Innovation in Climate Change Education

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TRAINING ITINERARY WITH METHODOLOGICAL GUIDE FOR E-INNOEDUCO2 TEACHERS

Concello de Outes · USC Universidade de Santiago de Compostela · CESGA · universidade de aveiro theoria poiesis praxis · Agrupamento de Escolas de Aveiro · XXVI LO · Alexandru Ioan Cuza University of Iași

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BIBLIOGRAPHY

MODULE 1:
SCIENTIFIC BASIS TRAINING ITINERARY WITH METHODOLOGICAL GUIDE

This training itinerary is divided into two parts, the first part structures the scientific bases for didactic transposition, a methodological guide expressing the didactic transposition of these scientific bases.

This training pathway is based on the concepts of ecosystem structure as determinants of ecosystem function and the provision of ecosystem services, also called nature-derived benefits. It focuses on the relationship between the provision of ecosystem services, the health of these ecosystems and benefits to human well-being, including human health.

It is structured in four main sections:

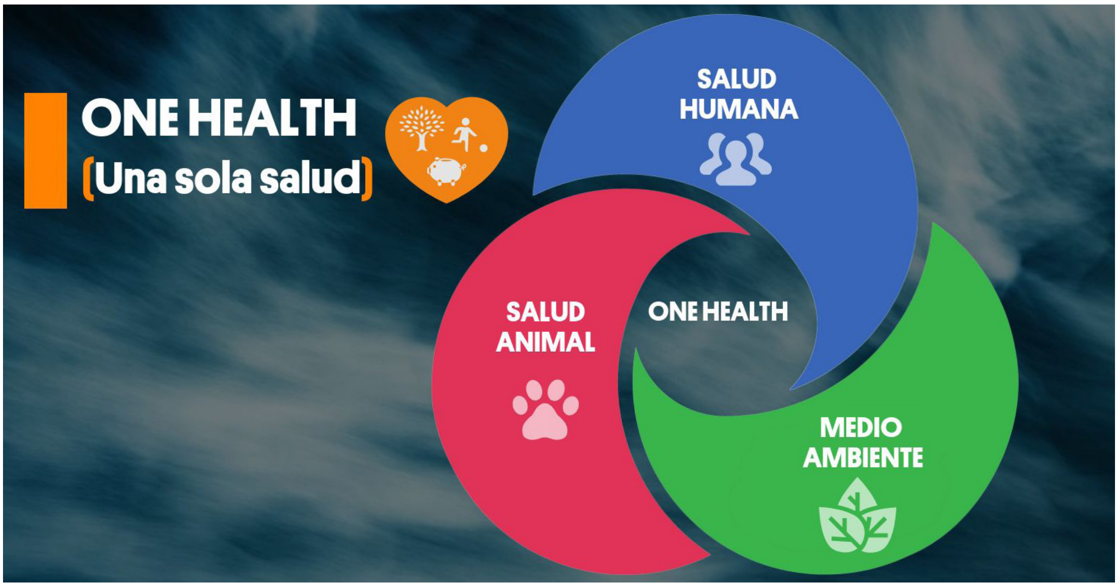
1. Ecological context,
2. Seagrass ecosystems,
3. Three case studies: Northwest Atlantic Upwelling, Baltic Sea, Black Sea
4. Description of training activities for each case study

1. ENVIRONMENTAL CONTEXT

1.1 ECOSYSTEM HEALTH AND HUMAN WELL-BEING

The belief that achieving a satisfactory level of health in today's human societies requires an interdisciplinary and therefore complex approach has become particularly widespread in recent decades. The concept of "One Health" has become a central element of public health policies in most countries, usually in response to some of the public health emergencies that have caused zoonoses, such as those associated with H1N1, Ebola or Zika viruses. The 'One Health' approach aims to achieve optimal human, animal and environmental health through the collaborative efforts of multiple disciplines working at local, national or global scales. Although it has become very popular nowadays, the concept cannot be considered new. As early as the 19th century, the German pathologist Rudolf Virchow showed his interest in the relationship between human and veterinary medicine by coining the term "zoonosis".

A few decades later, in 1964, Dr. Calvin Schwabe used the term "One medicine" in his textbook of veterinary and human medicine. But it was at the turn of the 21st century, in 2004, that the Twelve Manhattan Principles were published, proclaiming the need for an interdisciplinary approach to disease prevention, including disease transfer between humans, animals and the natural environment. Since then, numerous events have marked the development of the concept, culminating in the publication in 2008 of the document "Contributing to "One World, One Health: A Strategic Framework for Reducing Infectious Disease Risks at the Interface between Animals, Humans and Ecosystems", endorsed by representatives of over 120 countries and 26 international and regional organisations. Since this landmark moment, the development of the concept and the implementation of its application has proceeded with broad consensus among countries. The Hanoi Declaration, the Tripartite Concept Note and the recommendations of the United Nations, the World Bank and the European Union are examples of this.



The ONE HEALTH approach (Source: ISGloba)

The environment plays a central role in animal-mediated diseases. It acts as a reservoir in which substances accumulate and are transported and mediates the transfer of diseases to humans. Thus, there is growing evidence pointing to the crucial role of the environment in the physical and mental well-being of humans. The 'One Health' approach is therefore based on the triad of human health, animal health and ecosystem health, of which the last term is most often forgotten, as evidenced by its absence from a significant number of policy documents, although this is rapidly changing. The relevant role of the environment in the 'One Health' concept has become evident through the study of two phenomena that are becoming particularly visible today: antibiotic resistance and climate change. The case of climate change is paradigmatic in this context, as it compromises the integrity of living systems by causing changes in the life cycles of pathogens, their vectors and host organisms, favouring the development of new emerging diseases in plants and animals, favouring trophic cascades, affecting interspecific interactions and by its ability to alter habitats. Consequently, it becomes clear that the 'One Health' approach requires a thorough understanding of ecosystem functioning, including physical structure, biodiversity, temporal and spatial dynamics, species interactions, species-environment feedback loops and material and energy flows.

For millennia, natural systems have helped to provide the right conditions for many crops to thrive, providing food, water and energy or disposing of waste. However, human activity itself has affected ecosystems in such a way that the link between the environment and animal and human health is broken by anthropogenic processes that cause ecosystem degradation, such as changes in land use. Biodiversity loss or climate change and pollution.

Achieving the right balance between socio-economic development and environmental protection has become a key objective for achieving good environmental status from a “One Health” perspective.

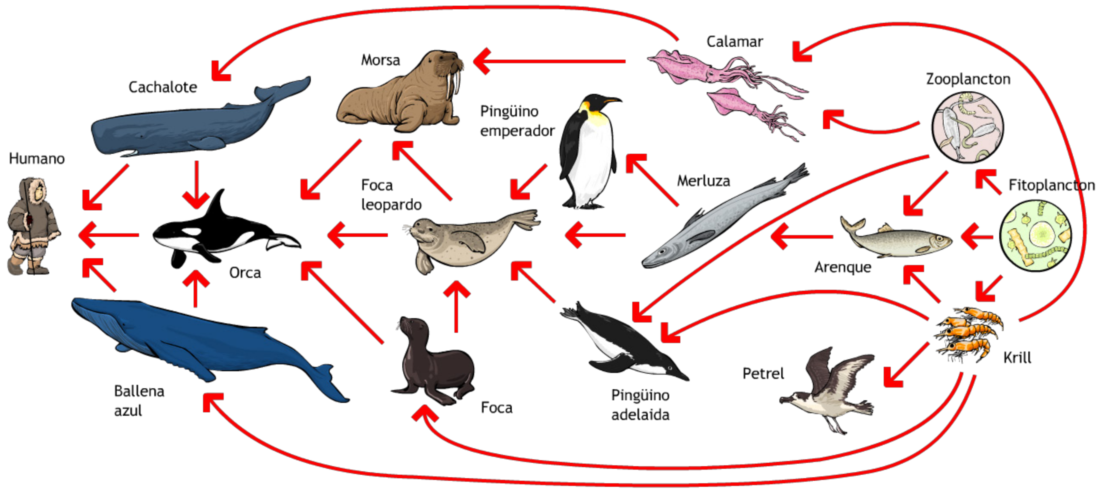
1.2 ECOSYSTEM STRUCTURE, FUNCTION, SERVICES AND BENEFITS

From the earliest moments of human societies on Earth, they have interacted with their environment to satisfy their needs for food, shelter or even culture or sacred rituals. In recent decades, the combination of the increase in human numbers and, above all, the technological development that this species has generated, has led to a massive increase in its ability to transform its environment. Today, about three quarters of the earth’s land surface is occupied by human-managed territories, be it agricultural land, forests, residential areas, etc. It is therefore increasingly necessary to approach the role of humans in nature from a holistic perspective, taking into account not only the direct impact of humans on ecosystems, but also the complex web of interactions that underpin their functioning. Understanding how ecosystems function and assessing the services and benefits derived from them is now essential if we are to manage our presence on the planet from a ‘one health’ perspective.

The ecosystem is the structural and functional unit of ecology in which organisms interact with each other and with the physical environment around them. Each ecosystem is made up of a physical component, the so-called biotope, i.e. water, soil, sediment, air, etc. On top of this physical supporting structure is the biological component, the biocenosis, made up of living organisms, which grouped in populations of different species form communities.

An ecosystem can be characterised on the basis of variables that provide information on its condition. Thus, in the case of the physical component, variables such as temperature, salinity, turbidity, humidity, etc., make it possible to define the environmental conditions in which living organisms develop. The condition of populations and communities can also be characterised by variables such as abundance, size or age structure, population growth rate, spatial structure, species richness or ecological diversity. All these variables allow the structure of ecosystems to be described, providing knowledge which, although very important, only partially illustrates the reality of these ecosystems.

On the one hand, the species that make up the biological community are not static parts of the ecosystem mechanism. On the contrary, each of these parts interacts with the others through a wide range of processes known as interspecific relationships, including competition, predation, facilitation, mutualism and parasitism. On the other hand, the biological community of an ecosystem, like any grouping of living things, requires a continuous flow of energy that leads to the synthesis of reduced organic compounds from inorganic, sometimes oxidised, matter and the circulation of this matter through networks of interactions based on predation or degradation processes of dead organic matter. This approach to studying ecosystems also includes variables that illustrate how they function. These include primary production, which represents the rate of production of organic matter by photosynthetic organisms, secondary production, i.e. the rate of production of organic matter by heterotrophic organisms, or the rate of remineralisation, i.e. the transformation of organic compounds into inorganic compounds, mainly linked to the action of the microbial component. These variables refer to the functions that ecosystems perform as a result of ecological interactions between living organisms and between living organisms and the physical environment. Ecosystem functions therefore refer to the processes by which ecosystems exchange matter, energy and information with the physical environment.



Food web structure of an ecosystem

The existence of these ecological functions on a given territory has consequences that can be translated into services which in turn generate benefits, some of which have economic value, while others are received by society as values. According to the definition in the UN Millennium Ecosystem Assessment, ecosystem services are the benefits that ecosystems provide for people to realise their full potential.

Thus, for example, if we consider riparian vegetation, characterised by a community structure that develops a series of biophysical processes, we can identify a number of ecological functions, such as water uptake, evapotranspiration and sediment and nutrient retention. These functions, which operate independently of human desire, result in the provision of a service, which in this case would be the provision of quality water, a service that directly translates into a benefit for people in the form of a drinking water supply with direct economic value (Illustration 3).

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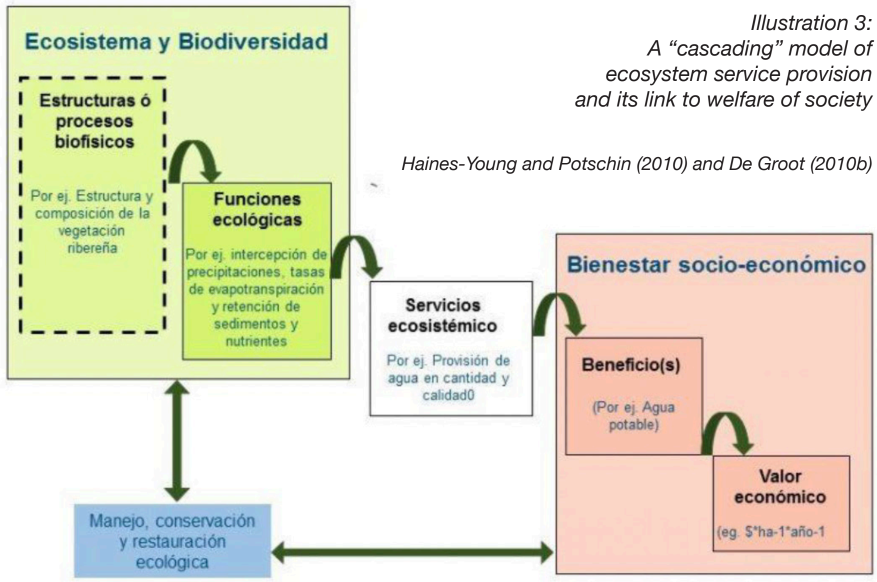


Illustration 3:
A "cascading" model of ecosystem service provision and its link to welfare of society

Haines-Young and Potschin (2010) and De Groot (2010b)

Human action has an effect on the ecosystem, either by affecting its structure or its functions, or both, through its use and management. This effect can become a negative impact or it can have a positive effect through regulations aimed at conserving ecosystems or implementing restoration actions.

The ecosystem approach based on service provision analysis provides an integrated view of human-nature interaction, allowing the incorporation of the multiple components underlying the dependence of human societies on ecosystems. For many of these components, service provision is taken for granted, as for example in the case of air or water quality or carbon storage capacity, and their value is generally ignored.

In general, four types of ecosystem services are considered: provisioning, regulating, supporting and cultural services. Provisioning services provide specific products that people extract from the natural environment, such as timber, food, raw materials or pharmaceuticals. Regulating and supporting services refer to the basic processes that ensure ecosystem functioning, such as the exchange of gases between the biotic component and the atmosphere or water, or the ability to purify harmful compounds.

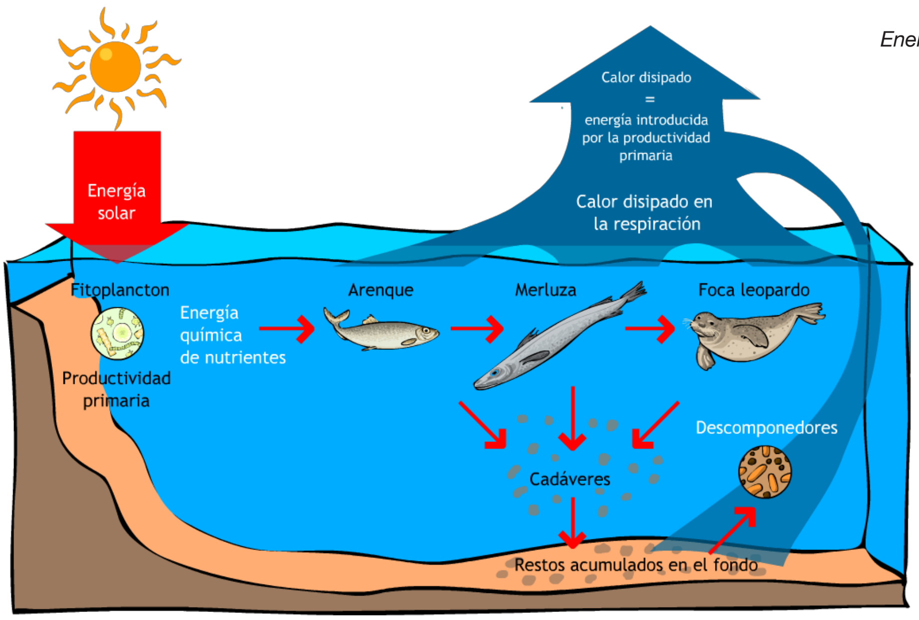
Both types of services are sometimes referred to as regulatory services, given the difficulty of separating them in many cases. Finally, cultural services are those that take into account the intrinsic values of nature, landscape values, cultural heritage and all manifestations of tourism in the natural environment (Fig

Relationship between ecosystem services classified by typologies. Retrieved from WWF

The ecosystem services approach makes it possible to address more effectively the various trade-offs that typically have to be resolved in the tension between using nature for human benefit and maintaining its functionality.

Recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which could be considered the IPCC equivalent for biodiversity (https://www.ipbes.net), revised the conceptual framework for ecosystem services that emerged from the Millennium Ecosystem Assessment to focus on two important issues. On the one hand, by recognising and reinforcing the central role of culture in defining the links between people and nature and, on the other, by elevating the role of local and indigenous knowledge in understanding the relationship between nature and people. As a result of this analysis, the new term ‘nature’s contribution to o a m e n i n g ‘ (NCP) has emerged, which is defined as all contributions, both positive and negative, of living nature (e.g. diversity of organisms, ecosystems and their associated ecological and evolutionary processes) to the quality of human life.

Human impacts on ecosystems can be very diverse in nature. They can affect the abiotic component, changing the structure of solid substrates (soils, rocks, sediments) or fluid envelopes (water cycle, water quality or atmospheric composition). They can also alter the biotic component, altering structure, biodiversity, interspecific interactions, trophic structure, etc. or functions, energy flows, rates of matter movement, etc. In any of these cases, changes to the ecosystem will result in positive or negative changes in the provision of ecosystem services and hence in the potential benefits that humans can derive from nature.



Energy flows

Ecosystem conservation management aims to maintain the integrity of ecosystems. Biotic integrity is understood as the presence of all elements in an ecosystem at the appropriate density, including processes at their appropriate rates. In general, it refers to the state of an ecosystem in relation to a reference state, its natural state. Ecosystem integrity (sometimes referred to as ecosystem health) includes the term biotic integrity, but also extends to physical and chemical processes. It is assessed on the basis of ecosystem functions such as productivity or remineralisation rates. This approach does not start from a static perspective, in which the ecosystem does not change over time or space, but incorporates spatio-temporal variability as a component of ecosystem integrity itself. Even anthropogenic impacts, insofar as humans are part of the biotic component of the ecosystem, can be considered as part of its dynamics.

From this perspective, where changes and impacts are an intrinsic part of the ecosystem, conservation actions must aim to maintain the capacity of ecosystems to recover from impacts. This ability to return to baseline after an impact-related disturbance is what we call resilience. Unlike mechanical systems, ecological systems can exhibit more than one range of stability, and resilience is the property that mediates between these states. Numerous examples of state transitions have been described in different types of ecosystems, from arid and semi-arid grasslands, to lakes, forests, coral reefs, macroalgal meadows and so on. In all these areas, ecological resilience is maintained by the ability of these systems to readapt structural and functional biodiversity in response to environmental stresses caused by disturbances. Maintaining this adaptive capacity that ensures ecological resilience is essential to maintain the functionality of natural systems under anthropogenic influence.

1.3. ANTHROPOGENIC IMPACTS AND DEGRADATION OF ECOSYSTEM SERVICE PROVISION

Human activity has long affected aquatic ecosystems, causing negative impacts on water quality and ecological status. In many parts of the world, and particularly in the European Union, drastic measures have been taken in recent decades to reduce the input of wastewater into the aquatic environment. However, hydromorphological alterations, eutrophication and loss of biodiversity continue to be major problems both in Europe and especially in other parts of the world. These impacts prevent our aquatic systems from achieving 'good ecological status' as defined by the EU Water Framework Directive.

Input of wastewater into the aquatic environment

Numerous studies illustrate the degradation of the earth's ecosystems. Some of them show that 75% of the planet's surface is affected to some extent by human action. The United Nations estimates that 20% of the Earth's land surface was degraded between 2000 and 2015. Nearly 60% of the oceans face cumulative impacts from climate change, overexploitation of resources, pollution or shipping. The degradation of terrestrial and aquatic ecosystems threatens the well-being of more than 3 billion people. Changes to natural habitats caused by human activities are one of the main threats to biodiversity and undermine the provision of ecosystem services and associated benefits to human societies.

The value of these services is often overlooked. This is often due to a lack of sufficient scientific knowledge about them. But to ignore the contributions that nature makes to people is to ignore the existence of the structure that sustains society itself.

Cleaning up the Galician coastline from the oil spill resulting from the Prestige accident in December 2022

Growing concern about the loss of ecosystem services leads to their study through their quantification and representation in space, as knowledge of their magnitude and distribution in space and time should become key tools in ecosystem management, which should be useful in the design and implementation of a wide range of policies. But the acceptance of these policies, and hence their effectiveness, inevitably depends on public knowledge of the mechanisms by which ecosystems provide services and through which they are transformed into benefits for society. In short, it is a priority for society to understand the role of ecosystems in One Health.

In the following sections, we will focus our attention on one particular marine ecosystem that is widely represented in all European seas: seagrass ecosystems.

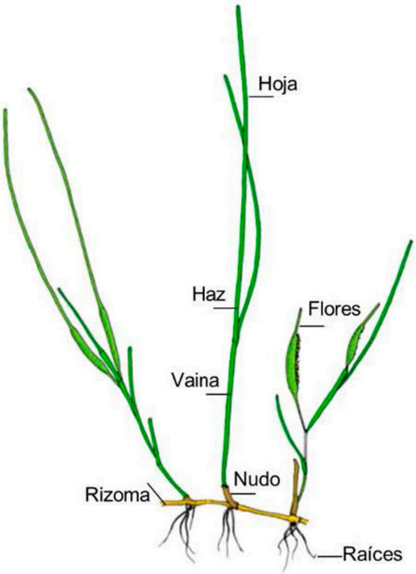
First, the most relevant general characteristics of seagrass meadows will be described and then the main features of three European marine regions, all inhabited by seagrass species of the genus Zostera, will be studied: the northwest coast of the Iberian Peninsula, affected by the process of water rise, the Baltic Sea and the Black Sea. The anthropogenic impacts on seagrass meadows in these three regions are very different in nature. The exploitation of shellfish resources associated with high productivity adversely affects seagrass meadows in the Atlantic growing region. In the Baltic Sea, eutrophication has the greatest negative impact on these ecosystems, while in the Black Sea, the greatest threat to seagrass beds comes from the input of persistent pollutants.

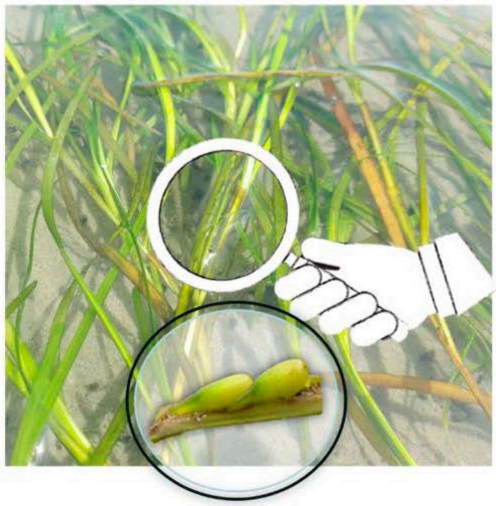
2. SEAGRASS ECOSYSTEMS

2.1 WHAT ARE SEAGRASS MEADOWS?

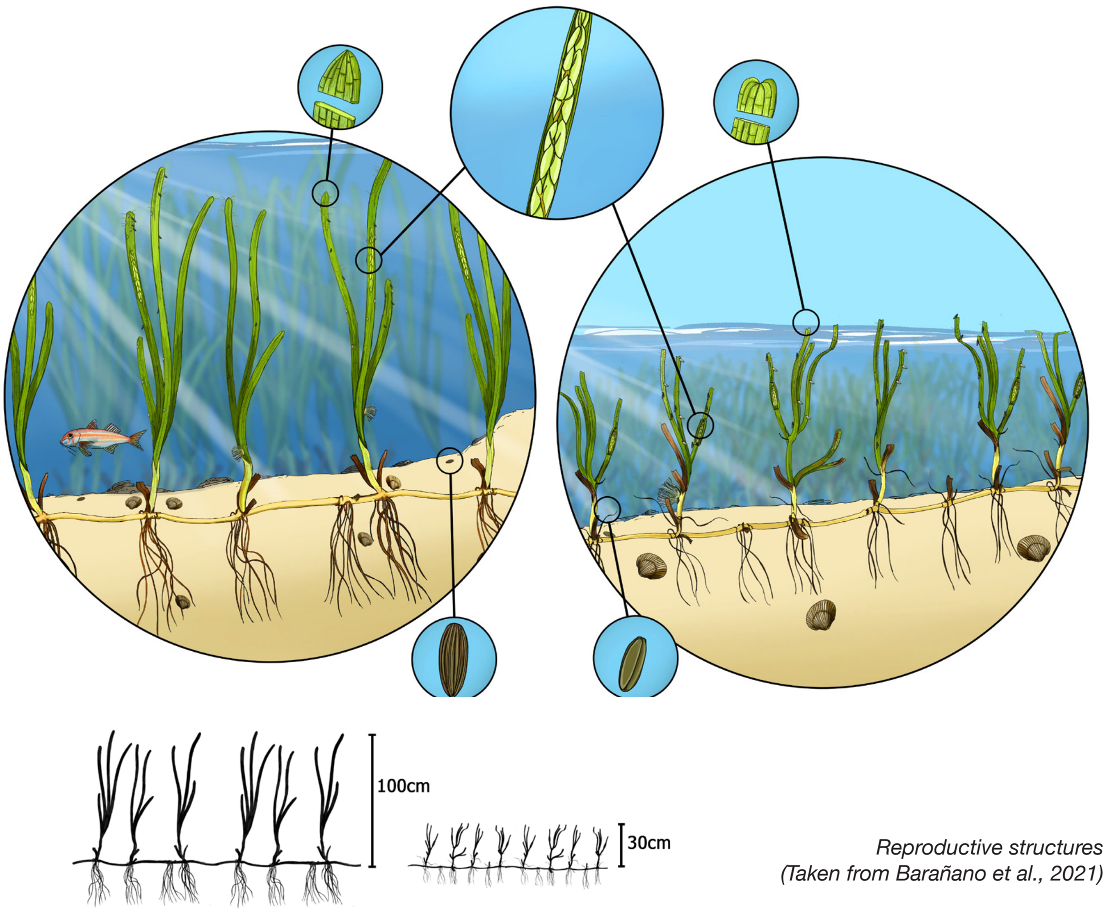
Seagrass is made up of flowering plants, i.e. angiosperms. They are modular plants with a clonal structure, composed of repeating units. Each unit is made up of a set of modules: a rhizome, from which a clump of leaves, called a ‘bundle’, grows upwards and roots grow downwards. In addition, the units may contain flowers or fruit, depending on the observation period (April to August). The leaves are needle-like in shape. At the base of the leaves is the sheath that groups the leaves into clusters and connects them to the rhizome via nodes.

Seagrass grows both vertically and horizontally (leaves extend upwards and roots extend downwards and sideways). They propagate by both asexual clonal growth and sexual reproduction, with flowers or inflorescences, usually discrete, producing fruit and seeds.





Zoostera morphology and biology
(Taken from Barañano et al., 2021).



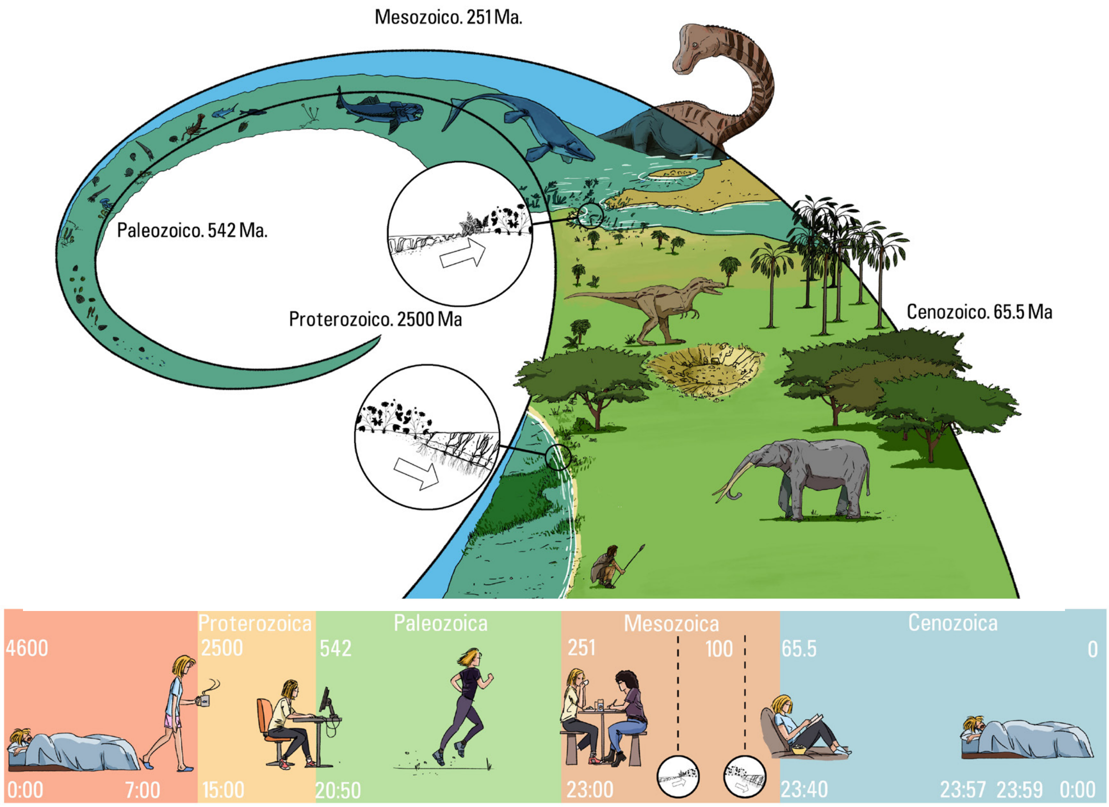
Reproductive structures
(Taken from Barañano et al., 2021)

The appearance of the meadows changes throughout the year, with a seasonal cycle marked by annual variations in light and temperature. To cope with these changes in nutrients and light, plants store some of the carbon they fix through photosynthesis as starch reserves in the rhizome. In winter, the water is colder and generally murkier due to storms. So, as in deciduous forests, it retains only its shortest and youngest leaves and begins to grow slowly, using the reserves stored the previous summer.

In spring, when the days become longer, plants benefit from higher levels of solar radiation to photosynthesise. The sun warms the surface water and the meadows grow quickly. The youngest leaves are deep green and are progressively colonised by a succession of different organisms that settle on them, organisms we call epiphytes. In turn, older leaves are more covered by epiphytes than younger ones, because they have been colonised for longer. In late summer and early autumn, the meadow begins to age.

2.2 EVOLUTION AND ADAPTATIONS OF MARINE PHANEROGAMS

Around 140-100 million years ago, in the time of the great dinosaurs, some green algae began to tentatively colonise freshwater and appeared on land and, in the process, developed adaptations that allowed them to live in terrestrial environments. To adapt to the new environments, these plants developed compounds such as lignin and structures to stand upright in air, a much less dense medium than water. The development of new adaptations to life on land allowed them to extract water from the soil and circulate it throughout the plant (roots and pots) and prevented the gametophytes and spores from drying out.

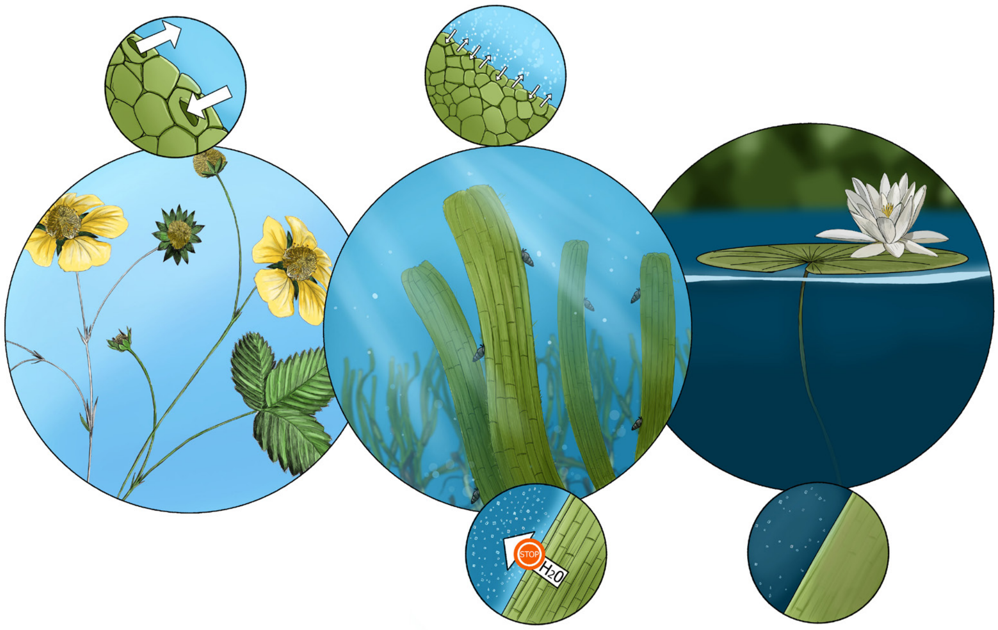


Locating the age of dinosaurs in geological time (Taken from Barañano et al., 2021)

So higher plants lived on continents, while algae occupied seas, oceans, lakes and rivers. The sea was the undisputed kingdom of algae. But these plants found in coastal ecosystems an opportunity to colonise in a space without competition to grow. However, this new environment required new adaptations to marine life, which derived from structures previously developed in the terrestrial environment, such as roots, rhizomes or flowers.

Life submerged in a watery and saline environment presents many challenges that require physiological and morphological adaptations. For example, as solar radiation penetrates the sea, it undergoes an attenuation process with increasing depth, so its intensity is lower than on land, so the photosynthetic apparatus must be modulated to adapt to these changes. On the one hand, they need a more efficient photosynthetic system to capture radiation at the right wavelengths. On the other hand, the effect of water on the extinction of solar radiation means that UV protection systems are not needed.

Stomata are small pores in terrestrial plants through which gas exchange takes place. In other words, it's where oxygen leaves and carbon dioxide enters the plant. Living submerged, marine plants do not need to avoid the loss of water that occurs when they are in contact with air. Stomata are therefore no longer needed for gas exchange, as gas exchange can take place over the entire surface of the plant.



Zostera leaves without stomata (Taken from Barañano et al., 2021).

Submergence exposes organisms to the forces of wave action and tidal currents, so they must have flexible, slightly lignified leaves that move with the currents so that they do not oppose the movement of the sea, thus avoiding breakage. Also, because they live underwater, they do not need to develop supporting structures, sometimes woody, to stay upright.

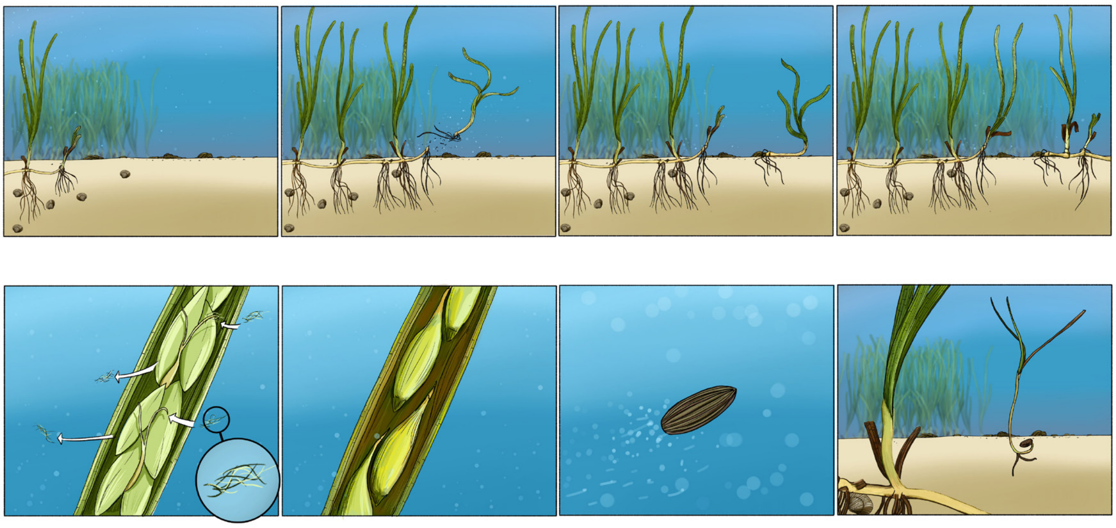
There are no insects in the marine environment, so these marine plants do not need to produce defence compounds against these organisms. On the other hand, they have no pollinators, so they have evolved to reproduce by hydrophilic pollination, in which currents are responsible for dispersing pollen. Seagrass meadows are often exposed to high levels of salt, which vary intensely over short time intervals, which has led to the development of salinity countermeasures.

2.3 REPRODUCTION

Like terrestrial grasses, the clumps we see in seagrasses are connected underground by an extensive network of structures called rhizomes. Rhizomes can spread beneath sediments and produce new shoots. When this happens, several stems within the same seagrass can be part of the same plant and will therefore share the same genome, which is why this type of growth is called clonal growth. In fact, the oldest known plant is a clone of the Mediterranean seagrass Posidonia oceanica, which could be as old as 200,000 years old, dating from the Late Pleistocene glacial period. In some species, a seagrass meadow can develop from a single plant in less than a year, while in slow-growing species such as Posidonia oceanica, this process can take hundreds of years.

A network of rhizomes that generates a network of roots that makes shell fishing difficult. (Taken from Barañano et al., 2021)

Although they are clonal plants, seagrasses rely on sexual reproduction to colonise new areas and maintain genetic variability after disturbance. In this case, pollination takes place in water, it is hydrophilic. The male flowers of these grasses release pollen into the water from the stamens. This pollen often accumulates in clusters, which favours its transport through water. The clusters are carried by currents until they land on the pistil of a female flower, where fertilisation takes place. There is also evidence that small invertebrates, such as amphipods (small shrimp-like crustaceans) and polychaetes (marine worms), feed on the pollen of these species, which may help fertilise flowers in a similar way to how insects pollinate flowers in terrestrial ecosystems.



Asexual reproduction of Zostera at the top and sexual reproduction at the bottom (Taken from Barañano et al., 2021)

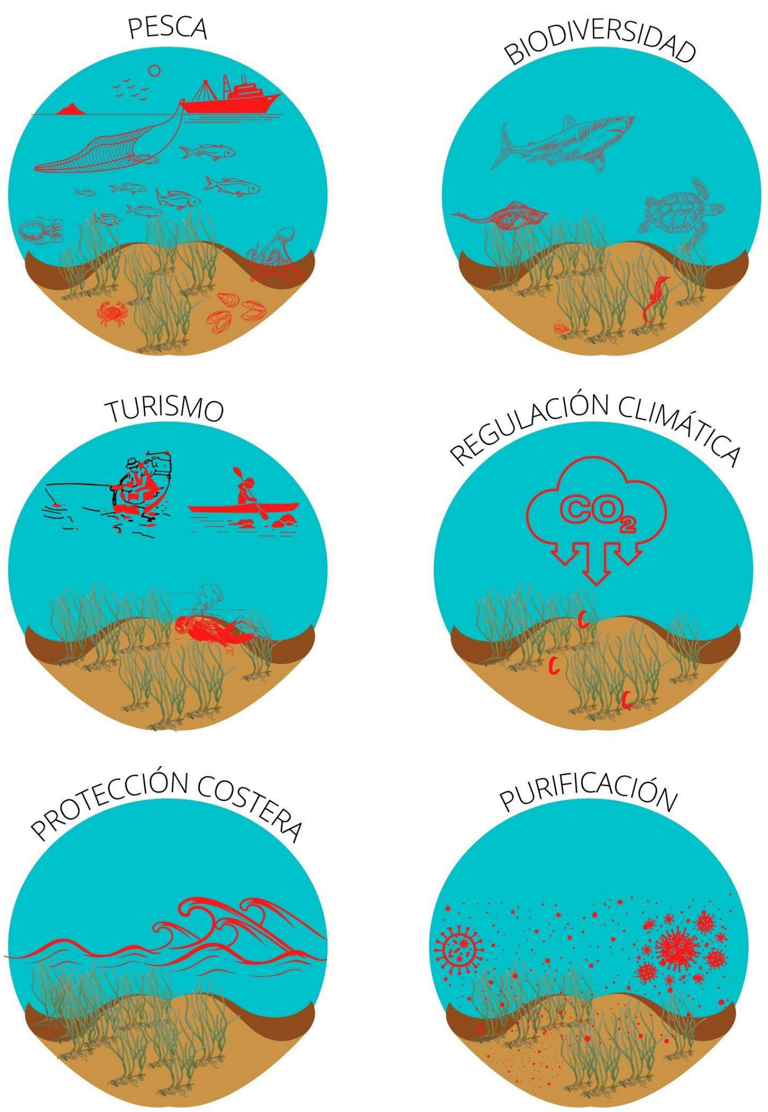
This mode of reproduction becomes much less efficient when population density is low. This is known in ecology as the ‘Allee effect’. This effect results in an increase in mortality rate or a decrease in birth rate when population abundance is low, leading to the existence of a certain population abundance, called the critical viable population size, below which reproductive success is drastically reduced, even leading to local extinction of the species. In seagrass meadows, pollen availability can be a limiting factor for seed or fruit production, causing reproductive decline and accelerated decline of dispersed or fragmented populations.

2.4. ECOSYSTEM SERVICES OF SEAGRASS MEADOWS

Like all ecosystems on the planet, seagrasses provide a wide range of services to humans. However, in the case of these ecosystems, there is very little knowledge about the benefits they provide to society, as demonstrated in several social perception studies. The following pages provide a brief summary of these services, classified according to the typology defined in the previous sections: provisioning services, supporting and regulating services and cultural services.

SERVICIOS ECOSISTÉMICOS

(Taken from Barañano et al., 2021)



PROCUREMENT SERVICES

Seagrass meadows provide valuable spawning habitat for more than 25% of the world's most important fisheries, including pike, the most fished species on the planet. In addition, the development of fisheries and shellfishing in intertidal areas associated with seagrass is a global phenomenon.

In the case of Galicia, the cuttlefish fishery should be highlighted. Seagrass meadows are key areas for the reproduction of this species, as they constitute an ideal habitat that provides shelter for the organisms and, thanks to their three-dimensional structure, allows them to attach their eggs.

Sepia (taken from Aquae Foundation)

Sepia sereproduce (taken from Virtual Biodiversity)

Grasslands are not only a source of indirect food, by creating habitats for species of commercial interest, but have also been used throughout history for direct human food. For example, the Seri Indians collected these plants to extract the seeds for use as grain or cereals. In addition, the leaves of plants of the genus Zostera were used in the past as fertiliser for fields, to make mattresses or to provide thermal insulation for buildings.

SUPPORT AND REGULATORY SERVICES

- **Generating habitats for other species**

The leaves of seagrass-forming species form an enormous surface area that can be colonised by sessile organisms that need a fixed substrate on which to live. Cyanobacteria and other bacteria or diatom algae and fungi form a microbial pellicle on which other macroscopic organisms, the epiphytes, gradually settle.

Sessile organisms that settle on leaves include algae, sponges, cnidarians, bivalve molluscs, bryozoans and tunicates. They are also home to mobile species that feed on leaf-covering epiphytes, such as polychaetes, crustaceans, gastropod molluscs, nematodes and echinoderms. These animals, in turn, are food for various species of fish.

- **Water purification**

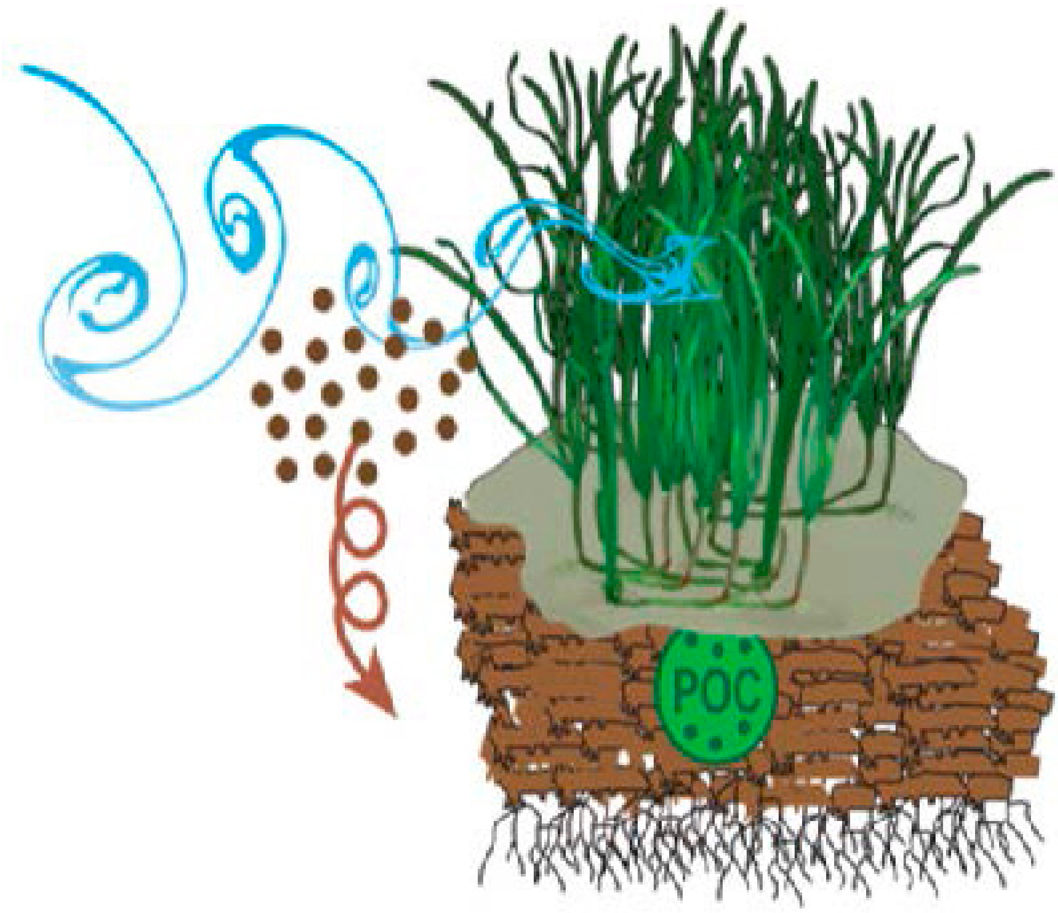
Seagrasses are a natural filter for suspended particles and dissolved compounds, contributing to water transparency and quality. They therefore act as effective natural purifiers, retaining or incorporating toxic or harmful compounds that they store in their roots and tissues or in the sediments themselves, thereby reducing pollution levels.

Meadow with seagrass Zostera noltii in Testal (Ría de Muros e Noia)

Seagrass beds help reduce exposure to bacterial pathogens in fish, invertebrates and humans. Areas where seagrass beds are present have been shown to have a 50% reduction in the abundance of bacterial populations that cause disease in both humans and marine organisms such as corals.

- **Sediment stabilisation**

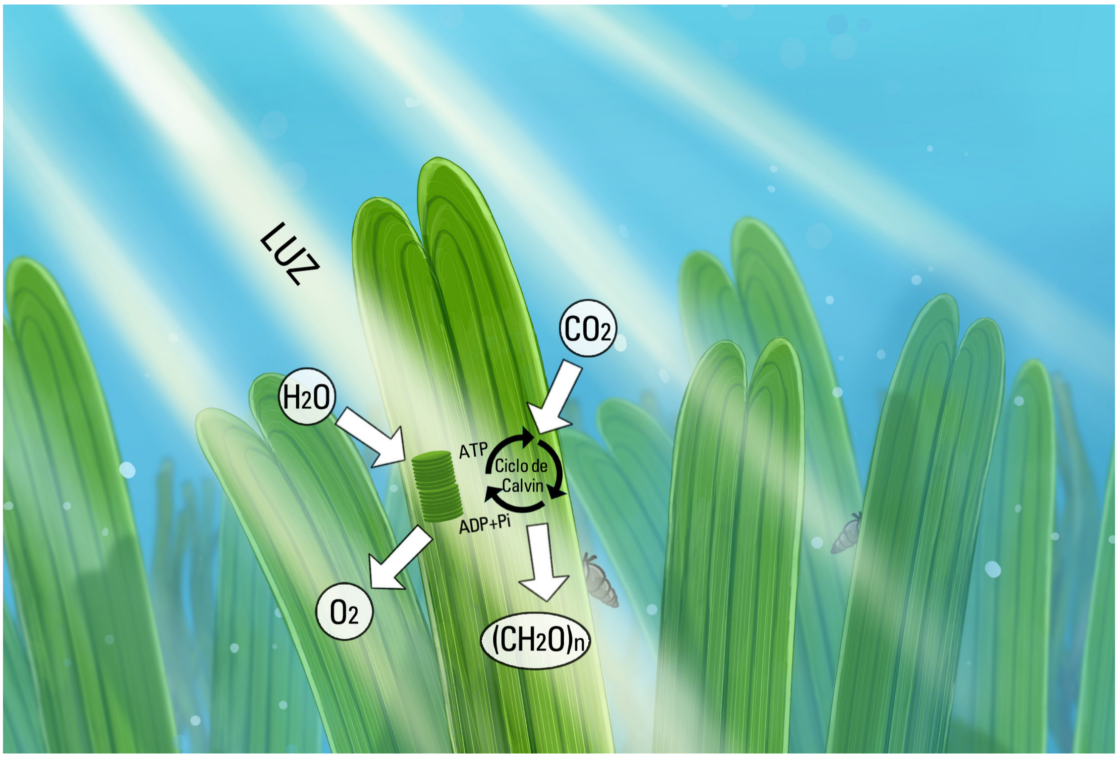
Seagrass meadows slow down the sea currents that carry sediment and other particles and favour the capture of sediment particles by rhizomes and leaves. The root network prevents resuspension and incorporation of these particles into the substrate, thus stabilising the sediment.



Sediment stabilization diagram
(Taken from Barañano et al., 2021)

As plants, seagrasses absorb CO_2 from the water, which comes from the atmosphere, and convert it into organic matter through photosynthesis. This organic matter, made up mainly of carbon, is partly stored in coastal sediments, where it can remain buried for centuries, making it a very efficient carbon sequestration system, partly as a consequence of the low oxygen conditions in these sediments, which make decomposition very slow.

Nearly two centuries ago, people started using fossil fuels for energy on a massive scale. As a result, this has stimulated the release of gases such as CO_2 into the atmosphere, which have the ability to cause an increase in atmospheric temperature, known as greenhouse gases. The fuel used came from deep underground, where it had accumulated over millions of years as coal and oil.



CO_2 uptake by seagrass plants (Taken from Barañano et al., 2021)

The increase in carbon (CO_2) detected in the Earth's atmosphere is causing changes in the Earth's climate and the chemical composition of the oceans, leading to their progressive acidification. In this scenario, ecosystems that have the capacity to capture and sequester carbon from the atmosphere are of particular interest. When we think of such ecosystems, we often think of forests and grasslands. However, although much less well known, a large part of the carbon sequestered by the planet's ecosystems is accounted for by marine habitats, including seagrasses and mangroves. This carbon absorbed by the ocean is called blue carbon.

Photo of Testal sea meadow at low tide with a eucalyptus forest in the background.

Seagrasses cover less than 0.2% of the seabed, but store about 10% of the carbon buried in the oceans each year. The importance of coastal ecosystems as CO_2 sinks has been ignored until recently. However, these ecosystems are now recognised as one of the most active natural CO_2 sequestration systems on our planet.

- **Cultural services**

Seagrass meadows provide spaces for recreation, leisure and tourism, as well as environments for education and research. The biodiversity that seagrass meadows support makes them areas of great interest for the development of various recreational activities, such as underwater nature observation through activities such as Scuba Diving, and they are popular areas for divers to enjoy the underwater landscape. In addition, as they support important communities of fish of fishing interest, these ecosystems are used by recreational fishermen.

Photo showing the tourism potential of the Testal sea meadows.

Similarly, the wealth of services they provide for human well-being and the complexity of the ecosystems they encompass make them environments of great research interest, and over the past 50 years they have been the subject of more than 1,000 scientific publications worldwide. The accessibility and proximity of these coastal ecosystems, as well as their ease of management, favour their use as a learning and dissemination medium for the implementation of environmental education and citizen science programmes.

2.5. IMPACTS AND THREATS: EUTROPHICATION, MECHANICAL DAMAGE, HABITAT ALTERATION, PATHOGENS, CLIMATE CHANGE

Estuaries and coastal waters are particularly vulnerable to a variety of pressures resulting from their close relationship with the terrestrial system and are therefore sensitive to the high levels of anthropisation characteristic of these areas. Seagrass meadows are declining at an alarming rate. On average, about one hectare of seagrass is lost every 30 seconds and it is estimated that 29% of seagrass has disappeared in the last century.

Photo of the mouth of the Tambre river that forms the Ría de Muros - We

In Galicia, pastures also present a worrying situation. This is demonstrated by a study in which the conservation status of several Atlantic Zostera noltei seagrass meadows was assessed by means of two variables: meadow cover in relation to the maximum recorded historical cover and trend, i.e. whether cover has improved over the years or, on the contrary, decreased. According to this study, the sea grass meadows in Rías Baixas have a negative favourable status, which means that they have a cover greater than or equal to 60% of the reference status, although their temporal trend is negative, which means that their cover is decreasing.

The loss of these habitats is linked to processes that alter water quality or clarity, such as nutrient and sediment inputs from runoff, sewage or dredging, leading to eutrophication processes and, consequently, decreased light availability, increased sedimentation or direct physical disturbance, as well as to the effects of global-scale environmental changes such as ocean acidification, rising ocean temperatures or sea-level rise.

Eutrophication of the coastlin

The clearest source of human impact on seagrass ecosystems is physical impacts, including fishing and aquaculture, navigation and anchoring of ships, and habitat modification (dredging, reclamation and coastal construction).

- **Eutrophication**

One of the main causes of seagrass loss is reduced water clarity, both due to increased nutrient loading, which stimulates microalgae growth, and increased turbidity associated with sediment resuspension. Nutrient and sediment inputs from human activities in the terrestrial system have a major impact on these ecosystems, as the relatively high light requirements of seagrasses make them vulnerable to reduced light penetration into coastal waters.

- **Mechanical damage: fishing, anchoring and navigation**

Mechanical deterioration is a major cause of seagrass decline. Removal of plants and damage to shoots and rhizomes leads to drastic reductions in seagrass cover. Seagrass is not physically robust, making it vulnerable to rhizome uprooting, leaf breakage and burial of seeds at depths that prevent germination, all of which are the result of activities such as trampling, the operation of fishing gear working on the seabed or the action of anchors or ship propellers. These types of activities leave scars on seagrass landscapes.

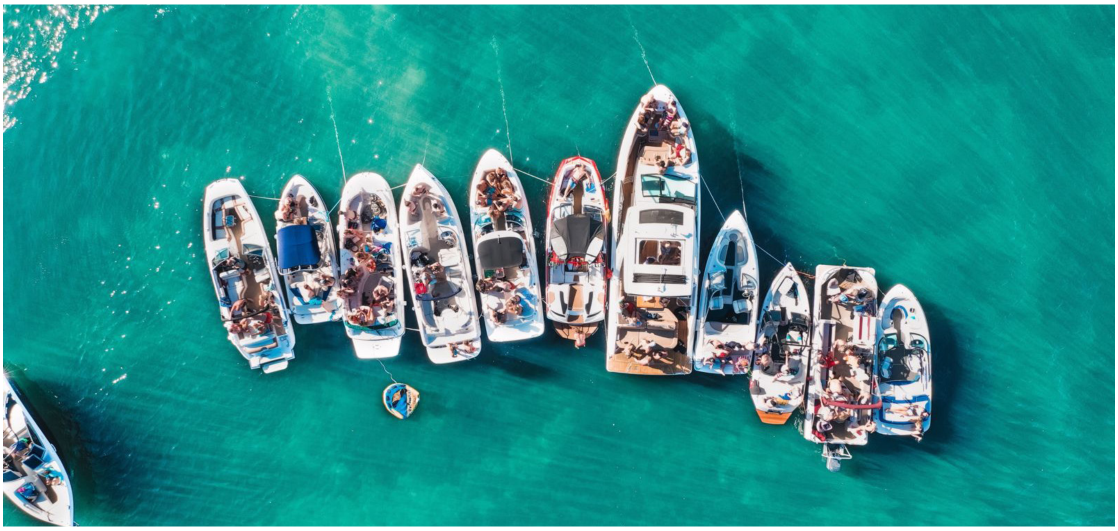


Photo of boats moored on a sea meadow showing anchor cleaning.

An example of the impact on seagrass beds characteristic of our area is the shellfishing activity, which uses fishing devices such as the raño or gancha to rake the seabed in search of clams and other bivalves of commercial interest, lifting the upper sediment layers, breaking and removing the shoots and rhizomes of the plants that form the seagrass beds.

- **Coastal construction**

Alteration of the coastal strip by human action, particularly in relation to increased population pressure, is leading to the transformation and fragmentation of seagrass habitats available in coastal waters.

Development pressure on Australia's Gold Coast

Dredging and reclamation of marine environments, either for sediment extraction or as part of construction or coastal engineering works, can also significantly affect these meadows. Shallow coastal infilling can directly remove the habitat in which these ecosystems are found.

- **Pathogens**

Some marine protists, such as the genus Labyrinthula, have been recognized as pathogens of sea grass causing wasting disease. Symptoms of infections caused by these organisms are the presence of dark brown or black lesions on the leaves, which extend longitudinally and cover the entire leaf after a few weeks. Infections usually occur on mature leaves, but during episodes of severe infection young leaves may also be affected. In the early 1930s, Labyrinthula zosterae was responsible for the dramatic decline of Zostera marina meadows on both coasts of the North Atlantic.

Effects of pathogens on Zostera (Taken from Barañano et al., 2021)

- **Climate change**

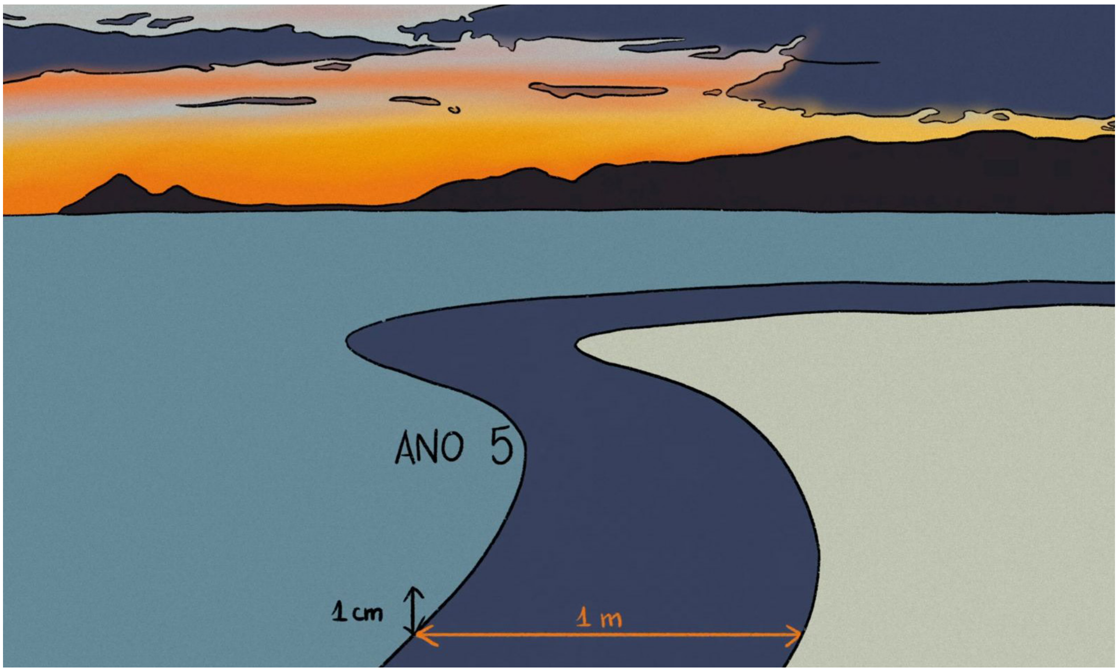
Global climate change is linked, at least in part, to the burning of fossil fuels and changes in land use, leading to increased concentrations of carbon dioxide in the atmosphere and emissions of other greenhouse gases. These changes, leading to increased atmospheric carbon dioxide concentrations, global warming, sea level rise and increased storm frequency and intensity, are likely to have a substantial long-term impact on seagrass ecosystems. In this respect, recent studies link heat waves to serious negative effects on seagrass species cover.

- **Temperature rise**

Temperature influences almost all aspects of the metabolism, growth and reproduction of seagrass-forming species, and has important implications for the geographical distribution patterns of these species. Progressive increases in temperature may therefore pose a threat to local populations of these species, particularly those living in regions close to their distribution limits.

- **Sea level rise**

Temperature rise over the next 25 years will result in a 10-15 cm rise in sea level, mainly due to thermal expansion of the ocean and, to a lesser extent, the melting of glaciers and ice caps on continents. Sea level rise could have numerous implications for circulation, tidal range, current and salinity regimes, coastal erosion and water turbidity, all of which could have a significant negative impact on seagrass.



Infographic on rising water levels, showing that one centimetre in height is one metre in length

- **Extreme weather events**

Mathematical models predict that global warming will lead to an increase in the frequency and intensity of storms, resulting in more coastal erosion. Sediment resuspension causes increased turbidity of waters, reducing the availability of solar radiation to marine benthic primary producer populations. Although many seagrass species are adaptable and can survive periods of low radiation and partial burial, storms often reduce growth and survival and require re-colonisation by seed to re-establish seagrass beds.

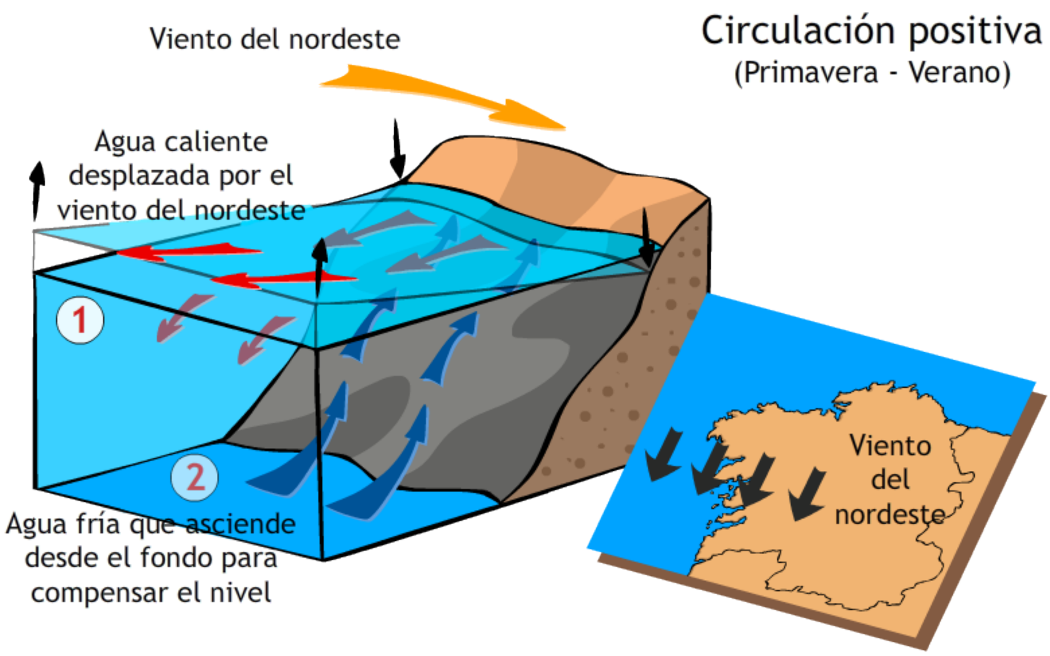
3. CASE STUDIES

3.1 NORTH-WEST ATLANTIC ATMOSPHERIC FLOW SUPPORT REGION (GALICIA)

• 3.1.1 Oceanographic features

The Galician coastal system is part of the 'Eastern North Atlantic Upwelling System', which extends from the 10ºN parallel to the northwest of the Iberian Peninsula at 44ºN, its northernmost part (Blanton et al., 1984).

Climatic conditions in the Northwest Atlantic upwelling region and the large-scale atmospheric processes operating in this region condition the thermohaline characteristics of the water column off the Galician coast. In particular, the atmospheric circulation due to the seasonal migration of the Azores anticyclone, linked to subtropical high pressures, and the Icelandic storm, associated with subpolar low pressures, modulate and determine the interannual variations of the upwelling and subsidence processes of the water masses. In addition, geomorphology and local coastal wind conditions also exert a strong influence on the temporal and spatial patterns of these processes (Nogueira et al., 1997).



NE winds are common in Galicia in spring and summer.

Local winds influence the circulation and conditions of the waters flowing into the estuaries due to the phenomenon of wind channelling in the SW or NE direction exerted by the mountains adjacent to these geological systems, which intervene, on the one hand, in the estuarine circulation and, on the other hand, in the mixing and homogenization of the first meters of the water column (Rosón et al., 2008).

On the Galician coasts, these events frequently occur in spring and summer, when the prevailing winds are from the north. As a result, Ekman transport creates a water shortage on the coast resulting in the development of cold, nutrient-rich North Atlantic Central Waters, which are located at depths between 100 and 500 metres. This phenomenon alters the physical (salinity, temperature) and chemical (nutrients, CO_2) characteristics of water bodies off the Galician coast, causing fertilisation of surface waters (Prego et al., 1999) and, consequently, massive phytoplankton blooms (Castro et al., 1997, Rosón et al., 2008).

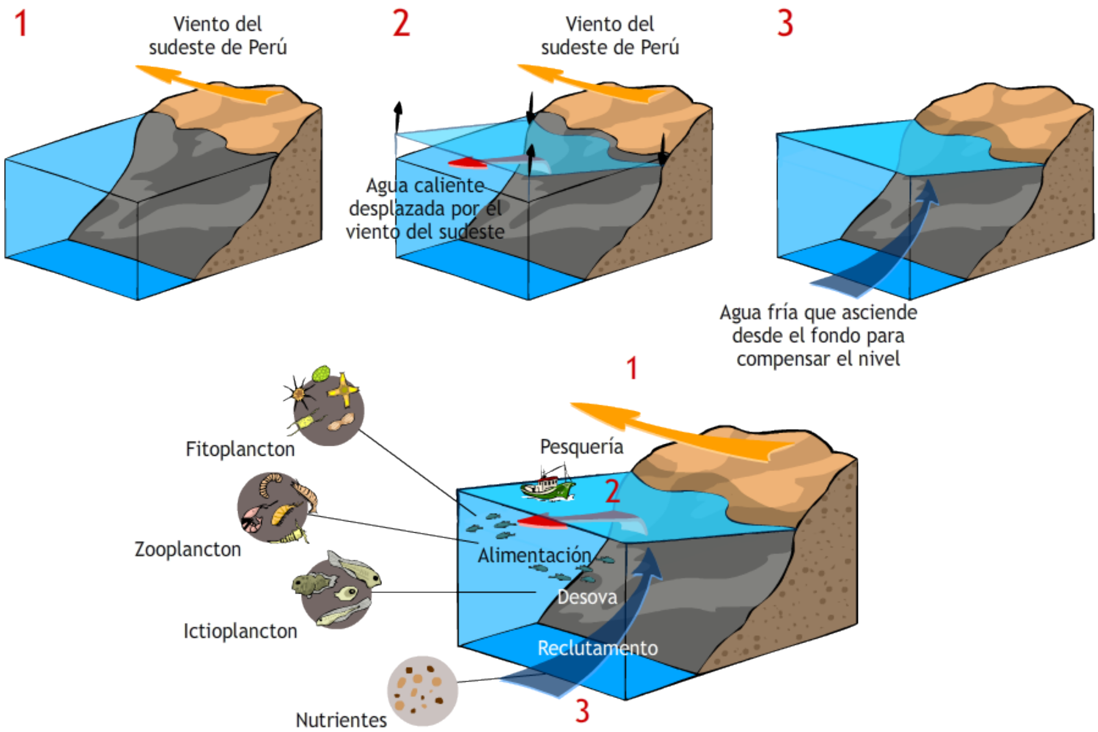
The characteristic production of temperate inflow systems is associated with a high capacity to produce planktonic biomass (Álvarez- Salgado et al., 1996; Figueras et al., 2002; Cermeño et al., 2006, among others), linked to the proliferation of diatoms that form relatively short herbivorous food webs. These phenomena are associated with important fisheries and large seabird populations (Fraga, 1981; Velando, 1997; Figueiras et al., 2002).

Average gross primary production during the tide season was estimated to be approximately 1.4 g C m-2 d-1, although sporadic peaks of 4 g C m-2 d-1 were recorded (Tilstone et al., 1999; Figueiras et al., 2002).

During winter, especially in December-February, this region is affected by another characteristic oceanographic event: the Iberian Poleward Current (IPC) (Frouin et al. 1990; Haynes & Barton, 1990). This current circulates poleward, encompassing the upper continental shelf of the Atlantic coasts of the Iberian Peninsula and France (Haynes & Barton, 1990), extending even to more northern latitudes.

This current has clearly differentiated physico-chemical characteristics, is warmer and saltier than typical for this region in winter, altering biogeochemical conditions and spatial distribution patterns of planktonic communities (Álvarez-Salgado et al., 2003; Prego et al., 2007), and may even penetrate into the interior of the Rías Baixas.

Variations in the physical conditions of the water column characteristic of inflow/sinking episodes and the relaxation and stratification of water masses associated with the inflow event result in high productivity events, in which the size distribution of phytoplankton associated with water column mixing/stratification states and hydrodynamic forcing largely determine the rate at which organic matter is exported to higher trophic levels or recycled back into the microbial circuit (Cermeño et al., 2006).



Increased water flow linked to productivity on the Peruvian coast due to blue winds blowing from the SE, from land to ocean.

These high productivity events are generally associated with the proliferation of certain phytoplankton populations, usually relatively large diatoms, which are favoured by the conditions of the upwelling process, thus dominating the phytoplankton community and favouring carbon flux to the herbivorous food chain and subsequent export to higher trophic levels, while in lower production phases, typical of oligotrophic water input processes during periods of subsidence, they are associated with the dominance of pico- and nanoplankton populations (Teira et al., 2001), which favour the channelling of produced matter to nutrient recycling by the microbial community (Figueiras et al., 2002; Cermeño et al, 2006) and with dinoflagellate blooms, including toxin-producing species that, accumulated by filter-feeding bivalves, pose a risk to human health and to the exploitation of crustacean resources (Fraga et al. 1988; Reguera et al. 2008). These processes tend to generate highly dynamic conditions in both the water column and plant communities, with frequent changes and high temporal frequency (Bode et al., 1993).

Spatial variations in the duration and frequency of upwelling events, in combination with water mass advection events, govern the production cycles of fisheries off the Galician coast (Tenore et al., 1995), whose richness of resources ensures the maintenance of a marine environment sufficiently productive to support the diverse communities that develop in the region and allow important traditional fish and shellfish harvesting activities to flourish.

- **3.1.2 Driving forces and anthropogenic pressures: population, changes in land use, eutrophication, pollution ...**

The Welsh coast is exposed to a range of anthropogenic pressures and threats that are having a negative impact on its coastal ecosystems and the services they provide. Uses of the coastal marine strip are multiple and often overlapping, such as shipping lanes, anchorages, fishing grounds, shellfish farms and mussel rafts, and port activities. Therefore, on the Galician coast, industrial and urban development activities coexist with service activities such as coastal tourism, with the presence of small-scale fisheries and mariculture, which are an important part of the regional economy.

Clams (Cerastoderma edule) in Testal

The study of the economic and social analysis of the marine strategies of the North Atlantic Marine Demarcation (MD) allows a simplified description of the main pressures resulting from human-coastal interaction in Galicia. This study includes an assessment of the main coastal economic activities in the region with a potential impact on coastal systems. The main activities identified are summarised below:

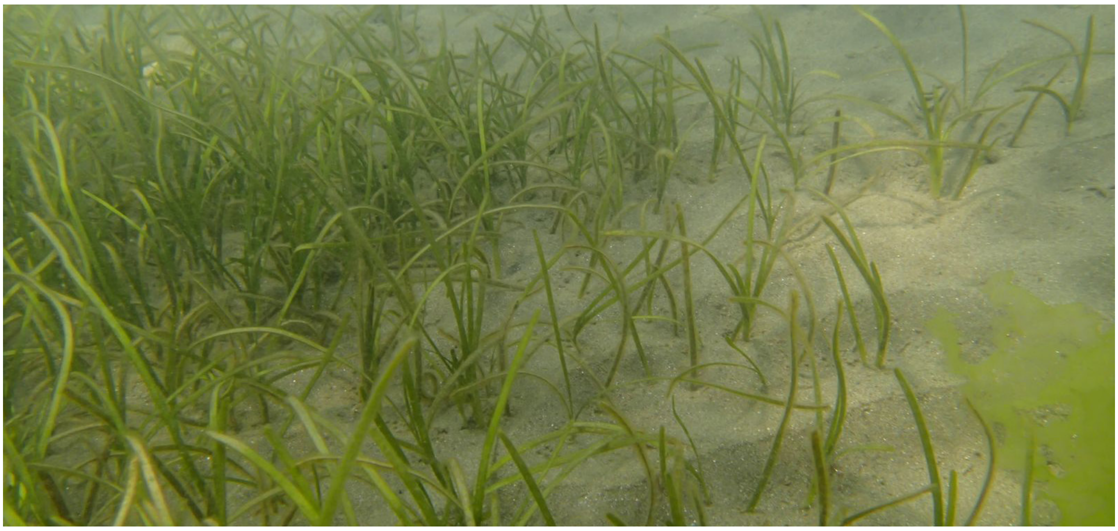
Table I Main coastal economic activities in the region. Adapted from Economic and Social Analysis of the North Atlantic Marine Demarcation Strategy.

Economic Activity	Description	Main Impacts
Physical restructuring of rivers, coastlines or seabeds	This includes coastal defence and flood protection, as well as restructuring the morphology of the seabed	Habitat change, pollution, impact on biodiversity

Economic Activity	Description	Main Impacts
Extraction of non-viable resources	Extraction of minerals such as rocks, metal ores, gravel, sand and shells	Degradation of habitats, loss of biodiversity, disruption of ecological processes
Energy production	Renewable energy production, including infrastructure and electricity transport and communications	Impacts on marine and coastal ecosystems due to the installation of infrastructure
Extraction of living resources	Fishing and shellfishing, fish and seafood processing	Overfishing, degradation of marine ecosystems, decline of fish and shellfish stocks
Cultivation of living resources	Marine aquaculture, including infrastructure	Eutrophication, habitat loss, introduction of alien species
Transport	Transport infrastructure and maritime transport	Water pollution, habitat disturbance, underwater noise
Tourism and leisure	Infrastructure tourism and leisure and tourism and leisure activities	Habitat degradation, pollution, pressure on natural resources

- **Physical pressures**

The seabed can be disturbed both in its profile and in its nature by the removal of sediment as a result of the installation of buried structures such as submarine cables; by the alteration of sedimentary processes produced by aquaculture facilities; by anchoring vessels; by the dumping of dredged material or by trawling, among others. Although the disturbance caused by these activities is temporary or reversible, they do result in changes to benthic habitats and communities.



Zostera seagrass meadow in the Black Sea disturbed by a dike

Table II. Categorisation of physical pressures. Adapted from Analysis of Pressures and Impacts of the North Atlantic Marine Demarcation Strategy

Type of Physical Pressure	Description
Physical disturbance of the seabed (temporary or reversible)	These can be caused by various activities such as coastal defence, flood protection and the restructuring of seabed morphology.

Type of Physical Pressure	Description
Physical losses (due to permanent change in substrate or seabed morphology and removal of substrate from the seabed)	Port infrastructure, coastal defence infrastructure, artificial reefs, hydrocarbon exploration and exploitation platforms, offshore wind farms and other offshore infrastructure can cause physical loss of the seabed.
Changing the profile and nature of the fund	The extraction of sediments from the seabed, either to regenerate beaches, to increase or maintain harbour draught or as fill for harbour infrastructure, and the creation of artificial beaches.

Among the physical pressures that cause permanent changes are the installation in the marine environment of various infrastructures that cause permanent alteration of the substratum and consequently alteration of benthic communities (port infrastructures, offshore wind farms, creation of artificial beaches, etc.).

Anchoring of commercial vessels is the assessed activity that could have caused the most disturbance to the seabed, although it corresponds to a low probability of disturbance. The areas with a high probability of disturbance are located in the vicinity of the ports of Marín and Vigo, while the rest of the ports of general interest generally show a larger area of disturbance than the rest of the ports, albeit with a lower probability of disturbance, with the port of A Coruña standing out with a moderate probability of disturbance in larger areas.

Disturbance of the seabed leads to changes in benthic communities and can lead to their destruction, either by direct removal or burial. If hazardous substances or nutrients are present in bottom sediments, they can be resuspended and become part of the food chain when ingested by organisms.

- **Pollution pressures (substances, waste and energy)**

This group of pressures includes inputs of nutrients from diffuse sources, point sources, inputs of other substances such as synthetics, and inputs of solid waste, including micro-waste. The main terrestrial inputs of nutrients to estuaries and coastal waters are direct discharges and inputs from rivers, with an associated higher likelihood of impact on water bodies with low turnover.

Table III Classification of pollution pressures. Adapted from Analysis of pressures and impacts of the North Atlantic Marine Strategy

Pressure	Description
Substances	Arrival of nutrients, organic matter and other substances into the marine environment via diffuse sources, point sources, atmospheric deposition or major incidents.
Rubbish	The presence of solid waste, including micro-waste, in the marine environment.
Energy	Energy input to the marine environment via anthropogenic sound, thermal discharges and point sources of water such as brine.

The Galician coast is affected by various anthropogenic activities, reflected, for example, in increased levels of heavy metals such as lead and copper in sediments (Prego and Cobelo, 2003; Howarth et al., 2005; Evans et al., 2011). However, one of the most important environmental problems facing the coastal ecosystem in Galicia is the input of incompletely treated urban wastewater into the water column. This has a significant impact on one of the most remarkable ecological services of the coast, such as the annual production of large quantities of mussels or shellfish. This has given rise to a major socio-ecological problem, intensely affecting shellfish production activities, as some shellfish production areas have been declared Zone B (when exceeding 4600 Escherichia coli per 100 g of flesh and intravalvular liquid, according to EC Regulation 854/2004) or Zone C (>46 000 E. coli per 100 g of flesh and intravalvular liquid), losing the commercial value of the product. According to the hydrological plan of the Galicia Costa region, the highest direct inputs of organic matter (excluding that generated in the marine environment itself) are observed in the Marín and Villagarcía estuaries. However, only Villagarcía is known to be affected by nutrients, together with the Noia and A Coruña estuaries.

Clam harvester removing dead clams in Testal

Sources of underwater noise can be short-lived (impulsive, such as seismic campaigns or the piloting of platforms and wind farms) as well as long-lived (dredging, navigation and energy installations). The main continuous input of anthropogenic sound to the marine environment in this study area is associated with shipping and navigation activity, the most representative indicator of which is the density of maritime traffic. The highest levels of noise emissions are associated with the main shipping routes, especially those passing through the Finisterre maritime traffic separation scheme. The ports with the highest average noise emission levels, close to 150 dB re 1µPa, are Vigo and Pontevedra and, to a lesser extent, Coruña and Ferrol, with 140 dB.

- **Illustrative case: Vigo Estuary**

The process of urbanisation, widely associated with the demographic and industrial development of Galicia's coastal areas, has led to significant changes in land use in the territory around the Rías. The case of the Ria Vigo is presented as an illustrative example of the coexistence of human populations, their associated economic activity, the consequent modification of the marine ecosystem, including the degradation of water quality conditions, the production of a considerable amount of shellfish and the presence of well-preserved marine ecosystems.

The study by Fernandez et al. (2016) illustrates the role of the Vigo estuary as a model system in which environmental pressures on the coastal ecosystem coexist with significant fish extraction and shellfish production activity, as well as near-pristine marine areas at a small spatial scale. To this end, the intensity of transformation and the dynamics of land use classes were quantitatively assessed for the period 1990-2006, showing that artificial land increased by 8 km2 during this period, mainly due to new industrial developments and urbanisation. This value corresponded to 2.1% of the total area of municipalities in the study area.

The literature review of the impacts and pressures of this system has described and quantified the loss of breeding and nursery habitats for commercial species due to the proliferation of landfills and deterioration of water quality, particularly as a result of nutrient, organic matter and fecal bacteria inputs via small rivers and poorly functioning sewage treatment plants along the coast.

Despite the considerable amount of chemicals and faecal bacteria entering this environment, water quality conditions are largely compatible with the provision of supply services by the marine ecosystem, due to the hydrodynamics of the Rías. However, pollution in the Vigo estuary is still significant and generates an intense social reaction, highlighting pollution-related conflicts, fish and shellfish exploitation activities, coastal urbanisation, coastal landfills and the regression of protected natural areas.

3.1.3 Northwest Atlantic: high productivity and exploitation of marine resources

As explained in the previous sections, the Rías Galicea are highly productive ecosystems that allow the development of important traditional fish and shellfish farming activities, as well as intensive mussel aquaculture in rafts. In Galicia, small-scale fisheries support more than 25,000 jobs, with around 10,000 fishermen (a third of whom are women working mainly in intertidal shellfish fisheries) and more than 17,000 indirect jobs (IGE - Instituto Galego de Estadística, 2021). There are over 3,827 registered small fishing vessels operating in coastal bays and shallow ocean waters (Xunta de Galicia, 2021). With more than 80 municipalities with a predominantly fishing-based social sector, many of the coastal towns and villages in north-western Spain are highly dependent on fishing and fishing-related activities (Villasante et al., 2022; Freire and García-Allut, 2000).

The scallop fishery includes the farming, catching and harvesting of a wide variety of marine species classified in fisheries legislation as ‘specific resources’. Specific resources include sessile or low-mobility species of high commercial interest, including species such as the sea scallop (Pollicipes pollicipes), the sea urchin (Paracentrotus lividus), the sea scallop (Ensis arcuatus) and the clam species Venerupis romboides and Venerupis corrugata (Navarrete, 2010). These resources are exploited by fishermen historically organised in groups of shellfish gatherers (cofradias and/or cooperatives), who draw up an annual exploitation plan (Decree 423/1993), based on the local knowledge of the fishermen, with the scientific advice of the technicians of the cofradias, which is supervised by the autonomous department with competence in this area. These exploitation plans must include a brief report on the state of fish stocks based on data from previous years, production and financial objectives, an exploitation plan with the fishing grounds to be considered, and the vessels and operators for which authorisation is requested.

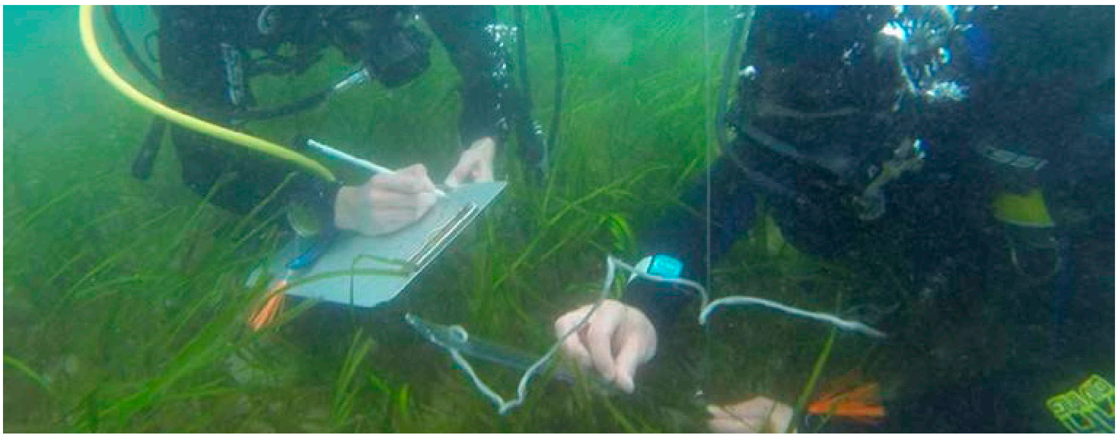
Shellfishing is carried out both on foot and from boats, in sea or sea-land areas, using selective gear specifically designed for each species. In Galicia, shellfishing is of great social importance as it provides income for around 4,000 people employed in the fishery on foot, most of them women. On the other hand, shellfishing on the water is mainly practised by men.

Illustration of bivalve shell fishing on foot and by boat as a major impact on seagrasses (Taken from Barañano et al., 2021)

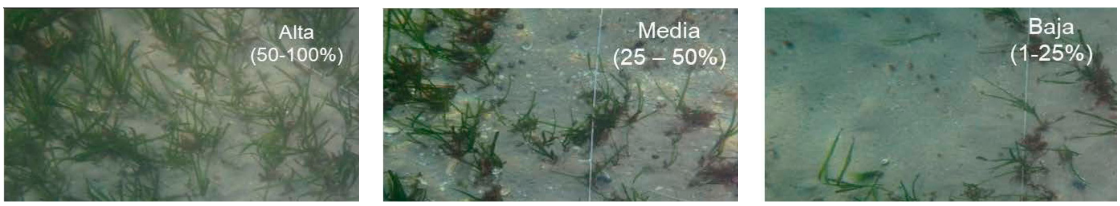
The conflict of uses between shellfishing and seagrass conservation arises because of the overlap of these two activities in the same marine area. On the one hand, shellfishing is an important economic activity that provides employment and income to coastal communities and is highly dependent on the exploitation of natural bivalve beds that are often found in areas where seagrass beds develop. On the other hand, seagrass beds are fragile and highly productive ecosystems that provide important ecological services such as coastal protection, improved water quality and habitat for a variety of marine species.

- **3.1.4 Resource exploitation and loss of ecosystem services from seagrasses**

Seagrass is found in coastal areas within the land-sea interface, developing dense and continuous meadows or mosaics of vegetated and bare areas (Fonseca et al. 2000; McKenzie et al. 2020). This characteristic spatial structure led to the formulation of the term 'seagrass landscape' more than two decades ago (Robbins and Bell 1994), which refers to a matrix of connected habitat patches exhibiting high spatial and temporal heterogeneity (Boudouresque et al. 2009).



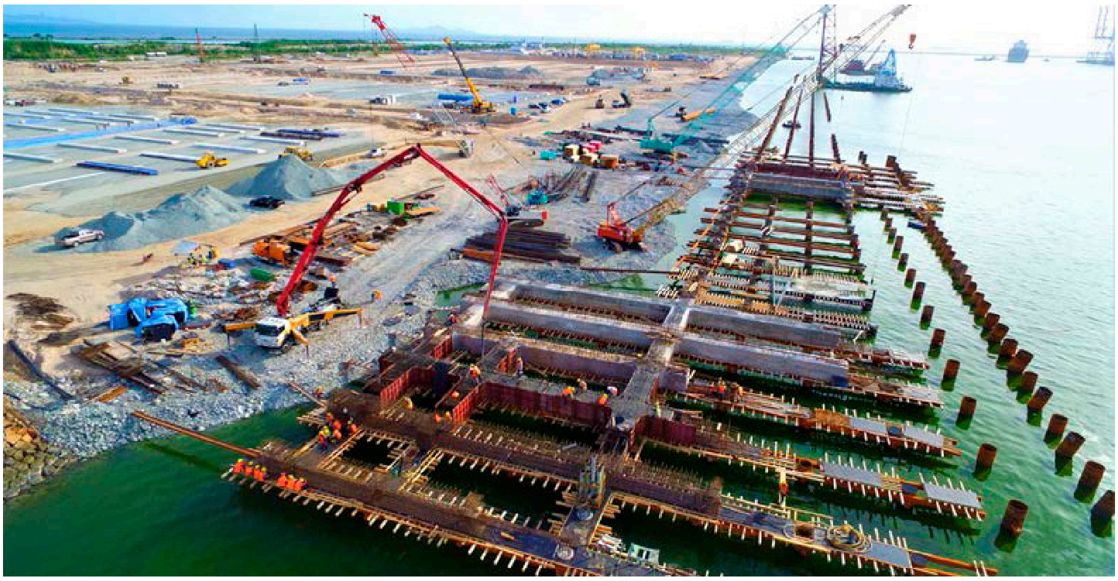
Researcher collecting coverage data (Taken from Barañano et al., 2021)



Three types of coverage (Taken from Barañano et al., 2021)

The process of habitat fragmentation refers to both a reduction in the range of a population and a change in its configuration, altering the spatial arrangement of patches in which it is distributed, as well as the distances between them and their connectivity or juxtaposition (Boström et al., 2011). This process is associated not only with a loss of diversity, but also with an alteration of ecosystem functions, in which a series of interrelated changes occur that affect habitat structure (changes in the number, shape, size and quality of patches) as well as ecological processes occurring in the system (Boström et al., 2011).

Anthropisation of coastal areas where seagrass meadows develop leads to increased habitat fragmentation (Montefalcone et al., 2010). In particular, physical disturbance of seagrass meadows, such as ship propellers, boat anchors or dredging (Boström et al., 2011), not only reduce the extent of seagrass meadows, but also affect their spatial structure (Montefalcone et al., 2010), which in turn alters meadow dynamics and the trophic structure associated with this habitat (Rielly-Carroll and Freestone, 2017).



Public works and eutrophication that can affect seagrass meadows

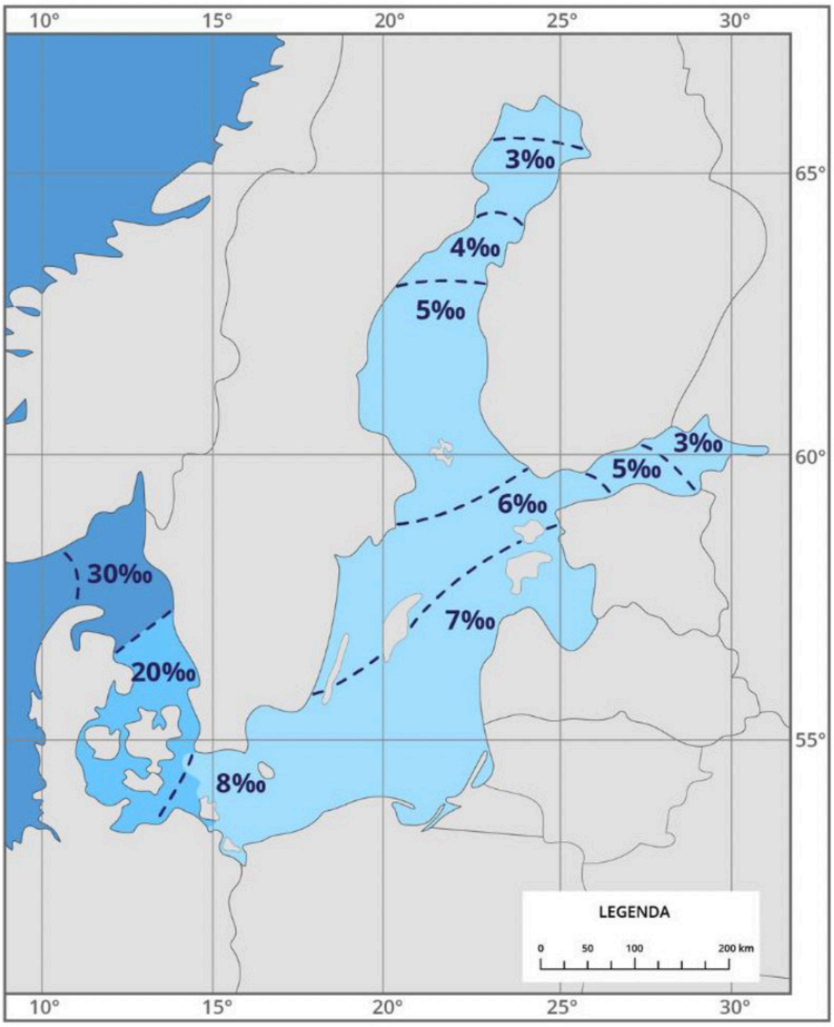
Recent research in this area has recorded the impact that shellfishing has on the ecology of these ecosystems, compromising their resilience. This interaction has been shown to alter spatial and temporal dynamics, decreasing density and cover, reducing their carbon storage capacity and associated sedimentary carbon stock. Patterns of genetic differentiation between affected and control populations have also been identified, linked to a decrease in genetic variability, which may reduce their evolutionary potential and long-term resilience.

3.2 BALTIC SEA

- **3.2.1 Oceanographic features**

The Baltic Sea is an inland sea in northern Europe. It is the least saline sea in the world. The average salinity of Baltic waters is only 7 per thousand. The saltiest waters of the Baltic Sea are found around the North Sea, where the salinity reaches 20 per thousand.

Photo of the Baltic Sea (taken from Surprising_Shot)



Baltic Sea Map Exit

Salt water in the Baltic Sea tends to sink to the bottom and create anaerobic zones there. The waters of the Baltic Sea are considered brackish, i.e. a mixture of fresh river water and seawater, with a salinity lower than that of most seas but higher than that of rivers. It is characterised by a very large catchment area into which some 250 rivers flow, the largest of which are: Vistula, Oder, Neva, Neva, Kemi, Niemen, Lule, Gotha, Ångerman and Dvina, which supply a large amount of fresh water. The low salinity of the Baltic Sea is also due to relatively low temperatures and, consequently, the lower rate of water evaporation.

The Baltic Sea is a cold sea, the water temperature varies depending on the geographical position of the location, from 12 to 22 degrees in summer and from 0 to 3 degrees in winter. The average sea temperature is 18 degrees.

The Baltic Sea basin is a highly industrialised and urbanised area, home to more than 140 million people. As a result of industrial, agricultural and municipal activities, pollutants and organic and inorganic wastes such as heavy metals enter the sea. These accumulate in seawater, suspended matter and sediments. Toxic substances enter the food chain, posing a threat to animal and human health.

- **3.2.2 Baltic Sea: eutrophication processes**

Eutrophication is probably the biggest environmental problem facing the Baltic Sea today. The main causes are excessive loads of nitrogen and phosphorus, which come from land areas in the Baltic Sea basin as well as from areas outside the basin. The Baltic Sea has been described as having changed from oligotrophic (clear water) to strongly eutrophic in the 20th century. The cause of the deterioration in water transparency is the excessive growth of green algae and cyanobacteria caused by nutrient input.

Because the exchange of water with the saltier and better-oxygenated North Sea is limited, organic matter that falls to the Baltic Sea floor during decomposition consumes available oxygen, activating the sulphate reduction pathway, which leads to hydrogen sulphide, causing the formation of dead zones on the bottom, so-called oxygen deserts, where the life of fish and other aerobic organisms is hindered or prevented. Since the beginning of the 20th century, the surface area of dead zones in the Baltic Sea has increased more than tenfold. They now account for almost a fifth of our seabed and cover an area larger than Denmark, which is the largest oxygen-deficient area in European seas.

Photo of eutrophication of Zostera meadows

Rivers are the main source of nutrients in the Baltic Sea (over 80% for nitrogen and over 90% for phosphorus). On the other hand, if we take a closer look at pollution carried by rivers, the most important category of anthropogenic sources is pollution from agricultural activities. This accounts for 46% of the total nitrogen load and 36% of the total phosphorus load entering the Baltic Sea from the Baltic States. One of the largest suppliers of nitrogen and phosphorus compounds to the Baltic Sea basin is Poland. This is because two major rivers, the Vistula and the Oder, flow through Poland, facilitating the transfer of nutrients from land to sea. In addition, there are three other major rivers that contribute to the nutrient loading of the Baltic Sea: the Dvina, Neva and Neman.

In 2010 alone, 80 000 tonnes of nitrogen and 3 200 tonnes of phosphorus entered the Baltic Sea (figures after normalisation for weather conditions). This is almost 5 times more nitrogen compounds and 9 times more phosphorus compounds than at the beginning of the last century. Today, about 50% of the nutrients entering the Baltic Sea come from agriculture. Its sources are animal faeces and excess fertilisers that plants cannot absorb. Forecasts indicate that agricultural production will continue to increase in the coming years due to a growing population and a wealthier society that is consuming more and more meat. Global food production could double by 2050, which will significantly increase nitrogen and phosphorus concentrations in water.

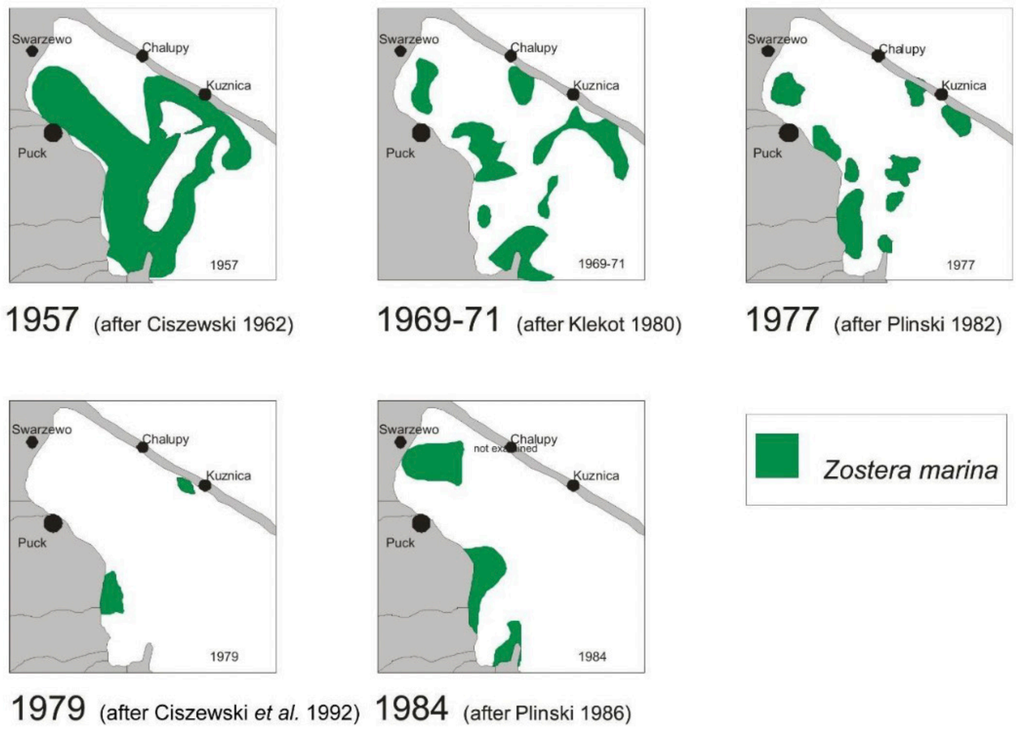
3.2.3 Eutrophication and loss of seagrass ecosystem services

Aquatic plants are useful in combating the effects of eutrophication because they use biogenic elements for their life processes, reducing their concentration in water bodies. An example of such a plant is the marine phanerogam Zostera marina, which a few decades ago covered most of Puck Bay, forming underwater meadows at 1-2 m depth. Today, this species is found in very few places in the basin. Seagrass meadows provide habitat and feeding areas for many aquatic animal species, stabilise sediments and reduce coastal erosion. They also lead to better oxygenation of coastal waters and improve water quality through the accumulation of pollutants (e.g. heavy metals) and excess nutrients.

Seagrass meadows also provide a natural habitat for the life and reproduction of many species of fish and invertebrates, which are often of great economic importance. Examples of species found in seagrass meadows in the Baltic Sea are the sand clam (Mya arenaria) and the common serpentine clam (Cerastoderma glaucum), among bivalves, the sea bass (Perca fluviatilis), the common burbot (Rutilus rutilus), sandperch (Sander lucioperca), pike (Esox lucius), flounder (Abramis brama) and plaice (Platichthys flesus) among the fishes, as well as the sea needle (Syngathus typhle) and sea bream (Nerophis ophidion).

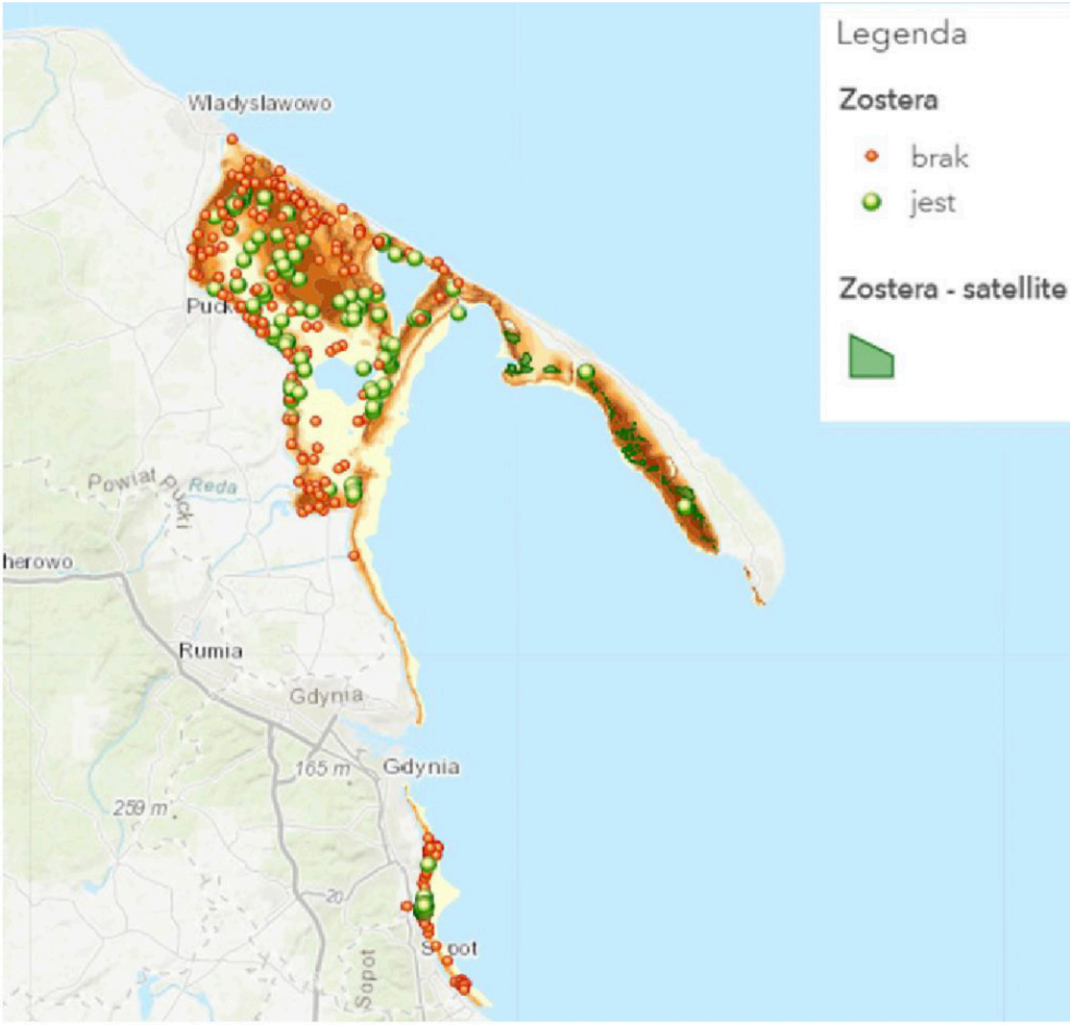
Eutrophication of the Baltic Sea is contributing to the decline of many plant and animal species. One example of a species that is in significant decline in Baltic waters as a result of eutrophication is Zostera marina. Another reason for the decline of seagrass meadows has been mass fishing and its use in the upholstery industry in the 1960s as a material for mattresses and furniture. Since the 1970s, the coastal area has also seen an increase in sand mining, which has also negatively affected the seagrass population.

The figure below shows changes in seagrass occurrence in Gdansk Bay between 1957 and 1984.



Changes in the occurrence of seagrass meadows in Gdansk Bay between 1957 and 1984

Gdansk Bay is a body of water with typical Baltic Sea conditions in terms of temperature and salinity (about 7-8 PSU) (SatBaltyk, 2019), and the dominant sediment type is sandy sedimentary (HELCOM, 2018). In Gdansk Bay it is possible to distinguish regions characterized by higher biodiversity than other areas of the seabed. One of these are communities of so-called seagrass meadows, which can be found, for example, on the Polish coast (Fig. 1). Z. marina is one of the vascular plants found in the Baltic Sea (Podbielkowski and Tomaszkiewicz, 1979).



Presence of Z. marina in Gdansk Bay [1].

Submerged Z. marina meadows are characterized by a higher density of invertebrates than adjacent unplanted areas (Bostrom and Bonsdorff, 1997; Włodarska-Kwalczuk et al, 2014; Dąbrowska et al, 2016). They provide habitat and feeding areas for many animal species, breeding areas for fish and shelter from predators for a wide variety of animals (Howard and Short, 1986; Nelson and Bonsdorff, 1990; Gonciarz, 2014).

The high diversity and density of animals may be due, among other things, to the greater number of refuges they provide from predators for organisms at the top of the food chain (Bostrom and Bonsdorff, 1997). In addition, seagrasses play an important role as species that can alter the direction of ocean currents and stabilise sediments, thus preventing bottom erosion (Hemminga and Duarte, 2000). Sediments found in seagrass beds are characterised by a higher amount of organic matter (Bostrom and Bonsdorff, 1997), which provides a food base for detritivores.

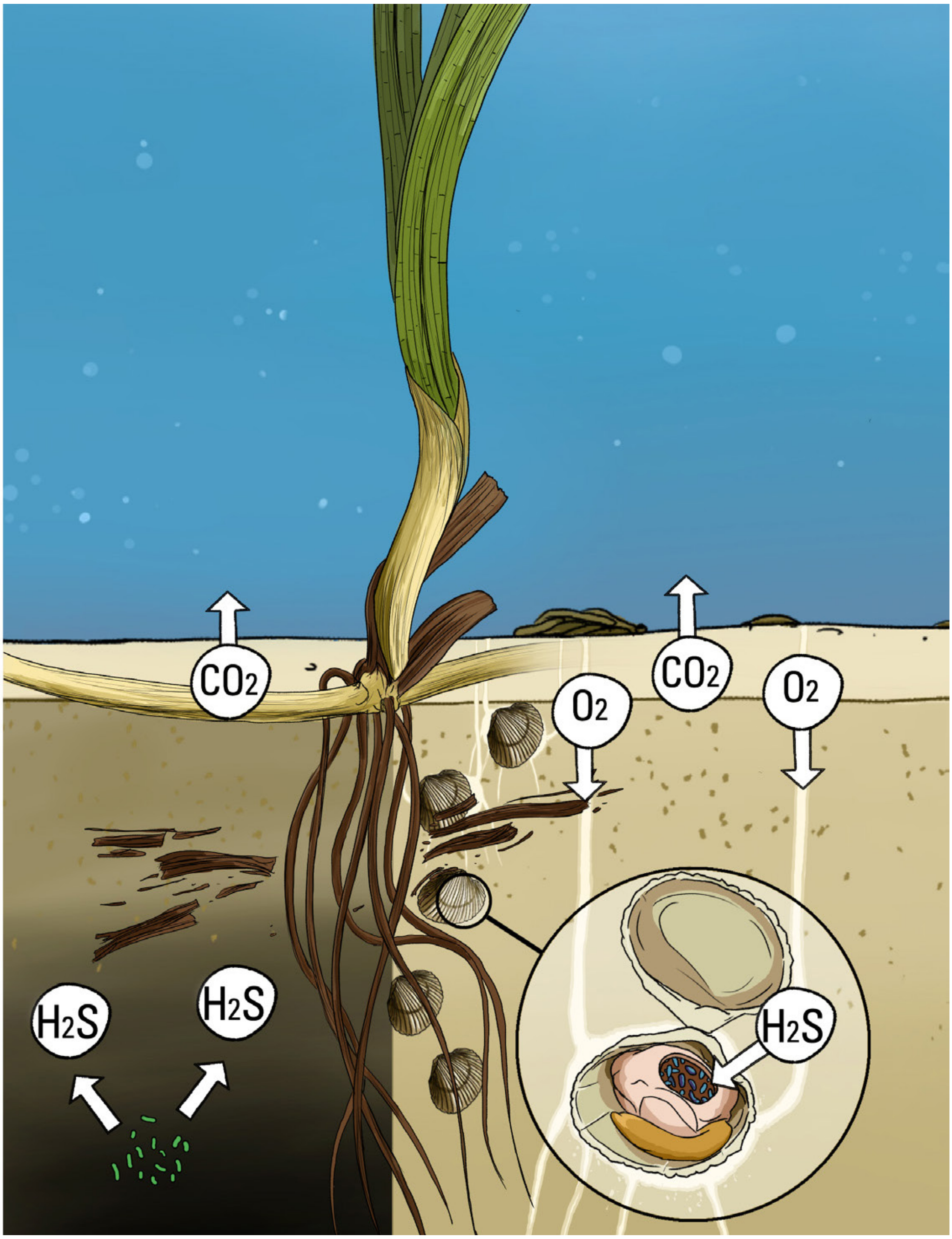
The ecosystems of Zostera's submerged meadows are very diverse. Many species of algae, vascular plants and animals can be found here. The most common phytobenthic species forming this habitat are, besides Z. marina, Zanichella palustris and Stuckenia pectinata (Dąbrowska et al., 2016). Phytobenthos provide habitat for many invertebrate and vertebrate species. Epifaunal species characteristic of the Zostera meadow complex include snails, crustaceans and insect larvae. Mussels are also common, e.g. Cerastoderma glaucum and juvenile mussels (Mytilus trossulus). Molluscs such as sand clams (Mya arenaria) and oligochaetes are abundant in the seagrass beds. Other organisms belonging to the infauna make up a small fraction (about 10%) and include crustaceans, insect larvae and polychaetes (mainly Pygospio elegans and Hediste diversicolor) (Bostrom and Bonsdorff, 1997; Dąbrowska et al., 2016). Among the benthic macrofauna in submerged meadows, several species can be found acting as keystone species. These species include herbivorous crustaceans of the genus Idotea and mussels that feed on suspended organic matter. In terms of abundance, submerged meadows contain large numbers of molluscs: juvenile forms of mussels and snails of the family Hydrobidae and crustaceans (Bostrom and Bonsdorff, 2000; Leidenberger et al., 2012; own research).

Macrofauna in seagrass beds

Macroalgae and vascular plants that form meadows are often covered by periphyton, which includes photosynthetic flagellates, sedentary diatoms, filamentous algae and animal organisms such as protozoa and rotifers. Periphyton microphenoliths are characterised by well-defined trophic relationships and sometimes exhibit a specific stacking structure. The base consists of algae and diatoms are deposited on top.

Another element of the periphyton structure are animals such as rootworms, rotifers, nematodes, scorpionfish, gastropods, flies and larvae of some insects, and algae that move freely among larger algae (Plinski, 1995). Periphyton can have a negative effect on the efficiency of photosynthesis by seagrasses. It reduces the availability of light, competes with the plant for nutrients and damages the leaves of the plants it covers (Howard and Short, 1986). However, periphyton is an important food source for gastropods of the Hydrobidae family and crustaceans of the amphipod group (Howard and Short, 1986; Dąbrowska et al., 2016). Gastropods that feed on periphyton are known as scrapers: they have a scraper with which they scrape epiphyton from various surfaces (Plinski, 1995). The presence of these animals considerably increases plant density. By consuming periphyton, which competes with seagrasses for resources, scrapers allow seagrasses to proliferate. In addition, studies show that the presence of periphyton-eating species reduces the negative effects of eutrophication: removing periphyton from Zostera leaves allows this species to absorb more nutrients from the water. The reduced amount of nutrients in the water does not allow excessive amounts of algae to grow, i.e. the effects of water eutrophication are reduced (Howard and Short, 1986; Philippart, 1995).

In addition to the plants that make up the meadows themselves, animal organisms include bioturbators found in submerged meadows: animals that, through movement or respiration, improve the living conditions in the sediments (Levinton, 1995; Herringshaw et al., 2010). Their means of obtaining food, burrowing, and living in sediment allow the exchange of chemicals between sediment and bottom water and irrigate and oxygenate sediment, preventing anaerobic conditions from forming in sediment (Levinton, 1995; Janas et al., 2017). This group of organisms includes mainly polychaetes, but also bivalves (Janas et al., 2017).

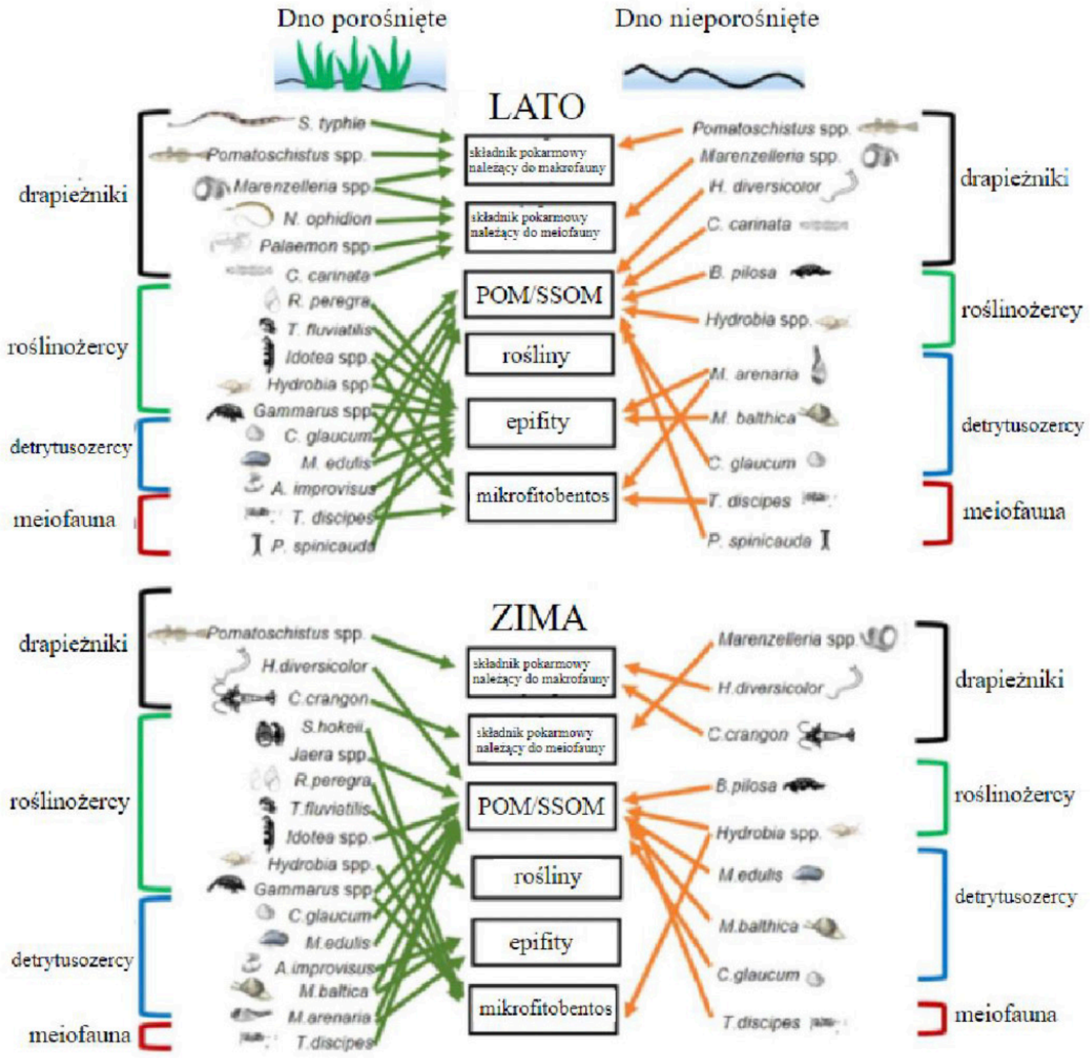


Relationships of Zostera with species that prevent the development of anaerobic conditions (Taken from Barañano et al., 2021)

Zostera meadows also provide shelter and a good nursery ground for fish such as beluga whales and pike (Czarnecka et al., 2013). The survival rate of fish larvae in submerged meadows is much higher than in undeveloped areas. This is due to the complexity of the meadow environment and therefore the greater number of refugia for juveniles (Heck Jr., et al., 2003). Submerged meadows are used as refugia by species such as conifers and serpents. These two species, which belong to the conifer family, have adapted to life in submerged meadows through mimicry: they resemble grasses in appearance and behaviour. Interestingly, the presence of these fish in underwater meadows is influenced by the periphyton mentioned above. Needlefish are more likely to choose Zostera habitats that are not covered by periphyton than those that are covered. This may be related to the better camouflage of fish among unplanted grasses and the higher abundance of Zostera in such meadows (Sundin et al., 2011).

Organisms found in submerged grasslands are linked through numerous trophic relationships (Fig. 2). In a species-rich ecosystem, energy flows through several links in the food chain. Producers in meadows include vascular plants, macroalgae and periphyton. Primary consumers are mainly herbivorous invertebrates such as gastropods and crustaceans. Second-order consumers are predatory invertebrates (e.g. Cyathura carinata and polychaetes of the genus Marenzelleria) and vertebrates: fish and birds. In addition, meadows also host numerous detritivores, such as polychaetes and bivalves, as well as filter feeders - cichlids (Amphibalanus improvisus) and mussels (M. trossulus) (Jankowska et al., 2019). However, it should be noted that organisms living in submerged meadows should not be attributed to a single food web group. Some organisms, e.g. crustaceans of the genus Idotea, may feed on plants, periphyton, dead plant parts, but also on smaller animals (I. balthica). Food preferences may also vary within a species depending on the area inhabited. For example, C. carinata feeds mainly on meiofauna if it inhabits seagrass beds, whereas in unimproved marine beds it feeds mainly on organic matter in the form of particles (Jankowska et al., 2018).

Co-funded by the Erasmus+ Programme of the European Union



Modeling trophic relationships in the vegetated and unvegetated zone (Jankowska et al., 2019)

As can be seen, seagrass meadows are very diverse habitats. However, they are highly vulnerable to climate change and anthropogenic impacts (Short et al., 2011). These factors affect the decline of Baltic seagrass meadows. Z. marina and Furcellaria fastigiata are strictly protected in Poland (Journal of Laws 2014, item 1409) and are included in the Polish Red List of Plants and Fungi with VU (vulnerable) category (Kaźmierczakowa et al., 2016). Therefore, they should be under active protection to prevent degradation of this habitat in the Baltic Sea.

3.3 BLACK SEA

- ### 3.3.1 Oceanographic features

The Black Sea is an inland sea at the south-eastern tip of Europe. It is bordered to the north by Ukraine, to the north-east by Russia, to the east by Georgia, to the south by Turkey and to the west by Bulgaria and Romania (Figure 3.1.1.1.1). It has a maximum depth of 2,210 m. The Black Sea has an area of 422,000 km2 and is linked to the Aegean Sea by the Bosphorus, the Sea of Marmara and the Dardanelles, and to the Sea of Azov by the Kerch Strait. Numerous rivers flow through its territory, including the Danube, Dniester, Dniester, Bug, Dnipro, Kuban, Kızıl and Sakarya. To the north lies the Crimean peninsula. Created when structural upheavals in Asia Minor separated the Caspian Sea basin from the Mediterranean Sea, Sea Black Sea a became gradually isolated (https://www.britannica.com/place/Black-Sea).

Figure 3.1.1.1. Black Sea (https://www.britannica.com/place/Black-Sea)

It is a saltwater sea, but has a lower salinity than the oceans. The salinity of the surface waters of the Black Sea varies between 17 and 18 parts per thousand, about half that of the oceans. In the Black Sea, at depths between 50 and 150 metres (https://www.britannica.com/place/Black-Sea), there is a sharp increase in salinity, up to 21 parts per thousand.

Europe's second and third largest river supplies fresh water to the sea and influences the salinity of seawater. The input of the Danube, the Dniester, the Nistru, the Nipro and the Don plays an even more important role in the water balance of the Black Sea (Figure 3.1.1.2) than the evaporation and exchange of saline water with the Mediterranean (which accounts for only 0.1% of the annual sea volume). The first three rivers, together with the Southern Bug, which enters the sea from the north-west, supply more than 70% of all freshwater flowing into the sea. The rivers on the east, south and west coasts have much smaller drainage areas and contribute about 20% of the freshwater flow. Geographical data are given in Table 3.1.1.1.1.

Figure 3.1.1.2. The most important rivers flowing into the Black Sea (according to Bat et al., 2009; (Jitar et al., 2015))

Table 3.1.1.1. Geographical data - Black Sea
(http://archive.iwlearn.net/bsepr.org/Text/ESP/Geography.htm)

Area / km /^{2}	423,000 (462,000 with the Sea of Azov)
Depth/m	1271 (average)/ 2212 (maximum)
Drainage area / km /^{2}	2,500,000
Volume /km /^{3}	547,000
Tide /cm/	3-10
Coastal length / km/	4090
Number of islands / km /^{2}	Approximately 10 (with an area greater than 0.5)

- **3.3.2 Driving forces and anthropogenic pressures**

Although long popular for its seaside resorts, the Black Sea has suffered in recent decades from severe pollution. Fishing has a long history in the region and has always provided a good income for some of the coastal population, except in the last four decades when industrial fishing has seen a significant reduction in both the quantity and variety of catches. Currently, Turkey's fish catches lead the region, followed by Ukraine and Russia, while Bulgaria, Romania and Georgia have token catches.

Industrial production in the region relies not only on agriculture, but also on local mineral and energy resources, as well as on the skills and traditions of the local population. Coal and mineral deposits provide raw materials for thermal energy and metallurgy, especially in Ukraine, Russia and Turkey. In other countries, coastal cities have often developed as important industrial centres, simply because their ports serve as gateways for imports or exports (http://archive.iwlearn.net/bsepr.org/Text/ ESP/ Geography.htm).

Tourism is a relatively new industry in the region. It offers very good options for combining conventional maritime tourism with seaside and cultural tourism. In the 1960s and 80s, impressive resorts were established along the west coast, including large resorts for international tourists, such as Sunny Beach and Golden Sands in Bulgaria and Mamaia in Romania.

The Romanian side of the Black Sea is the most exploited tourist area in Romania. Along the sea coast there are 2 municipalities, 2 larger and 2 smaller towns, as well as numerous summer resorts. The main cities and the main area of interest, where most of the resorts and tourist attractions are located, are in Constanța county; the other county bordering the sea is Tulcea county, both part of the historic Dobrogea region. The main city, which is also considered the capital of this region, is Constanța (290,000 inhabitants). The second largest is Mangalia (50,000 inhabitants), followed by Năvodari (39,000 inhabitants), both in Constanța county. Other towns are Constanta - Constanta, Constanta - Constanta, Constanta - Constanta: Sulina (3,300 inhabitants) (Tulcea), Eforie (10,000 inhabitants) and Techirghiol (7,000 inhabitants) (https:// ro.wikipedia.org/wiki/Litoralul_rom%C3%A2nesc).

Heavy metal pollution of the Black Sea is a multinational problem caused by anthropogenic activities near coastal areas and rivers flowing into the sea. It is important to identify each source of polution, but it is quite difficult to present an inventory of point and diffuse sources of pollution because of the numerous and varied transboundary activities and discharges (Jitar et al., 2015).

Table 3.1.2.1. Main anthropogenic sources and type of activity undertaken (Jitar et al., 2015)

Anthropogenic sources	Type of substrate
Harbour (small boats and yachts) and tourist activities	Rocky
A1 - Municipal wastewater treatment plant Constanta Nord	Rocky
A2 - Constanța Sud - municipal wastewater treatment plant (which also treats wastewater from the port)	Rocky
A3 - Eforie Sud - municipal wastewater treatment plant	Rocky and sandy
A4 - Mangalia municipal wastewater treatment plant	Rocky and sandy
Tourist activities	Sandy

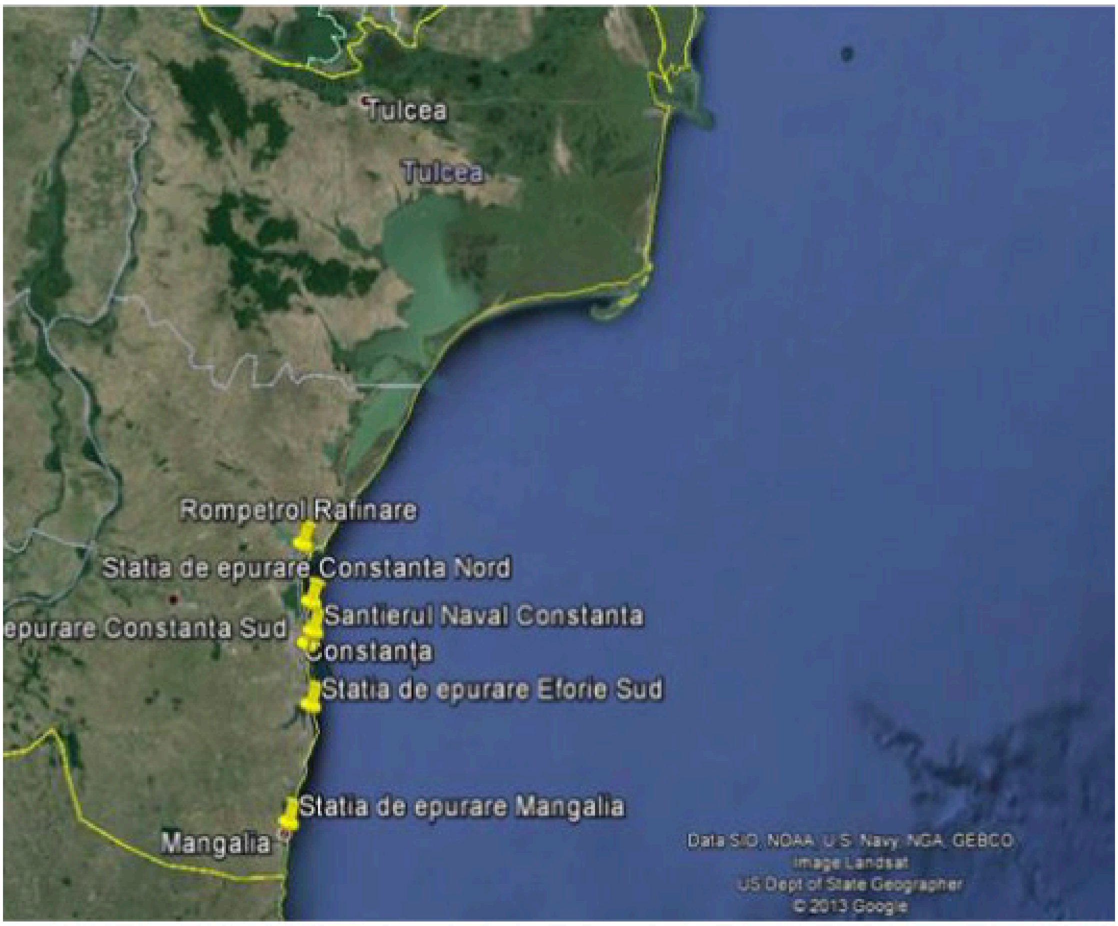


Figure 3.1.2.1. Main localised point sources of pollution along the Romanian coastline (Google Earth, Jitar et al. 2015)

According to official sources of information provided by the national Black Sea monitoring programme (INCDM "Grigore Antipa" and the Dobrogea-Litoral Basin Administration, ABADL), the main sources of heavy metal pollution for the Romanian sector of the Black Sea are: Danube, local pollution, sources in the Romanian coastal area and pollution sources located in the Ukrainian sector of the Black Sea (Jitar et al., 2015) (Figure 3.1.2.2.).

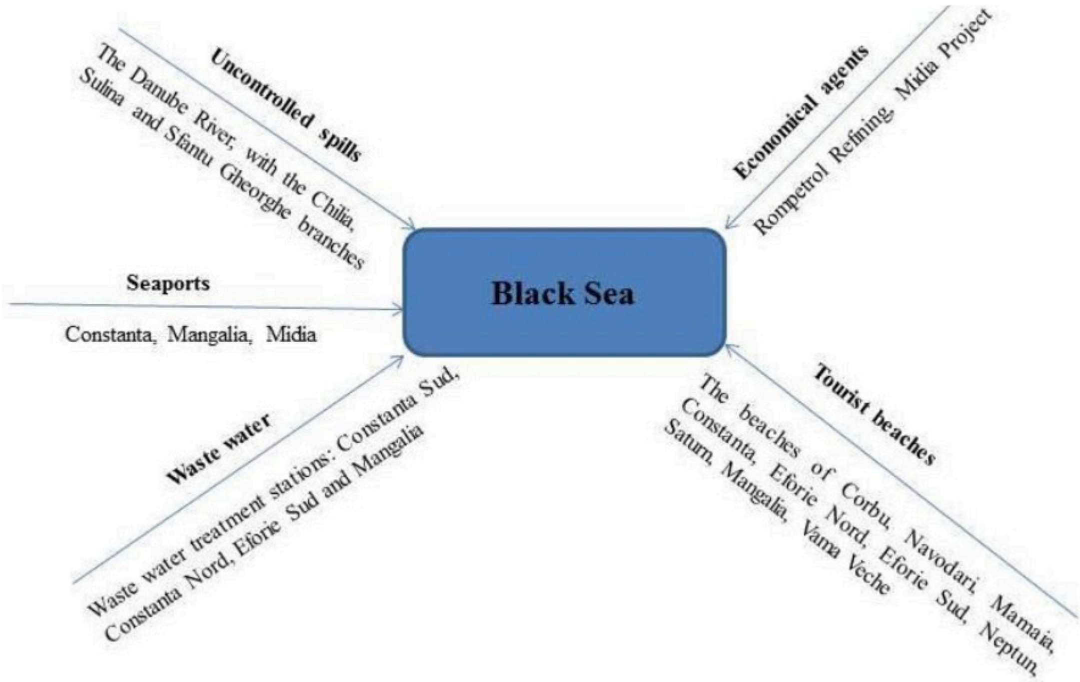


Figure 3.1.2.2. Localised sources of pollution on the Romanian Black Sea Coast
(https://www.spiritbsb.online/sources-of-pollution-and-pollutants-from-the-coastal-area-of %E2%80%8B%E2%80%8Bthe-black-sea-in-romania/)

The National Research and Development Institute for Marine Geology and Geoecology - GeoEcoMar has identified the following major pressures with a massive impact on marine ecosystems in general and Zostera meadows in particular:

- Suffocation (e.g. putting man-made structures in place or dumping dredged spoil);
- Obstruction (e.g. by permanent constructions);
- Changes in sedimentation (e.g. during spills, increased flows or dredging/discharge of dredged spoil);
- Erosion (e.g. due to impact on the seabed from commercial fishing, shipping, mooring manoeuvres);

- Introduction of non-native species and translocations;
- Major changes in salinity regime;
- Significant changes in the temperature regime;
- Introduction of nutrients and other substances rich in nitrogen and phosphorus;
- Introduction of organic substances (e.g. sewage, mariculture), alluvium);
- Introduction of microbial pathogenic organisms;
- Selective extraction (e.g., due to exploration and exploitation of biological and non-biological resources on the seabed and subsoil);
- The introduction of synthetic compounds;
- Introduction of non-synthetic substances and compounds;
- Introduction of radionuclides.

In accordance with EU references (Directive 2000/60/EC establishing a framework for Community action in the field of water policy (WFD); Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources; Directive 2008/98/EC on waste; Directive 91/271/EEC concerning urban waste water treatment; Directive 2006/7/EC concerning bathing water quality management; Directive 2000/59/EC on port reception facilities for ship-generated waste and cargo residues, as amended by Directive 2002/84/EC, Directive 2007/71/EC and Regulation No. 137/2008; Directive 2009/123/EC amending Directive 2005/35/EC on ship-source pollution and on penalties for infringements of MARPOL 73/78; Convention for the Protection of the Black Sea against Pollution - Protocol for the Protection of the Marine Environment of the Black Sea against Pollution by Dumping; Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment; Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment Regulation (EU) No.... 1380/2013 on the Common Fisheries Policy; Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive); International Convention for the Control and Management of Ships' Ballast Water and Sediments; REGULATION (EC) No. 708/2007 on the use of the Common Fisheries Policy; Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive); International Convention for the Control and Management of Ships' Ballast Water and Sediments; Council Regulation (EC) No 708/2007 concerning use of alien species in aquaculture and locally absent species;

Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species IMO Guidelines for the control and management of marine bio-stocks to minimise the transfer of aquatic invasive species (Resolution MEPC 207/62)), a number of measures are proposed to protect marine ecosystems:

- Managing and reducing diffuse sources of pollution, including atmospheric deposition;
- Development of the Regional Marine Litter Action Plan (a common regional methodology to quantify marine litter, identify sources, detect offenders, etc.);
- Improving ship waste management;
- Coordinated organisation and/or support of regular (annual) awareness-raising campaigns for the business community (traders, beach operators, fishermen, etc.) and the public (tourists, students, children, etc.) on the sources and consequences of marine litter on the environment and the need to recycle waste;
- Establishment of facilities at landing sites to deal with marine litter collected by fishermen and organic waste resulting from the processing of catches on board vessels/ships;
- Facilitating and implementing environmentally friendly 'fishing from waste' practices;
- Amend existing legislation, where necessary, by introducing an authorisation regime for activities in the marine environment;
- Designation of areas where beam trawl gear is allowed and long-term observation of its impact;
- Develop/update MPA management plans in line with MSFD requirements and including both national and common RO - BG Objectives Establish coherent and representative networks of MPAs, including MPAs in Romania and Bulgaria, including management plans. Increased monitoring of regulated activities in MPAs;
- Creating ecological corridors between marine protected areas;
- Creation of risk maps for habitats in Natura 2000 protected areas;
- Harmonise Maritime Spatial Planning (MSP) with the zoning plan to support species and habitat protection and conservation measures;

- Harmonise Maritime Spatial Planning (MSP) with the zoning plan to support species and habitat protection and conservation measures;
- Develop distribution maps of protected marine species (regional/national scale) within marine protected areas (e.g. Zostera);
- Improving management plans by developing conservation measures on termen environment and lung for MPAs;
- Assessment of ecosystem functions and services.

• 3.3.3 Coastal infrastructure and the loss of seagrass ecosystem services

In the Black Sea, Zostera noltei and Zostera marina are abundant seagrasses, but little is known about their sensitivity to coastal development.

According to the State of the Black Sea Environment Report, a considerable decline of the phanerogams Zostera marina and Z. noltei (seagrass) has been observed in the past decades. In the last 30 years, the seagrass population has increased tenfold in shallow waters. The main reason for the degradation of Zostera communities has been the mobilisation of mud by dredging in the coastal zone. This depletion of the macrophyte community has been observed in many rocky-bottomed areas and has led to the current decline in biodiversity in the north-western Black Sea (http://www.blacksea-commission.org).

Many of the coastal defence structures (groins, breakwaters and jetties) along the southern coast of Romania have deteriorated and their effectiveness in controlling beach erosion and protecting the coast has been significantly reduced (Halcrow UK et al., 2011-20).

The rebuilding of dykes and the construction of artificial beaches on the Romanian Black Sea coast is a major threat both to the survival of seagrass meadows (Zostera noltei) and to most of the Natura 2000 habitats present in the site.

MODULE 2:
SCIENTIFIC RESEARCH FOR DIDACTIC TRANSLATION

In order to provide evidence, data and proofs that allow for argumentation in the school scientific investigation presented in the Teaching Guide set up in Module 3, two experiments have been designed to facilitate the didactic transposition of the scientific research collected in this training itinerary. In line with the search for what is most paradigmatic from a School Science curricular point of view within the "One Health" approach.

a. First experiment: CONTROL OF NOXIOUS ORGANISMS THROUGH THE ZOSTERA. The aim is to train students in the basic knowledge and acquisition of data and justifications to enable them to argue about the ability of Zostera to control the growth of various types of marine microorganisms that are harmful to humans.

b. The second experiment: the test on the content of organic matter in the SEDIMENT. The aim is to train students in basic knowledge and acquire data and justifications that allow them to argue about the ability of Zostera to filter sediments and act in the blue carbon arena by removing carbon from the atmosphere and acting as a carbon dioxide reservoir.

Students discuss data and evidence from a laboratory activity as part of an investigation into seagrass ecosystem services

1. A DESCRIPTION OF THE POTENTIAL TO DEMONSTRATE THE ABILITY OF SEAGRASSES TO IMPROVE HUMAN HEALTH

In order to develop arguments in school science research, evidence, along the lines of the WHO's 'One Health' model, is needed on the environmental contributions of seagrasses to enable consideration of human health. One of the major problems that can result from the consumption of bivalves for human health is the production of toxins by dinoflagellate algae that cause red tides. The first poisonings were only reported in 1976, when poisonings occurred in Switzerland and France due to the consumption of mussels exported from Galicia, with 23 serious hospitalisations due to paralytic toxins at that time. There were also hospitalisations in Santiago de Compostela and Segovia in Spain that year. The symptoms of the poisoned people hospitalised were muscular paralysis.

Seawater with reddish tints

The producers of these toxins are single-celled algae known to turn red when they proliferate. Dinoflagellates are microscopic unicellular algae that are part of the marine plankton and are a food source for bivalve molluscs and gastropods. These unicellular algae are responsible for the reddish colour when they proliferate, they produce paralytic, diarrhetic and amnesic toxins which, when filtered and concentrated in large quantities by bivalves, can cause serious health problems for humans when consumed. The main cause of red tides in Galicia is the southerly winds, when the north-north-easterly winds that facilitate water growth cease, as explained in Module I. When these north-easterly winds change to southerly winds, red tides can occur.

The question of whether ecosystem services exist to mitigate the proliferation of dinoflagellates is therefore of interest from the perspective of the WHO's 'One Health' cross-cutting approach. Precisely among their many contributions to human society, there is one that is little known and is currently enjoying the attention of the research community. This is clearly beneficial to human health, as it is their ability to control the growth of various types of marine micro-organisms harmful to humans.

These investigations are of great interest for curriculum proposals focusing on "One Health", which is why it is interesting to develop simulations of the experimental process for school use, as investigations are very difficult to replicate in school science fieldwork. For this reason, simulations and mental experiments are of interest in the processes of investigation and argumentation typical of school science, because they leave evidence, proofs and justifications capable of reaching the necessary conclusions for the interpretation of experimental processes that allowed us to know to what extent Zostera can be beneficial for human health. Therefore, simulations and didactic translational mental experiments play a role in developing argumentation processes to obtain effective mental representations that can be applied to understand the importance of "One Health" of seagrass meadows.

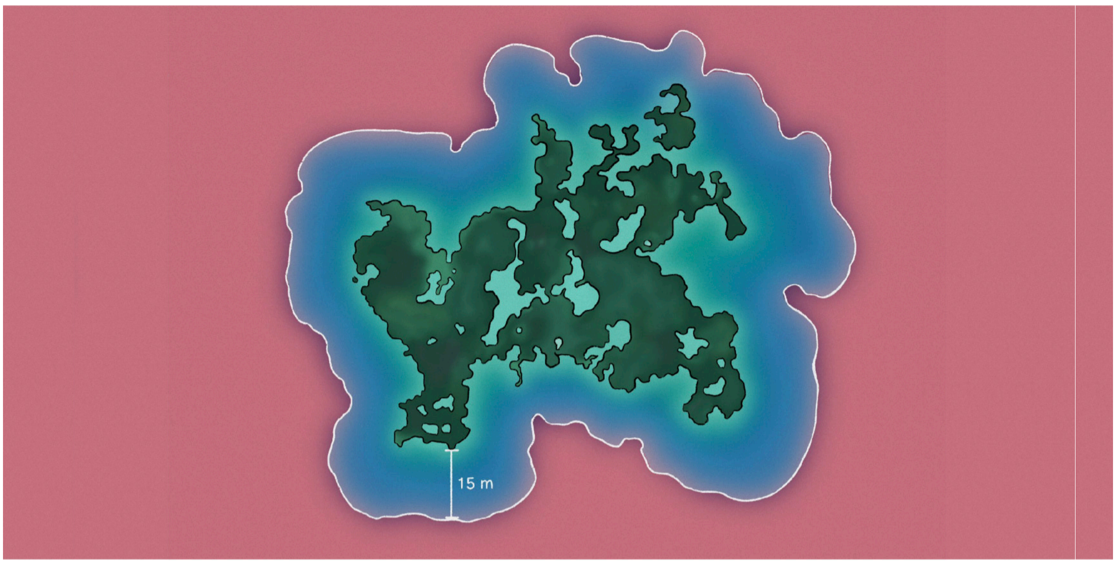
Groups of students collecting evidence for their arguments in a research process.
in school science on the functions of Zostera meadows

Moreover, these didactic argumentation processes can be interesting to introduce students to the didactic translation of the scientific method applied by researchers in favour of ecosystem services and human health. In order to extend Zostera's value in interpreting the benefits of grasslands on human health, while introducing the harmful role of dinoflagellates, it is interesting to take the opportunity to introduce the other type of species harmful to humans, namely pathogenic microorganisms, mainly bacteria, which, unlike dinoflagellates, which are unicellular eukaryotes of the protoctista kingdom, bacteria belong to the monera kingdom, and are therefore unicellular prokaryotes. To this end, the following case studies are formulated in a genuine problem-based argumentation format.

- **1.1 Real issue 1: Can Zostera help reduce toxins in the red sea?**

In a recent research paper published in 2020 (see Appendix I), they studied the composition of the microalgal community living in the water in and around seagrasses, focusing in particular on dinoflagellates, as this is the group of microalgae to which most of the toxin-producing microorganisms in the sea belong. They observed that these organisms were significantly less abundant in the area where seagrasses are present. In all cases, abundance was higher in the area dominated by bare sediments. Continuing the analysis of the same study, when comparing the abundance of dinoflagellates above the meadows with the abundance of these organisms at increasing distances from the meadows, it is concluded that the lower abundance of dinoflagellates is not only above the meadows, but is also observed in areas adjacent to the meadows, at least up to a distance of 15 m from the meadows.

1. Interpretation of the problem: The teacher can approach the problem at the school level from the infographic below, in which a seagrass meadow emerging from shallow water is visualized as a green patch. The reddish water is associated with the presence of a dinoflagellate of the genus Alexandrium. What appears within 15 metres in blue is seawater without the presence of dinoflagellates.



Infographic to intuitively present the problem to the students with the colour of the red tide and its disappearance on the meadow and at a distance of 15 m from it.

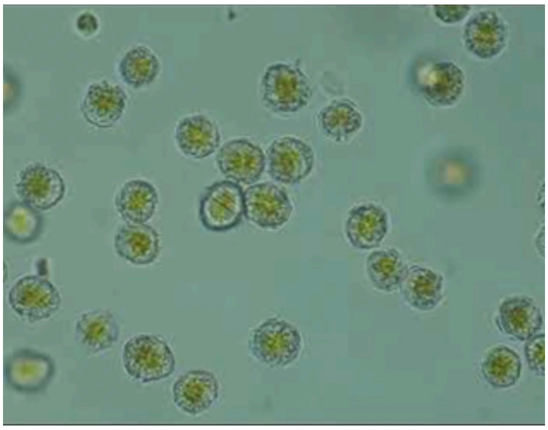
2. In this way it is possible to advance in the development of the argument that allows the collection of evidence necessary for the interpretation of the problem:

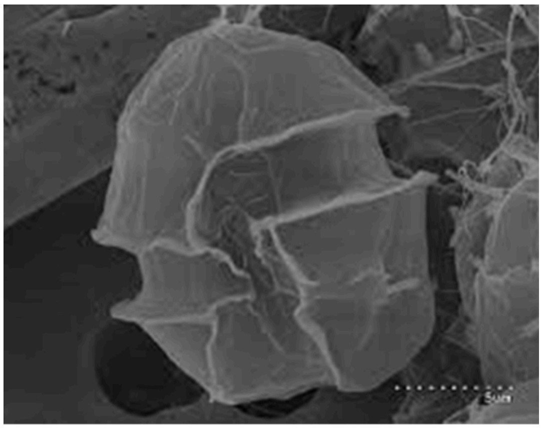
a. Why do you think there are fewer dinoflagellates in pastures?

b. If the low number is maintained at a distance of 15 meters, as the data shows, is there anything in the plant structure that stops the dinoflagellates?

c. If the answer is no, you can ask: Can plants also influence decline at a distance of 15 metres? If so, how would they exert this influence?

d. In the experimental culture, the researchers included dinoflagellates of the genus Alexandrium. What is their interest in this genus, given the effects of red tides on humans?





Group of Alexandrium dinoflagellates (a) and detail of one of them (b)

e. If it is confirmed that the higher the concentration of Zostera, the lower the concentration of Alexandrium, what are the consequences of this evidence?

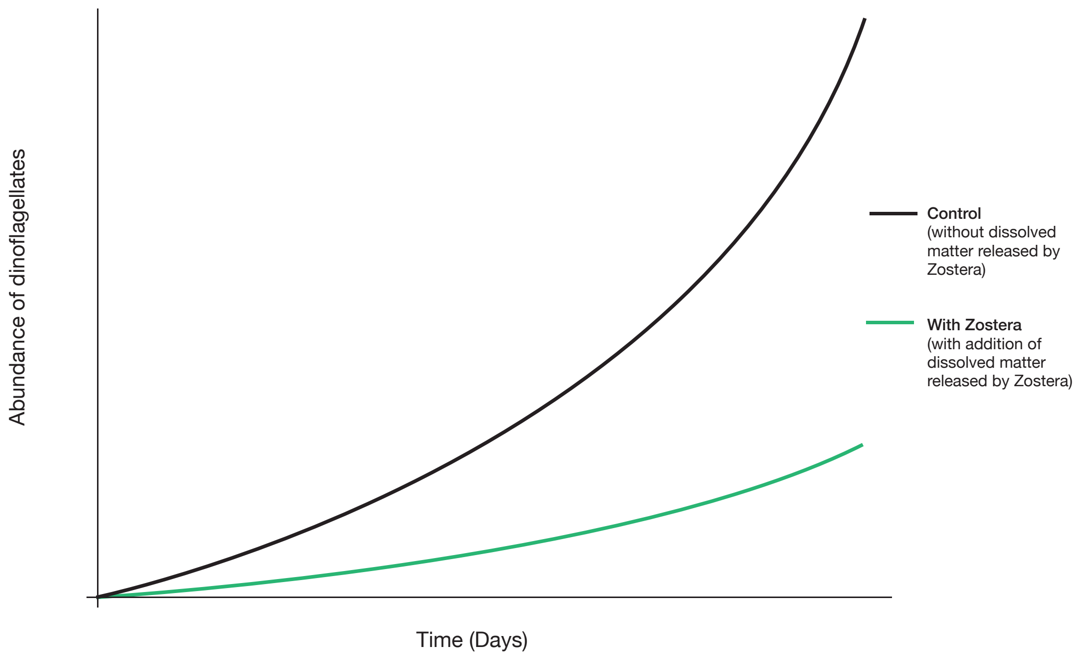
3. Hypothesis formulation: Provide an answer to the problem by anticipating the solution (formulating the hypothesis), keeping in mind the wording of the problem, using the words: abundance of grassland and dinoflagellates.

4. They are told that they will test the veracity of the hypothesis using 5 vials of Alexandrium culture and 5 vials of Alexandrium culture + Zostera plant. To continue the argument for solving this problem, the following question is asked: Why do you give us 5 vials of each type? Shouldn't only one vial be enough?

5. In order to further integrate the data involving background knowledge that allows him to justify the validity and rejection of the hypothesis, it is interesting to argue following this framework:

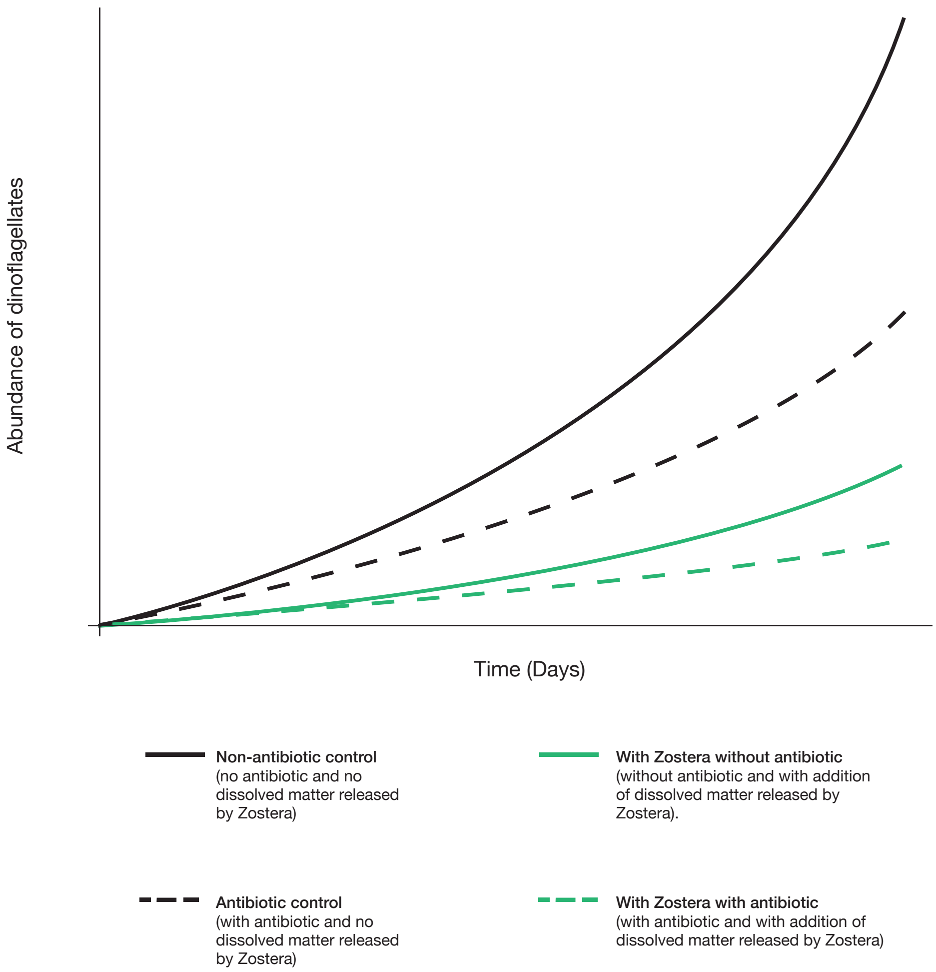
a. Look at the graph showing the results for mixtures of the two species and answer:

- In one of the vials there is no dissolved matter released from Zostera plants. Which one and why? Justify your answers.
- Which species is the concentration of matter released by Zostera? What benefits do we intend to discover for human health from species relationships?
- To what extent might the absence of red tide up to 15 metres from the meadow have resulted in the species of interest being grown not with Zostera but with the dissolved matter released by Zostera?
- What are the concentrations of each colour?
- What is the relationship between the concentration of matter released by Zostera and the density of the dinoflagellate?
- How many days did the investigation last?
- Would it have the same value if the experimentation time was 6 days? Please justify your answer.
- To what extent do the results support or refute the hypothesis? Justify your answer.



b. The researchers checked the meadow for multiple species that could influence the outcome and found that there were many bacteria on the plant surface. At that point they introduced antibiotics into the research.

- Why is the antibiotic introduced in the study?
- When the antibiotic was introduced, the previous experiment was repeated, but this time adding more antibiotic to the results expressed using the dotted graphs, which keep the concentrations corresponding to their colour, but in this case also incorporating antibiotic. What will motivate the researchers with this expansion of the tests?
- Look at their results with the results they are getting now, keeping in mind that the antibiotic results are the ones represented by the dotted line. How does the antibiotic influence dinoflagellate growth over time?



- What do the results of introducing antibiotics tell us about the increase in dinoflagellate populations?

- If the effects on protozoan reduction in Zostera meadows are seen up to 15 m from the plants, given the results of antibiotic introduction, how can these results be explained?

c. Given the results of the introduction of antibiotics, formulate a justified conclusion using the words: compound, growth, released, bacteria.

d. Although when dinoflagellates are grown only with compounds released by Zostera in the presence of antibiotics and when these compounds carry antibiotics, effects on dinoflagellate growth are obtained, the effects are not the same. Express your conclusion about the differences in protozoan growth by involving the words: inhibitor, bacterium, producer.

e. Having come to the latter conclusion, the researchers decided to remove what lives on the surface (mainly bacteria and microscopic algae) and conducted a new experiment, comparing the growth of dinoflagellates on plants with epiphytes with that of plants without epiphytes. It was found that dinoflagellate growth was significantly lower in plants with epiphytes. Given this last test, and taking into account all the previous tests, formulate a conclusion about the effects of the meadows on dinoflagellate growth using these three words: compound, algae, inhibitor.

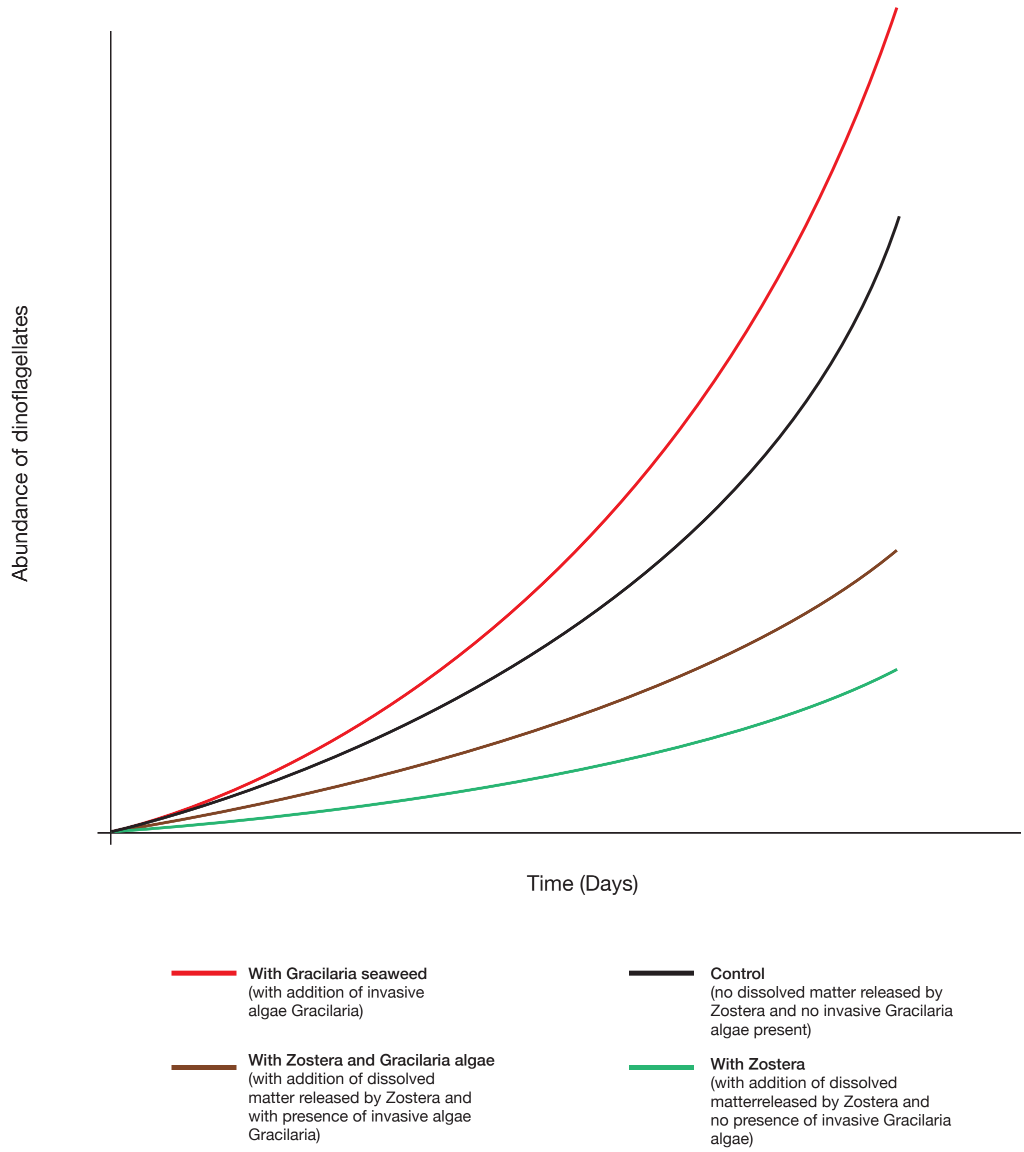
6. Having developed this argument, it is interesting to give them the information that the chemical that inhibits the growth of Alexandrium is not known. Based on this, a debate will be held in which they will argue about the need to research what has been discovered in order to advance the discovery of the unknown. They will be asked to make proposals to make progress in discovering what we are missing. They will also, as a conclusion to the resolution, argue about the importance of maintaining the health of ecosystems to maintain our health.

- **1.2 Real issue 2: Can invasive algae from seagrasses affect the inhibitory activity of dinoflagellates?**

Once it was concluded that inhibition of dinoflagellate growth may be due to the production of soluble substances and that these may change when other species come into play, the invasion of Zostera meadows by an invasive red alga raises a new question. This new question can be formulated as follows: can the presence of invasive algae reinforce or counteract the inhibitory effect of Zostera on toxic dinoflagellates?

Invasive red alga Gracilaria in a Zostera meadow (top) and its details (bottom).

To answer this new question, a new model is proposed that will compare the growth of Alexandrium incubated in the presence of Zostera or in the presence of invasive algae with that of Alexandrium grown without the presence of these organisms. It is also incubated with Zostera and algae. The results of the new experiment are shown in the graph below:



After the problem was extended to incorporate the variable occurrence of invasive algae on grassland, a new experiment was conducted, the results of which are shown in this graph. Based on the results expressed in the graph, a brief outline formulated in these terms is again proposed to the teachers:

a. Comparing the increases expressed by the green line (Zostera + Alexandrium dinoflagellate) to the black control (dinoflagellate only), how does the presence of Zostera affect the increase in Alexandrium dinoflagellate compared to the control treatment (green line compared to black control)?

b. Now comparing the red line (Gracilaria algae + Alexandrium dinoflagellate), how does the presence of Gracilaria influence the growth of Alexandrium dinoflagellate compared to the control treatment (red versus black line)?

c. Finally, how does dinoflagellate culture with Zostera and invasive algae (brown line) compare to the control treatment (brown line compared to control in black)?

8. Once it is concluded that algal invasion stimulates the growth of dinoflagellates and diminishes the inhibitory effect of Zostera, it can be proposed.

a. When a seagrass meadow is colonised by invasive Gracilaria algae, to what extent can it cause health effects?

b. This algae was introduced into Galician estuaries with the cultivation of an Asian oyster. What conclusions can we draw about the convenience of searching for new resources with foreign species?

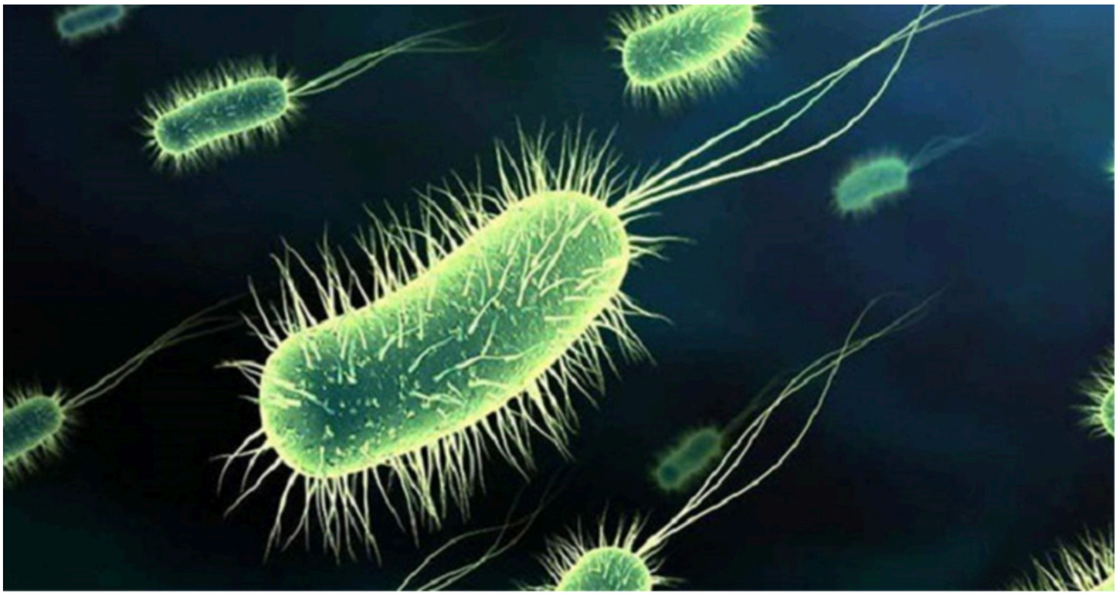
Again, it is clear that the presence of Zostera inhibits the growth of Alexandrium compared to the control treatment (green versus black line). However, the presence of Gracilaria algae does stimulate the growth of this dinoflagellate in the early growth stages (red line). When the dinoflagellate is grown together with Zostera and invasive algae, the inhibitory effect is maintained, although its intensity is lower (brown line).

- **1.3 Real issue 3: Can Zostera help reduce pathogenic bacteria?**

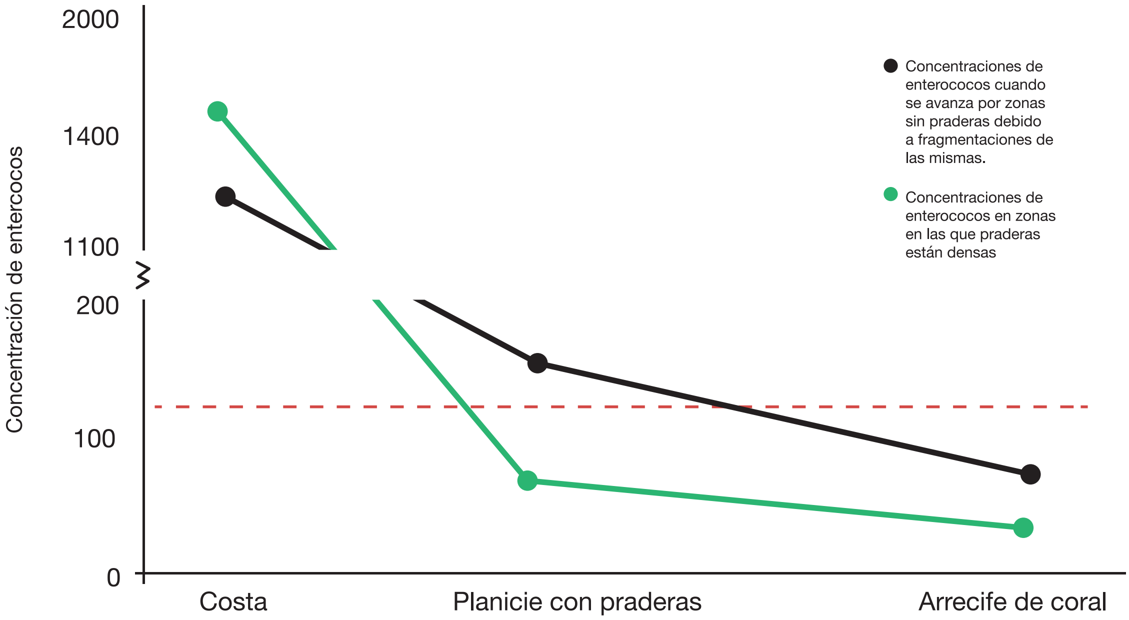
The framework of reasoning in search of solution 1 leads to the conclusion that the presence of Zostere has the ability to control the growth of toxic dinoflagellates. The search for more ecosystem services of Zostera meadows raises the real question about this relationship between environment and health, with the "One Health" approach to this question:

Will Zostera, which has been shown to inhibit the growth of dinoflagellates, have the same ability to reduce the amount of pathogenic bacteria in the surrounding seawater?

The rationale for the conclusion that provides an answer to this question is based on the following data: *'In research conducted in Australian waters, researchers have looked for possible links between Zostera and the reduction of pathogenic bacteria (enterococci). To do this, they measured the concentration of enterococci between the intermediate zone located between the coast and the reef to compare the concentration of enterococci (gut bacteria) in the Zostera zones and obtained the data expressed in a graph."*



Photomicrography of pathogenic enterococci bacteria



Seagrass meadow between coast and coral reef

With the help of the data expressed in the graph, the proposed scaffolding is proposed in order to obtain the necessary justifications to reach the desired conclusion:

1. In the representation of enterococci concentration, the green line refers to enterococci concentrations in areas where Zostera is present, the black line refers to concentrations in areas where grassland is absent, and the dashed red line expresses levels of pathogenic bacteria that no longer reach abundances that pose a risk to human health.

a. Are enterococci concentrations higher, equal or lower in areas where Zostera is present (green line) compared to areas where there is no grassland (black line)?

b. Looking at the Flat area, how do enterococci concentrations in areas where Zostera is present (green line) compare with those in areas where there is no grassland (black line) in relation to the limit set as a risk to human health (dotted red line).

2. The conclusion to be drawn, with the justifications obtained with the proposed two-stage sketch is that enterococci (gut bacteria) are clearly less in areas where Zostera is present (green line) compared to areas where there is no grassland (black line). It should also be concluded that the presence of grassland causes levels of pathogenic bacteria to reach abundances that do not exceed the limit set as a risk to human health (dotted red line).

Once this conclusion is reached, the argument is carried forward by challenging the following question: how can Zostera grassland influence the decrease of enterococci? In order to move the argument towards the conclusion that answers this question, this outline is followed:

1. A known fact is that seagrass meadows are rich in biodiversity in terms of filtering species of microorganisms. How can this have an impact on the decline of enterococci?

2. What is the ecosystem service of seagrass in preventing pathogenic microorganisms from reaching us when we eat raw crustaceans such as oysters or clams?

2. DESCRIPTION OF THE POTENTIAL OF ARGUING THE INFLUENCE OF CARBON SEQUESTRATION BY SAGO GRASSLANDS ON CLIMATE CHANGE MITIGATION (BLUE CARBON FUNCTION)

We know that these seagrass meadows, such as those of the genus Zostera, which are widespread in almost all European oceans, are in decline globally due to causes such as climate change, invasive species, marine pollution and public works. These seagrasses are essential for one of the ecosystem services we need - blue carbon. This function is carbon sequestration and sequestration, a priority ecological function for mankind because of the importance of excess greenhouse gases in the atmosphere that cause global warming.

Greenhouse gas emissions at an industrial installatio

That's why we need to take care of all the C uptake pathways we now need for sequestration, such as seagrass meadows, which are now in decline globally. For sequestration to be effective, humans do not need to intervene in seagrass meadows for centuries or even thousands of years. There is an urgent need to protect this function because it is more important than ever to mitigate climate change, and the paradox is that climate change itself is contributing to seagrass decline. Therefore, to prevent damage to these meadows, it is important to take strict conservation measures to ensure that certain areas of meadows are not used for exploitation, such as shell fishing or trawling, and also to avoid the impact of public works and ship anchoring. These cores to be protected must be sufficient for these systems to be effective in the medium and long term in terms of sequestering C to help mitigate climate change and reduce sources of pollutants.

School scientific survey of a seagrass meadow at Testal

Given this role of seagrass blue carbon, the following genuine question arises:

2.1 Real issue 3: Do vegetated areas protected from shellfishing in the upper part of the Testal intertidal zone (Ría de Muros and Noia) have a higher capacity to capture organic matter than unprotected areas?

In order to carry out the process of argumentation that will lead to the conclusion that answers this question, the following framework is proposed:

1. After analysing the data collection process that follows, it is proposed to develop an argument relating the processes to the data, justifying these processes with the necessary background knowledge, in order to reach the conclusion that answers the question.

Sediment sampling as part of the school science survey at a seagrass meadow in Testal

Procedure: 'Surface sediment samples were collected at the three tidal levels in Testal in vegetated and unvegetated areas. Samples were stored in plastic bags and transferred to the laboratory of the Department of Ecology of the University of Vigo, where they were frozen. Three days later, samples were placed in aluminium trays and dried at 60ºC for 48 hours in a forced-air oven. After this time, the dried sediments were transferred to laboratory crucibles. The crucibles were weighed together with the sediments from each sample with a precision balance (0.0001 g). The crucibles were then placed in a muffle furnace where they were maintained at 500 °C for 5 hours. After this period, the crucible was reweighed together with the sediment remaining in the crucible.

Plug-in ovens

Sample placement rinsers in them

a. Given that the protected grassland is located in the upper part of the intertidal zone, with an area reminiscent of a lagoon, and there is no grassland in the lower part, what is the point of sampling all three levels of the intertidal zone?

b. Given that sequestered C is retained in the C chains of organic matter and that a different gas is released when the sample is heated to 60°C than when it is heated to 500°C, what is the point of heating to 60°C before the first weighing?

c. The difference between the two weighings allows us to extract the organic matter content data shown in the table. How were they obtained?

Nivel	Zona	% Mat Org (Average)	% Mat Org (Desvst)
Top	Vegetation	1,26	0,05
Top	Non-vegetated	0,57	0,03
Environment	Vegetation	1,12	0,14
Environment	Non-vegetated	0,70	0,06
Lower	Vegetation	1,00	0,15
Lower	Non-vegetated	0,71	0,03

d. What is the point of increasing the temperature to 500°C between the two weighings to get the data from the table?

e. How does the data allow comparison of plots in terms of their sequestering capacity CO_2 ?

f. Given the data in the table, are there significant differences between vegetated and non-vegetated levels and vegetated levels? If so, can they be expressed in terms of carbon sequestration? If yes, justify the reason for higher sequestration capacity, if applicable.

g. At the upper level, shellfishing is prohibited and the meadows are heavily covered. At the middle level, shellfishing affects the meadows and the meadows are fragmented, and at the lower level, the meadows are hard to see because they are very fragmented. Can the comparison of the results for vegetated areas at the three levels express differences in sequestering capacity?

Biodiversity sampling of a protected grassland in Testal

2. As data integration is developed through the justifications required by the challenges, agreement should be reached on an answer to the question, steering the debate towards the conclusion of the importance of integrity (non-fragmentation due to the absence of anthropogenic intervention) to enable the CO_2 sequestration function of seagrasses to defend the need for their protection.

MODULE 3:
CASE STUDY ON ARGUMENTATION IN SCHOOL SCIENCE SURVEYS FOR RESPONSES TO GLOBAL CHANGE

This is a case study of a school ecology investigation in which argumentation processes were developed, focused on promoting argumentation processes to achieve the modelling needed to interpret the ecosystem services of Zostera seagrass meadows in the Testal intertidal bivalve crustacean service ecosystem in the Ría Baixa de Muros e Noia (Galicia-Spain).

Location of meadows under scientific study - school study

The participants were 30 students of the optional subject Climántica in the 2nd ESO (13-14 years) and the 15 students who chose in the 4th ESO (15-16 years) the subject Biology and Geology at IES Poeta Añón de Outes in the academic year 2020-2021. It is about sharing the analysis of the results obtained in a field practice to study the effects of Zostera noltii meadow fragmentation on biodiversity and water self-purification capacity in the intertidal zone of Testal bivalve mollusc beds in the upper part of the Ría de Muros e Noia (Galicia - Spain).

1. DEVELOPMENT OF FIELD WORK

- **1.1 Contextualisation for situated knowledge**

The fieldwork took place on the morning of 9 April 2021. The argument was triggered by the question: 'What species make up the green surface we walk on? In response to the answer that it was algae, they were asked about the differences between plants and algae. When the answers revealed that algae do not have roots, a plant was plucked so that, through the direct intuition of observing reality, they could identify the fact of the presence of roots in Zostera. When it became clear that Zostera had roots, explanations were initiated with a 30-minute argumentative colloquy on the following characteristics:

- Evolutionary origin of grassland species: adaptations to the marine environment Structure
- Zostera: checking rhizome structure. Reproduction.
- Services provided by grasslands: sediment retention, nursery, carbon sequestration, water purification.
- Relationship between grassland and wildlife diversity
- Relationship between diversity and stability
- Threats to grasslands: pollution, coastal alteration, mechanical impact: seabed, shellfishing
- Interaction between grassland and wetlands Human impact and habitat fragmentation
- The fragmented habitat-diversity relationship

Contextualisation of cognition located in Testal

In order to meaningfully integrate these characteristics with the One Health approach, the argumentative inquiry to be developed using field data and their analysis in the intertidal zone and laboratory focused on three main variables:

1. Abundance and diversity of fauna, number of Zostera feet and biomass (dry weight). Number of faunal species and number of individuals of each species.

2. Zostera abundance: coverage

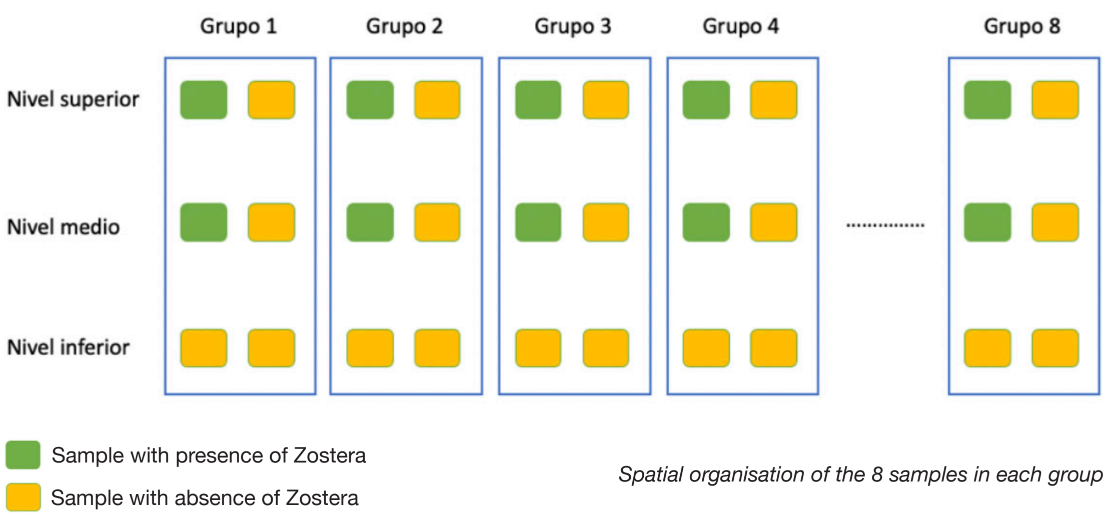
3. Carbon sequestration capacity of grasslandsCarbon sequestration capacity, where present.

Analysis of the three variables converges to lead to conclusions that answer the question: what environmental and health functions are likely to be lost if climate change and other environmental impacts lead to a regression of seagrass meadows such as Zostera?

Realising these conclusions involves relating the data obtained in the study of the three variables by means of justifications, in the sense that if integrity is maintained and even if its extension could be achieved, the function of blue carbon is favoured, and by increasing the C sequestration capacity, water purification is favoured, which could generate an environment in which numerous organisms can live, which in turn can be food for others. In addition, this biodiversity is likely to act as a barrier to toxins and pathogens that reach us, such as enterococci, when we consume organisms that live in these grassland areas, as is the case with shellfish and molluscs.

- **1.2 Organisation of experimental activity**

After the colloquium explanations on contextualizing situated cognition were completed, the field practice began. For this, students were organised in groups of 3 (about 10 groups). A large area was delimited which will include both dense grasslands, fragmented grasslands and bare sediments. Ten transects will be placed on this area, placing 8 samples in each (2 in the upper, 2 in the middle and 2 in the lower levels) at a distance of about 5 meters, taking care to collect a vegetation sample and a sand sample in the upper and middle levels where there is grassland.



Spatial organisation of the 8 samples in each group

For each sample, a visual and tactile analysis of the sediment is carried out and samples are collected to measure organic matter in a laboratory at the University of Vigo, as the necessary cooking equipment is not available in the school laboratory. When the sample coincides on the meadow, the approximate diameter of the patch of Zostera on which it is taken is noted. A sample is then taken with a caroter (tube) 15 cm in diameter. The collected sediment was placed on a 0.5 mm mesh sieve, which was taken out to sea to be washed to remove as much sediment as possible. Material retained in the net was placed in a plastic bag and coded with the sample code described in the subsection on analysis of data collection on the biodiversity variable in the field. These samples were stored in bags to be taken to the school's laboratory for quantification of starts, species, individuals of each species and biomass counts.

A 1-metre sampling square, divided into 20 x 20 cm squares, is also placed at each core sampling point to estimate the Zostera cover described in the subsection on field analysis of the cover variable.

- **1.3 Abundance and diversity of fauna, number of Zostera feet which will allow laboratory calculation of biomass (dry weight)**

The abundance survey began with the following question:

Presentation of the problem on arrival at Testal

Are the areas where Zostera is present richer in biodiversity than those where it is not? Do you scientifically test whether the beneficies of habitat generation for different species are met in Testal? Students are challenged to look for evidence that allows them to test experimentally whether or not this is true. The argument adopts the hypothesis that grassland areas are better than sandy areas. In order to test this hypothesis, the argument is made for what needs to be tested experimentally: characterising grassland areas and sandy areas that are not colonised by plants, using a cylindrical tube with a minimum sampling volume unit.

Sampling technique for sediment volume collection for analysis of the relationship between Zostera and biodiversity

For this purpose, a transect is made using a measuring tape that takes the meadow and extends beyond the meadow, covering the sandy area without plants.

The student stretches a tape measure to define the transect

Eight samples are taken from each transect at a distance of 5 metres from each other. Ideally 4 samples in grassland areas and 4 samples in sandy areas. At each of the 8 points the tube is inserted into the sediment.

Sampling with a sediment cylinder

With each sample, place a handful underneath, place it in a mesh bag and place it in the water so that only the plants and animals in the sample remain in the sedimentation tube.

Sediment removal to retain plants and associated wildlife

After the sediment is cleaned, the sample is transferred to a bag that is labelled with the transect number of the equipment, separated by a dot from the sample number in that transect: 1.1, 1.2,..... 1.8.

Two students collect plants and animals after the sediments have been cleaned.

Each group was responsible for keeping these bags to measure the number of species in the laboratory work, looking for results showing the relationship between Zostera and ecological niches for different animal species.

- **1.4 Zostera abundance: coverage**

At each point where the cylinder was inserted to collect samples in coded bags, Zostera coverage was also measured in situ. For this purpose, a 1 m x 1 m quadrat subdivided into small rectangles of 20 cm x 20 cm was used to measure the proportion of grassland in the total square.

Location of the 100-square dial for coverage measurement

To take the measurement, place the dial into which the tube is to be inserted and count the number of small squares in which the plants appear. Since the dial has 25 small squares, if the plants appear in 5 squares, we will have 20% coverage.

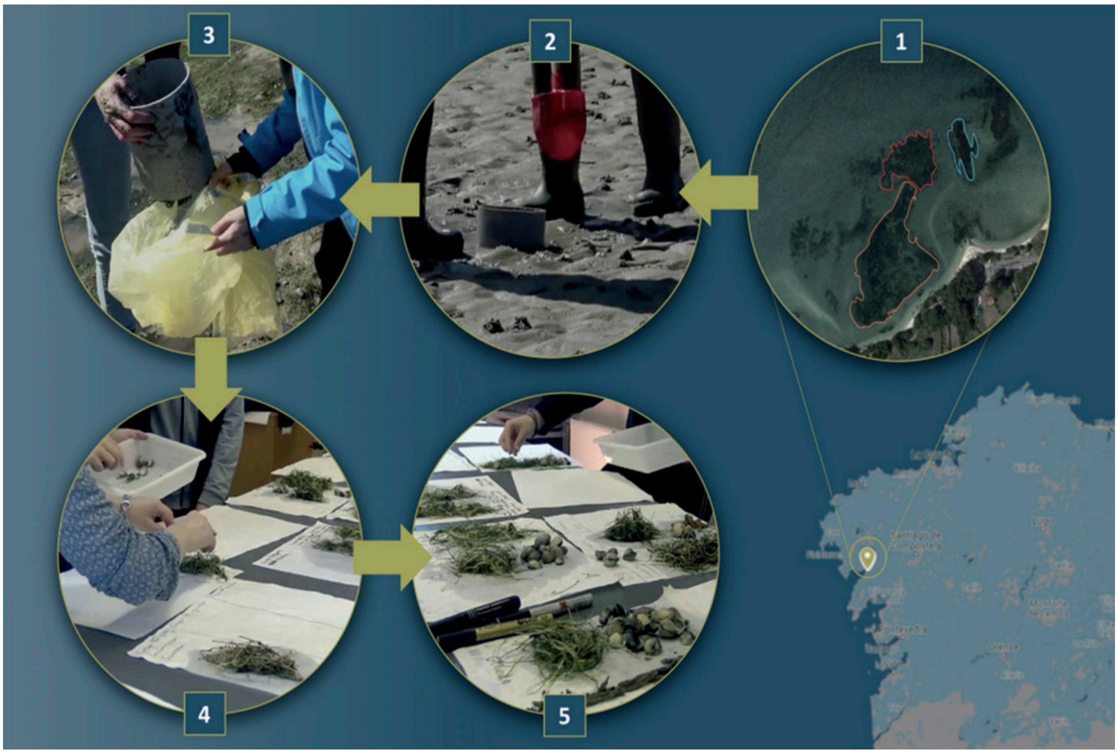
All entries, in addition to being made on paper, were made using the geolocated sampling app on the e-InnoEduCO_2 website and are recorded in the notebook and on the mobile device.

Collection of geolocation and stadium data

2. CONDUCTING LABORATORY WORK

- **2.1 Processing and results of biodiversity and biomass collected in bags**

Samples collected in Testal and recorded in coded bags were analysed in the laboratory. Each of the groups processed the 8 samples collected and coded in their transect. Initially, they separated Zostera plants by counting the number of legs in each sample. All Zostera plants were placed on flat paper and allowed to dry for one week.



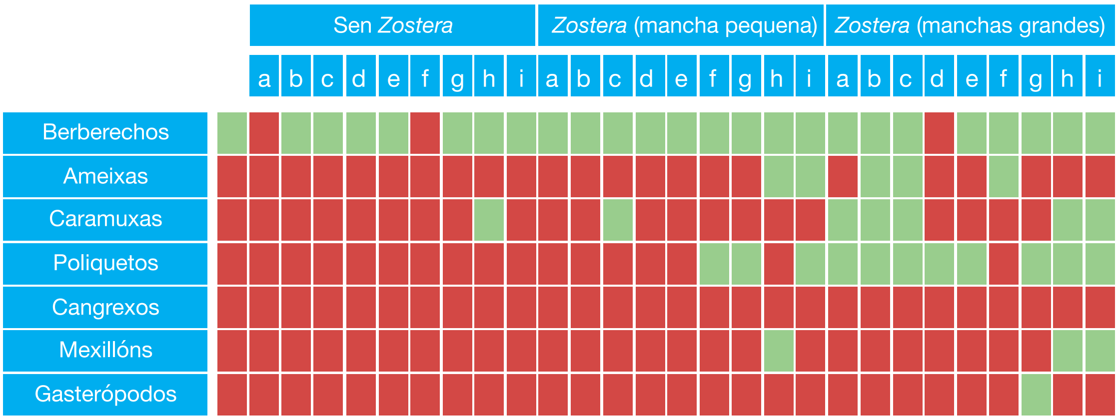
Integration of field and laboratory procedural steps to obtain results on Zostera legs and biomass and their relationships to zoological taxa, number of species and number of individuals per species.

As for the fauna, for each sample, the different organisms were separated into sets of taxonomic groups and the number of individuals in each taxonomic group was quantified.

Sharing results on Zostera abundance and its relation to animal biodiversity

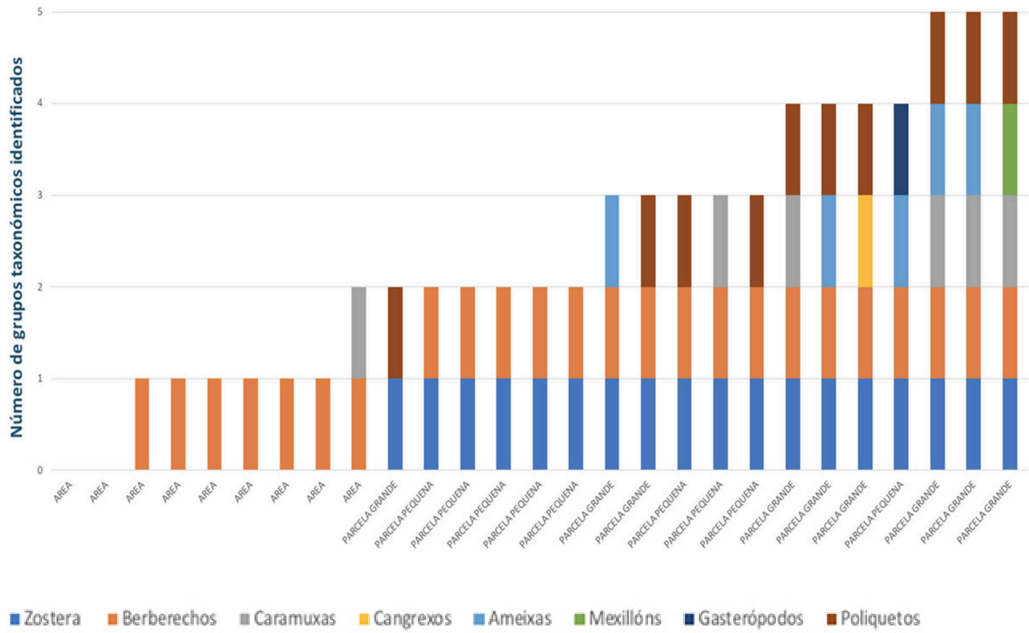
The results show that the number of taxa is higher in Zostera patches than in sediments without plants. In turn, the number of taxa increases the larger the patches.

Co-funded by the Erasmus+ Programme of the European Union



Biodiversity results of zoological taxa according to the presence and absence of Zostera, and in the second case according to patch size.

At the same time, it was found that taxon diversity decreases as you move towards the lower intertidal zone, where there is no grassland, and increases towards the upper part, where grassland is preserved, not subject to shellfishing and therefore not highly fragmented, and plots are larger. It was also found that the results of higher zoological diversity also coincide with those of higher cover measured in Testal.

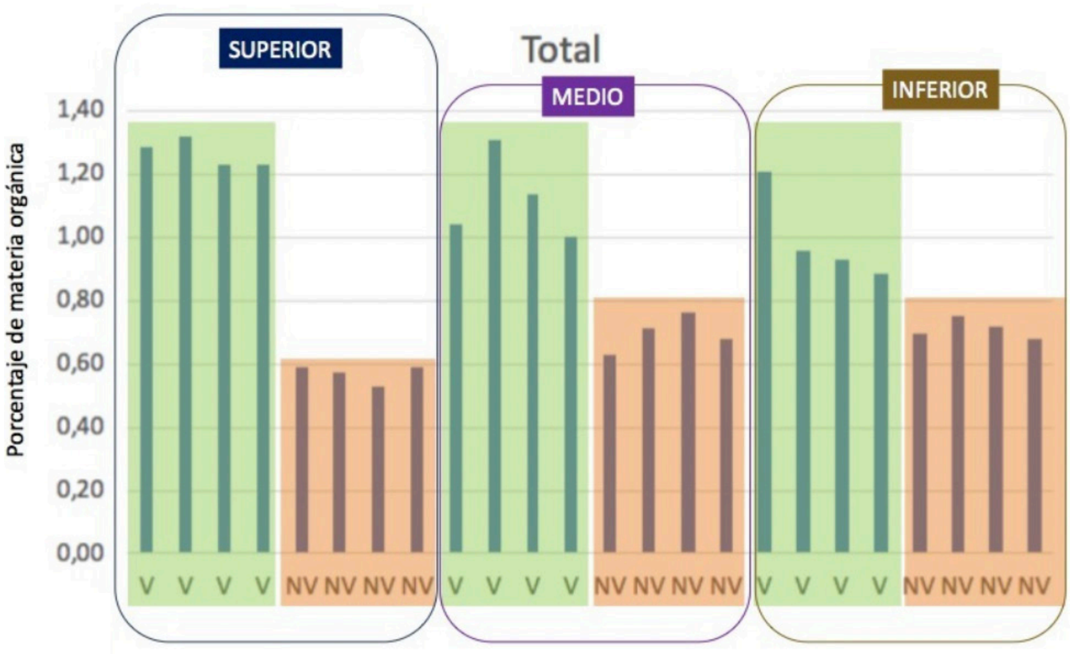


Sharing results on Zostera abundance and its relation to animal biodiversity

After one week of drying, dried Zostera was weighed to calculate the dry biomass of this species in each sample, which coincides with the number of legs and the fact that, as with the number of legs, the dry biomass of Zostera is higher where there are more taxa.

- **2.2 Results on sedimentary matter in vegetated and unvegetated plots at upper, middle and lower levels.**

Prior to laboratory practice, organic matter data were received and organized into upper, middle and lower levels and, within each of the three levels, into samples where plants occur and where they do not. As can be seen in the graph, there were clear differences in the organic matter of the sediments in the three zones: the upper zone, which is slightly fragmented by human activity, the middle zone is already very damaged (fragmented by human action), and in the lower zone there is no grassland. This analysis guided the students towards an ecological understanding of the need for unfragmented grasslands.



V: Vegetation
NV: Non vegetated

Percentage of organic matter in the 4 samples with vegetation and 4 samples without vegetation in the upper, middle and lower zones.

As can be seen in the next point, in terms of the reasoning in the last session, the students concluded that where there is more organic matter is in the vegetated part of the upper zone. They justified that in this upper vegetated part the plants efficiently retain organic matter and deposit it where it is, with less organic matter reaching the unvegetated part than the middle and lower areas, as can be seen in the graph with the maximum difference between the vegetated and unvegetated areas. The lower part, where there is practically no vegetation, is where the organic matter is evenly distributed, which is why there is less difference between the vegetated and unvegetated parts. In this way, in the course of the argumentation associated with the analysis of these graphs, a modelling was carried out that made the initial mental models evolve towards the functioning of the Zostera, which functions as a filter that retains particles of organic matter. They interpreted, using the comparison to a comb, that a fragmented meadow is a comb with missing teeth. They took the opportunity to explain that the isotopic data showed that the matter it retains is of planktonic origin, i.e. it does not accumulate terrestrial matter or dead Zostera per se, but actually combs the sea and therefore has an important filtering role that improves water quality.

3. ARGUMENTATION IN POOLING

• 3.1 Context of information exchange

It involved students participating in field and laboratory activities. It took the form of a colloquium led by the Principal Investigator, with support from the applied mathematics teacher who worked on the data analysis. An experimental science teaching researcher acted as an observer, whose field notes provided the data for the argument analysed in this section. The argumentation took place during a regular lecture session (50 minutes) in a large classroom. The session began with the analysis of graphs obtained with the numerical results of the field sampling and developed during applied mathematics classes. The teacher of this subject himself started the session by trying to check whether, from the analysis of the graphs, they understood the evidence expressed in the data integration representation. Based on the analysis of the results expressed in the graphs and the arguments expressed by the students, the researcher guided the argumentation through questions that asked them to reach conclusions justified by scientific models.

3.2 Data and their analysis

The discourse analysis data correspond to an advanced observer's classroom notes on sharing results expressed in graphs. The notes allude to the characteristics of strategies for stimulating argumentation in the investigative experience, based on the evidence of the data represented in the graphs. Data, justifications and conclusions expressing the evolution of School Ecology models and their progress with the intervention have also been recorded.

For the analysis of the strategies followed in the research, a literature review of interventions of a similar nature was conducted, in which oral discourse was oriented towards modelling and eliciting arguments in which data are linked to conclusions that provide justified answers to questions based on students' conceptual models. These models need to evolve, with the very development of the discourse and the expert's scaffolding, from the initial mental models with which students arrive, to more evolved models, consistent with scientific models.

3.3 Analysis of results extracted from field notes

The intervention was oriented as action research with an observer on the ground. It was geared towards analysing how the argumentation developed in the sharing integrates key data to reach conclusions involving modelling processes. It is interesting to know how these developments of models derived from relating key data have developed through justifications that put knowledge into play within a conversational scaffolding approach. This didactic intervention is generated during the social interaction carried out by the principal investigator and developed through a linguistic system of oral scientific argumentation, with a didactic transposition of the scientific method as a reference for scaffolding, which brings the style of didactic intervention of the scientific expert closer to that of inquiry proper to Science Didactics. This conversational scaffolding stems from the teacher's mediation activity when exercising a tutorial support function to generate learning in Ecology. The conversational scaffold that the scientist articulated was oriented towards actions of adjusting the help given by the scientist in his role of mediator between the students' initial conceptual models (Greta and Moreira, 1998) and the possibilities of their evolution towards models closer to those of Ecology, so that the scientist promoting the argumentation could adapt to the current state of the students' knowledge, previous experiential schemes, individual differences, strategies and learning styles.

In doing so, he adapted his scaffolding plan to the principles set out by Blachowicz et al. (2006). In doing so, his scaffolding allowed him to explicitly describe the strategies used to develop the argument, including when and how to use them, making implicit demonstrations through the argumentation strategies of the scientific method to move towards successful modelling.

In developing the model-oriented conversational scaffold, the scientist modifies his language as he interacts with learners, following Wood, Bruner, and Ross's (1976) notion of scaffolding. He sought analogical metaphorical aids in the sense of Bruner's (1980) use and extension of this concept. This led him to adopt in practice aids to the development of argumentation strategies that would lead to students themselves discovering pathways to cognitive modelling (Bandura, 1971) by developing argumentation strategies that would facilitate the maturation of initial cognitive models. To this end, the line of argumentation of the practical fieldwork was followed through the guidance and recapitulation of the researcher who led the argumentation. By means of the developed conversational scaffolding, the aim was to acknowledge the needs of what was done in the field, as well as to clarify the objectives of the activities, clarify any doubts and provide the methodological keys followed. This conversational scaffolding sought tools to achieve the development of cognitive and metacognitive skills p r i n c e t h a t t h e researcher provided constant feedback, and offered to achieve possible and desirable learning in that context.

3.3.1 Arguing and modelling the relationship between grassland cover and biodiversity

One of the arguments that appears in this discourse concerns the relationship between coverage and diversity. Students start from the graphical representation to draw conclusions about this representation. They draw on the graphical representation of the cover and abundance of each species, showing that the more cover there is, the more diversity there is. However, the relationship between the data is not correct in the justification, as evidence of lower cover is perceived as higher species diversity. The researcher prompts them to count the species so that they realize the evidence is the same and prompts them to look for differences in evenness. Based on this observation of greater species equity where there is greater coverage, the researcher leads them to approach the conceptualization of error.

Although they did not seem to have any clear preconceptions about this concept, they concluded that when there are few plants, the appearance of larger plants introduces a larger error in the mean plant size value. In the same vein, they also concluded that if someone got the mean wrong, this error is more important than in the area with greater coverage, because in the latter case more measurements were made due to the presence of more plants.

Advancing the concept of more diversity with the same number of species, where there is more equity, has not proven to have initial mental models. The scientist starts from the evidence that there are the same number of species in the most covered area as in the most fragmented area to ask whether, given the evidence that species are more 'distributed' in the most covered area, one can conclude that there is more diversity. The response of one of the students showed their resistance to change their initial cognitive model, reiterating once again that the area with more abundant plants is more diverse. Faced with this repetition of the same conclusion, which was not congruent with the data on the number of different species and therefore not in line with the scientific model, the expert guide acting as a tutor, generating the necessary scaffolding, asked for justification to allow him to respond with this conclusion. To this challenge, the student responded, alluding to species-specific data, that there are more crocodiles where there is more grassland because there is more food there. A second pupil then intervened to elaborate on this justification, mentioning that there are more crocodiles where there is more grassland. He justified that more cover means more roosters, crustaceans and polychaetes. To force them to argue using models and theories of basic knowledge in Ecology and Spatial Biology in their justifications, the researcher who acted as a tutor leading the modeling argument asked if crocodiles eat plants, to which the student indicated that they filter. Given the general puzzlement in seeking answers, and to further strengthen the argument based on the use of the background knowledge involved, the researcher asks if the lizards and polychaetes "tuck" plants in. The student concludes, based on what seems logical to him, assuming he has no data, that neither of these zoological groups feed on plants.

A third different student goes on to argue on the basis of an assumed increase in biodiversity on the basis of an assumed increase in the number of species, which turns out to be further evidence that the influence of equity on biodiversity does not enter into his analysis at an explicit level. But it is possible that it has an implicit presence, as it is clear that the graphs show the same species in both cases, but with more clear equity in grasslands with more or less fragmented cover, and it is possible that it is this visual evidence that influences the conclusion that higher cover also means higher biodiversity.

The second student, in order of intervention during the colloquium, in a desire to link the justification to the conceptual models of reference, resorts to the analogy with trees, referring to the fact that, on another scale, many species live in trees. This prompts the researcher, in the role of expert colloquium leader, to use the Zostera plant-tree analogy to ask - Why is there more diversity in a forest than in a desert? This second student answers by resorting to models of intraspecific relationships: -Because of interspecific relationships. The moderator takes the opportunity to evolve the conceptual model implicit in the plant-tree analogy with the phrase: -In ecology we say that they generate places where they can live. In reply, the same student intervenes to say: - Grassland filters.

3.3.2 Argumentation and modelling of filtration capacity and its relation to pH

Introducing the student to the concept of filtration, the researcher took the opportunity to explore the initial conceptual models of this seagrass ecosystem service. He then challenged the second student, who participated in the sharing, to explain the idea, to which the student responded: -Seagrasses filter pathogens. He then asked him to say what he thought needed to be done to prove that seagrasses filter. He replied that he would take two steps: 1) Consult the literature and 2) Go there to investigate whether this hypothesis is fulfilled by measuring the pH.

The emergence of the pH model related to filter capacity measurement was of interest for the line of argument the scientist was looking for, so he oriented his conversational scaffolding to look for conclusions justified by scientific models on the relationship between pH measurement and filter capacity measurement. To advance this line, he asked whether pH would be more acidic the more filtered the water. The student responded by giving an answer that concluded a clear opposition to this possible relationship, concluding that filtered water would be more basic than unfiltered water. This gave rise to the projected discursive scaffolding as the discourse progressed, the scientist challenged the student to justify why plants make water more basic. This question was answered by the third student who took the floor at the beginning of the colloquium to introduce the scientific model of absorption CO_2 into the justification.

3.3.3 Arguing and modelling the ability of grasslands to act as a CO_2 sink

The emergence of this conceptual model by the third student who spoke during the sharing provided an opportunity to introduce the role of these ecosystems in mitigating climate change through the ability of plants to remove carbon dioxide. Therefore, this contribution was used by the researcher to open a new line of conversational scaffolding in the group to provide opportunities to advance the model. Thus, he asked her to justify what she says is made more basic because it absorbs more CO_2. Along the lines of ensuring that the conceptual model evolves appropriately, the researcher asked her to give an answer to how the fact that filtered water is more basic can affect shellfish. The student's answer was that it "crushes" the shells. The moderator made him see the inconsistency of his initial model, opposing what the student had expressed and providing the background knowledge that corresponds to the scientific model, explaining that making the water more basic protects the shells. The student then proves agile in restructuring his mental model, linking the scientific knowledge he had just assimilated with what happens when bivalve shells are used. This application of the newly evolved model with the scientist's input to the use of shells in culture plots was expressed by the student in the following way: -That's why we throw shells into the farm!!!!. The moderator brings up as a point of comparison the fact that the pH of seawater is more basic than that of soils alone.

Next, the scientist, continuing his role as an expert tutor leading the argumentation necessary for the modelling needed to interpret seagrass ecosystem services, challenges the students by asking what it means that plants filter. In the discursive scaffolding he has devised, he has sought to focus the argumentation necessary to conclude that roots are capable of fixing sediment. Based on this information, he asked students to think about designing an experiment to relate pH, water basicity and substrate. His scaffold advanced this supposed experimental proposal by asking them to think about an experiment designed to conclude whether there are more or fewer faecal bacteria where there are meadows and where there are no meadows. He concludes his formulation of the question by asking them for a hypothesis. The pupil who spoke first in the sharing session takes the floor again with his hypothesis expressed in this way: - There will be less faecal bacteria where there are more plants. His scaffolding strategy is then geared towards controlling the variables, asking him whether in this supposed experiment he will only take into account the number of plants or whether he will have to consider something else. To this, the student replied that size should also be taken into account.

When the size variable appeared in the model constructed using the argument, the researcher asked them if they thought plants could be weighed. This gave rise to an interesting response from the point of view of sampling as an experimental technique in ecology. The student, which was key to the second argument, asked whether they would be weighed one by one or all together. To this question, the scientist replied that they would have to find a way to include the weight of all of them together.

The researcher-designed scaffold advanced, seeking the evolution of the plant model as filter feeders, towards an evidence that they perceived through smell in field work, which is the smell derived from anoxic sediments. He then wondered about the origin of this perception. The third student who participated in the argument again stated that where there is grassland, living things grow and reproduce better because plants clean the water and remove CO_2. The scientist added that it also retains sediment. The student who was the first to speak during the discussion added that roots remove CO_2 and filter pollution.

Finally, the researcher asked them if they were surprised or not surprised at all, or if the analysis was of any use to them. Student 3 replied that they were surprised by so many differences between the meadow and the sediment without plants.

3.4 Conclusions

- The science-inspired conversational scaffolding used by the teacher proved to be effective in promoting modelling processes based on argumentation of the ecological importance of Zostera grasslands.

- The need to build on the concepts of error and equitable participation in the concept of biodiversity, which required a planned scaffolding by the expert researcher, highlighted the weakness of using these key concepts in Ecology in the school sciences.

- The pH model is proving valuable for students to relate to measuring the capacity of seagrasses to absorb carbon dioxide and therefore mitigate climate change, but such a model is missing from the lower secondary school curriculum. The expert's scaffolding strategy leaves an interesting formula for addressing this concept at the lower school science curriculum level, especially in such situated knowledge contexts where students know that shells are being added to the ground. Important in this regard is the challenge posed by the teacher's conversational scaffold of comparing sea pH to that of crop fields. Without going into the algorithmic development of the model, one can associate acidity with a high level of protons and develop the chemical reaction at the curricular proficiency level of the physics and chemistry subject matter in the 3rd and 4th grade ESO of CO_2 and H_2O.

- The design of the teacher's conversational scaffolding is agile, flexible and with quick and relevant reorientations to move the argument in the direction required by evolving conceptual models.

- Opportunities to do school ecology in the ecosystem itself and to analyse their own data allow students to talk about ecology in an appropriate way, based on the school ecology they have practiced in the intertidal zone, all of which facilitates students learning good ecology based on the science they have developed.

- The three students who followed the challenges of the conversational scaffolding of the expert tutor researcher became quality learning agents, providing meaningful and relevant training in advancing their initial mental models towards more evolved ones in the orientation of Ecology's reference models.

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