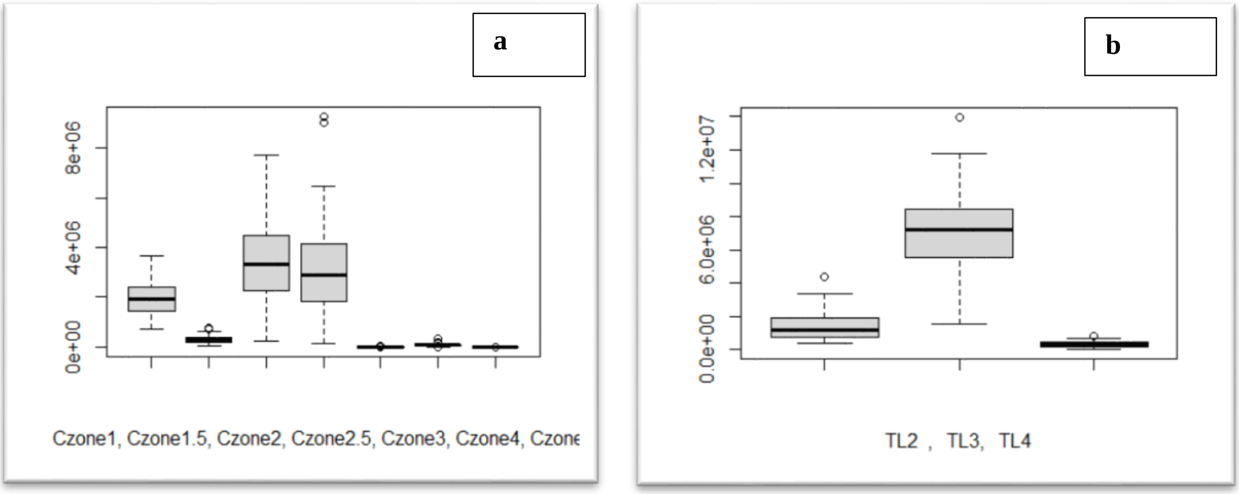


Figure 40. Boxplot of absolute values showing the dimension of data for each climatic zone (a). Boxplot of absolute values showing the dimension of data in terms of trophic levels (b). Source: Author.

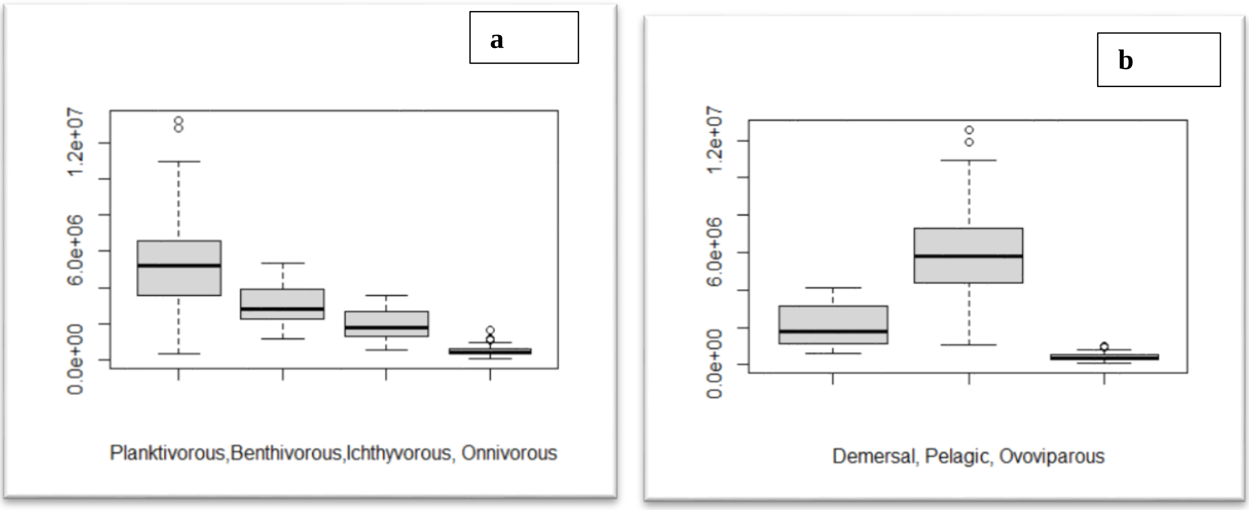


Figure 41. The boxplot representing absolute values of marine species organized per diet as functional trait (a). Boxplot representing abundance of species for what concerns offspring behaviour functional trait (b). Source: Author.

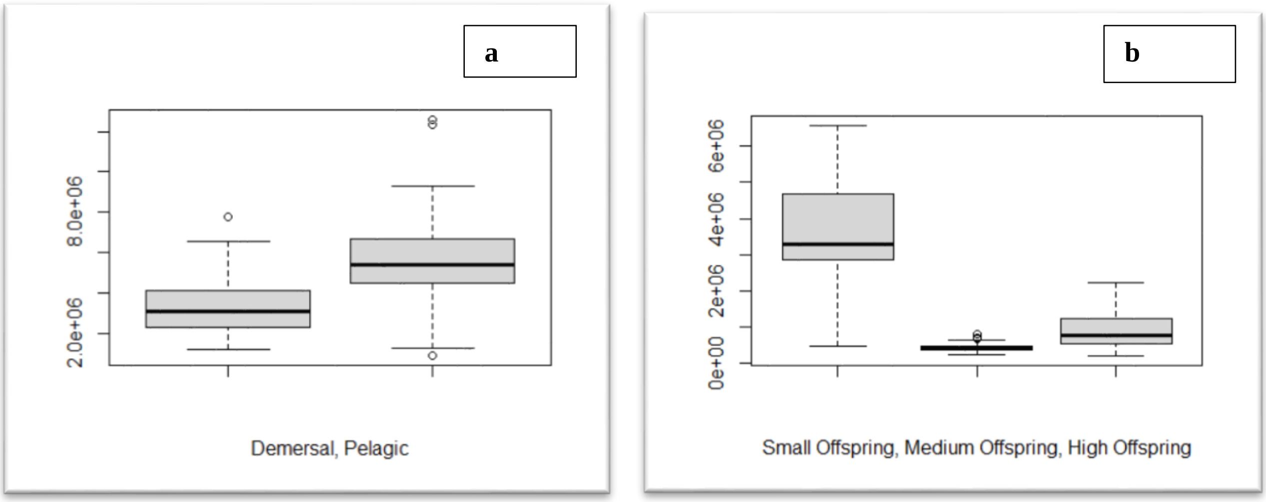


Figure 42. Boxplot representing the dimension of data regarding the functional trait habitat (a). Boxplot showing the higher abundance of species using small eggs (b). Source: Author.

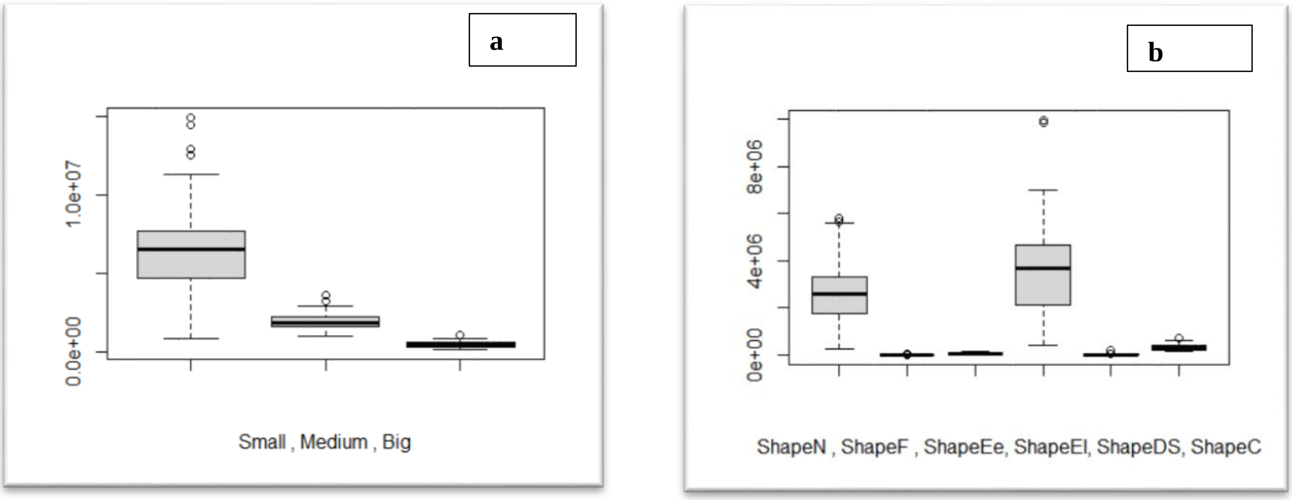


Figure 43. Boxplot of body size, with the majority of species with small body size (a). Boxplot showing the majority of species with elongated and normal shape (b). Source: Author.

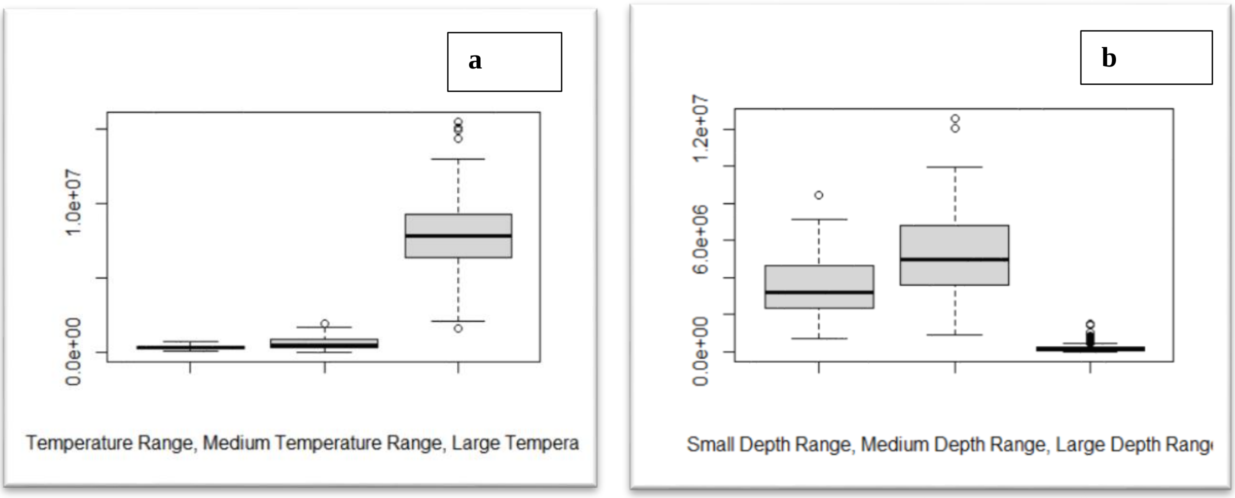


Figure 44. Boxplot of data divided per temperature range, with the prevalence of species with high tolerance (a). Boxplot of depth tolerance ranges, with the majority of species with a medium depth tolerance range (b). Source: Author.

Appendix B

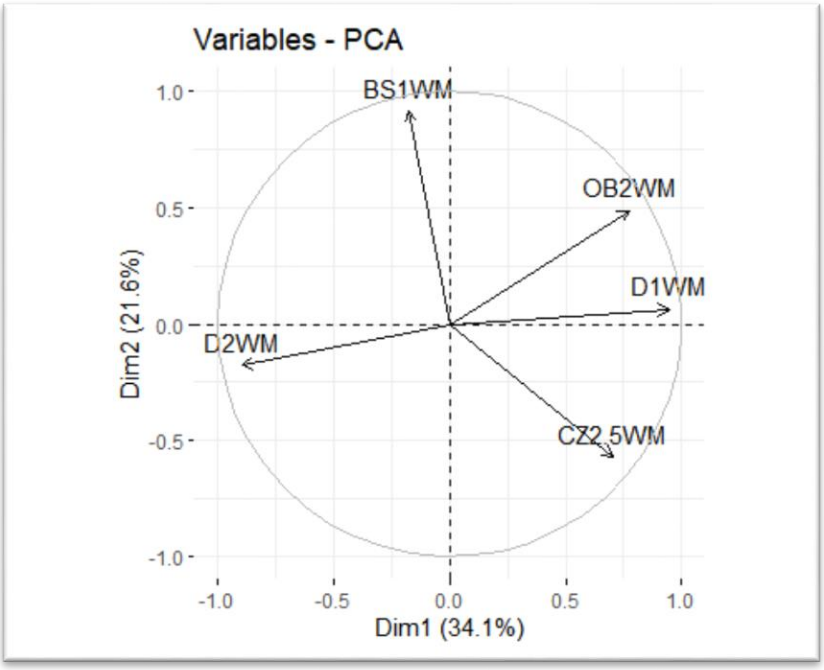


Figure 45. The variables-PCA plot showing the first 5 variables, the characteristics of functional traits, influencing variance of data, according to their cos2 values. Source: Author.

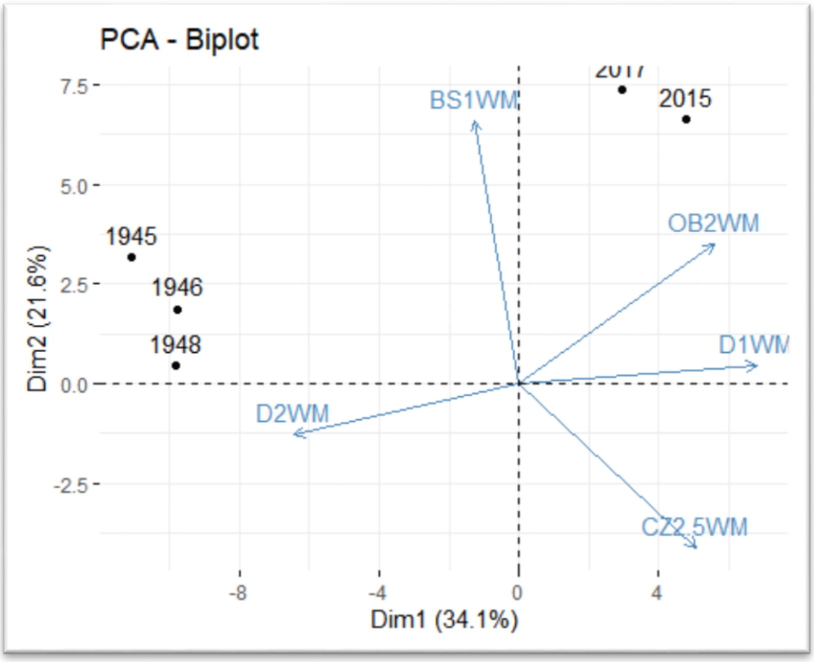


Figure 46. PCA analysis. The biplot showing the first 5 variables per cos2 value. Source: Author.

References

Appiotti, Federica & Krzelj, Maja & Russo, Aniello & Ferretti, M. & Bastianini, Mauro & Marincioni, Fausto (2014) “A multidisciplinary study on the effects of climate change in the northern Adriatic Sea and the Marche region (central Italy)”, Regional Environmental Change, 10.1007/s10113-013-0451-5.

Apply command in R, https://r-coder.com/apply-r, www.datacamp.com/tutorial/r-tutorial-apply-family, www.rdocumentation.org/packages/base/versions/3.6.2/topics/tapply.

Aune M, Aschan MM, Greenacre M, Dolgov AV, Fossheim M, Primicerio R (2018), “Functional roles and redundancy of demersal Barents Sea fish: Ecological implications of environmental change”, https://doi.org/10.1371/journal. pone.0207451.

Barton, B. I., Lenn, Y., & Lique, C. (2018) “Observed Atlantification of the Barents Sea Causes the Polar Front to Limit the Expansion of Winter Sea Ice”, *Journal of Physical Oceanography, 48*(8), 1849-1866, https://journals.ametsoc.org/view/journals/phoc/48/8/jpo-d-18-0003.1.xml.

Bianchi, C., Caroli, F., Guidetti, P., & Morri, C. (2018) “Seawater warming at the northern reach for southern species: Gulf of Genoa, NW Mediterranean”, *Journal of the Marine Biological Association of the United Kingdom, 98*(1), 1-12. doi:10.1017/S0025315417000819.

Bindoff, N.L., W.W.L. Cheung, J.G. Kairo, J. Arístegui, V.A. Guinder, R. Hallberg, N. Hilmi, N. Jiao, M.S. Karim, L. Levin, S. O’Donoghue, S.R. Purca Cuicapusa, B. Rinkevich, T. Suga, A. Tagliabue, and P. Williamson (2019) “Changing Ocean, Marine Ecosystems, and Dependent Communities”, In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)], Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 447-587.,https://doi.org/10.1017/9781009157964.007.

Chioggia pesca, Mercato ittico di Chioggia, www.chioggiapesca.it.

CIESM (2008) “Climate warming and related changes in Mediterranean marine biota” N° 35 in CIESM Workshop Monographs [F. Briand, Ed.], 152 pages, Monaco.

Cury P., Shannon L., Shin Y.-J., “The functioning of marine ecosystems”.

CWM analysis, https://monashbioinformaticsplatform.github.io/r-more/topics/tidyverse.html.

Drinkwater K., Hunt G., Lehodey P., Lluch-Cota S., Murphy E. J., Sakurai Y., Schwing F., Beaugrand G., Sundby S. (2010) “Climate forcing on marine ecosystems”, Marine Ecosystems and Global Change, Oxford Biology, New York.

EEA, European Environment Agency, “biological diversity”, http://biodiversity-chm.eea.europa.eu/nyglossary_terms/B/biological_diversity.

Fossheim M., Primicerio R., Johannesen E., Ingvaldsen R. B, Aschan M. M., Dolgov A.V. (18/05/2015) “Recent warming leads to a rapid borealization of fish communities in the Arctic”, Nature climate change, Doi: 10.1038/NCLIMATE2647.

Frainer A, Primicerio R, Kortsch S, et al. (2017) “Climate-driven changes in functional biogeography of Arctic marine fish communities”, Proceedings of the National Academy of Sciences of the United States of America, Nov;114(46):12202-12207, DOI: 10.1073/pnas.1706080114. PMID: 29087943; PMCID: PMC5699037.

Frainer A., Primicerio R., Dolgov A., Fossheim M., Johannesen E., Lind S., Aschan M. (07/04/2021) “Increased functional diversity warns ecological transition in the Arctic”, Proceedings of the Royal Society b, https://doi.org/10.1098/rspb.2021.0054.

Goswami, M., Bhattacharyya, P., Mukherjee, I. and Tribedi, P. (2017) “Functional Diversity: An Important Measure of Ecosystem Functioning”. *Advances in Microbiology*, doi: 10.4236/aim.2017.71007.

ICES (2019) “Barents Sea Ecoregion – Ecosystem overview”, In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, Section 5.1, https://doi.org/10.17895/ices.advice.5747.

IPCC (2018): Summary for Policymakers. In: “*Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty”* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. *World Meteorological Organization, Geneva, Switzerland, 32 pp.*

IPCC (2019): Summary for Policymakers. In: “IPCC Special Report on the Ocean and Cryosphere in a Changing Climate” [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)].

IPCC (2021): Summary for Policymakers. In: “Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change” [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.

Ispra (2012) “Valutazione iniziale sottoregione Mae Adriatico”, Strategia per l’ambiente Marino, Carattertistiche fisiche, www.strategiamarina.isprambiente.it/consultazioni/consultazione-2012.

Ispra, Istituto Superiore per la Protezione e la ricerca Ambientale, “Biodiversity”, https://www.isprambiente.gov.it/en/activities/biodiversity.

Lacoue-Labarthe T., Nunes P. A.L.D., Ziveri P., Cinar M., Gazeau F., et al. (2016) “Impacts of ocean acidification in a warming Mediterranean Sea: An overview”, Regional Studies in Marine Science, Elsevier, ff10.1016/j.rsma.2015.12.005ff. ffhal-01253944f.

Levin P. S., Möllmann C. (01/05/2015) “Marine ecosystem regime shifts: challenges and opportunities for ecosystem-based management”, https://doi.org/10.1098/rstb.2013.0275.

Linear filter, https://search.r-project.org/CRAN/refmans/tis/html/tisFilter.html.

Marini M., Bombace G., Iacobone G. (2015) “Il Mare Adriatico e le sue risorse”, Carlo Saladino Editore s.r.l., Il mare Adriatico ambiente, pesca e cultura, www.assonautica.an.it/iniziative/2017/tonno/Il%20Mare%20Adriatico%20e%20le%20sue%20risorse%20-%202017.pdf.

Matrix and time series in R, www.datamentor.io/r-programming/matrix/, www.rdocumentation.org/packages/stats/versions/3.6.2/topics/ts.

Michel C., Bluhm B., Gallucci V., Gaston A.J.,. Gordillo F.J.L, Gradinger R., Hopcroft R., Jensen N., Mustonen T., Niemi A. & Nielsen T.G. (2012): “Biodiversity of Arctic marine ecosystems and responses to climate change”, Biodiversity, 13:3-4, 200-214.

Moatti J.-P., Thièbault S. (2016) “The Mediterranean region under climate change”, IRD E’ditoìions, DOI:10.4000/book.irdeditions.22908.

Mollman C., Casini M., Daskalov G. M., B. de Young (2011) Virginija KELMELYTE, “Regime shifts in marine ecosystems: how overfishing can provoke sudden ecosystem changes”, Directorate-general for internal policies, policy department structural and cohesion policies, https://www.europarl.europa.eu/RegData/etudes/workshop/join/2011/474557/IPOL-PECH_AT(2011)474557_EN.pdf.

Noaa Fisheries, “Invasive and Exotic Marine Species”, https://www.fisheries.noaa.gov/insight/invasive-and-exotic-marine-species.

Nock, Charles A, Vogt, Richard J, and Beisner, Beatrix E (February 2016) “Functional Traits”. In: eLS. John Wiley & Sons, Ltd: Chichester, DOI: 10.1002/9780470015902.a0026282.

Pastor, F., Valiente, J.A. & Palau, J.L. (2018) “Sea Surface Temperature in the Mediterranean: Trends and Spatial Patterns (1982–2016)”, *Pure Appl. Geophys.* 4029, https://doi.org/10.1007/s00024-017-1739-z.

PCA analysis, www.datacamp.com/tutorial/pca-analysis-r.

Pedersen T, Mikkelsen N, Lindstrøm U, Renaud PE, Nascimento MC, Blanchet M-A, Ellingsen IH, Jørgensen LL and Blanchet H (2021) “Overexploitation, Recovery, and Warming of the Barents Sea Ecosystem During 1950–2013”, *Front. Mar. Sci.* 8:732637, doi: 10.3389/fmars.2021.732637.

Plot and Boxplot in R, https://r-coder.com/plot-r/. https://r-graph-gallery.com/boxplot.html.

Pravoni F. (2020) materials from “Ecosystem functioning and climate change”. Department of Environmental Science, Computer Science and Statistics, University Ca’ Foscari of Venice.

R software for statistical computing and graphic, www.r-project.org, www.rstudio.com.

Raicich F., Colucci R. R. (2019) “A near-surface sea temperature time series from Trieste, northern Adriatic Sea (1899-2015)”, *Earth System Science Data*, 11, 761-768, https://doi.org/10.5194/essd-11-761-2019.

Raicich F., Colucci R. R. (2021) “Trieste 1899-2015 near-surface sea temperature”, SEANOE. https://doi.org/10.17882/58728.

Rivetti I., Fraschetti S., Lionello P., Zambianchi E., Boero F. (2014) “Global Warming and mass mortalities of benthic invertebrates in the Mediterranean Sea”, https://doi.org/10.1371/journal.pone.0115655.

Rizzi, J., S. Torresan, A. Critto, A. Zabeo, D. Brigolin, S. Carniel, R. Pastres, and A. Marcomini (2016) “Climate Change Impacts on Marine Water Quality: The Case Study of the Northern Adriatic Sea.” Marine Pollution Bulletin 102, no. 2: 271–82, doi:10.1016/J.MARPOLBUL.2015.06.037.

Smith, R. Leo and Pimm, Stuart L. (2019) "ecology." *Encyclopedia Britannica*, https://www.britannica.com/science/ecology.
The Ecological Society of America, https://www.esa.org/about/what-does-ecology-have-to-do-with-me.

Tilman D., “Functional Diversity”, Editor(s): Simon A Levin, *Encyclopedia of Biodiversity* (Second Edition), https://doi.org/10.1016/B978-0-12-384719-5.00061-7.

Torresan S., Critto A., Rizzi J., Marcomini A. (2012) “Assessment of coastal vulnerability to climate change hazards at the regional scale: the case study of the North Adriatic Sea”, Natural hazards and Earth system sciences. doi:10.5194/nhess-12-2347-2012.

Treccani enciclopedia, “Mar Adriatico”, www.treccani.it/enciclopedia/mar-adriatico.

Treccani Enciclopedia, www.treccani.it/enciclopedia/gis_%28Enciclopedia-Italiana%29.

United Nation environment programme Mediterranean action plan (2015) “Adriatic Sea: Ecology”, http://rac-spa.org/nfp12/documents/information/wg.408_inf14_eng.pdf.

Wikipedia, “Alto Adriatico”, https://it.wikipedia.org/wiki/Alto_Adriatico.

Würtz, M. (2010) “Mediterranean Pelagic Habitat: Oceano graphic and Biological Processes, An Overview”, Gland, Switzerland and Malaga, Spain: IUCN.

www.fishbase.de

www.sealifebase.ca