DIDACTICS OF ANTHROPOGENIC GLOBAL CHANGE IN MARINE ECOSYSTEMS

EduCO2cean
Oceanos de sabedoria

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

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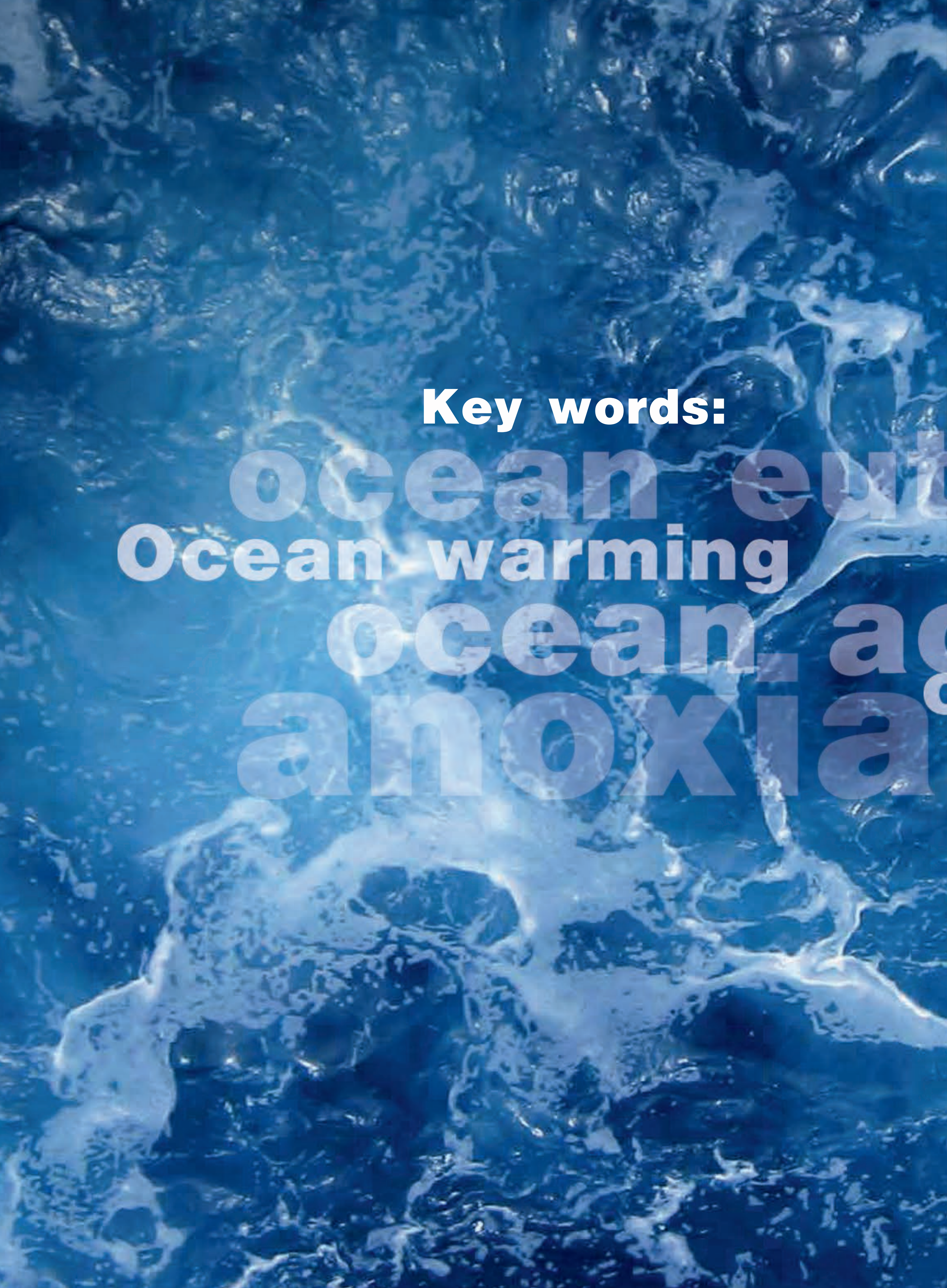
Climántica
Science
Education
Society
Enviromental Education Project CLIMATE CHANGE


Key words:
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Ocean warming
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anoxia


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ocean stratification

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Introduction

Didactics of Global Change in Marine Ecosystems is the first block of curricular content published by the EduCO$_2$cean-Erasmus + project. Its contents include the four main topics related to the impacts of global change in the ocean: impacts of ocean waming on its productivity, eutrophication, invasive species and acidification.

The last two focus on intertidal ecosystems, where scholarly research on the application of the global change knowledge field will be developed. Acidification and invasive species are only addressed to the extent that they affect intertidal ecosystems, which will be the object of in situ study by schoolchildren, because there are specific didactic blocks in the project for their in-depth didactic development. In the acidification block it will be in which this model of research activities in the intertidal ecosystems themselves will be addressed.

This first educational content block of EduCO2cean includes a flexible and adaptable didactic proposal to be able to incorporate the effects of global change in marine ecosystems into any European curricular area of basic secondary education and secondary education.

The ocean is the set of ecosystems most influential and least understood on the planet. It contains a complex network of interactions between species, on which all life depends (food, climate, even the air we breathe). To protect this resource from the global threats of global change, it is necessary to generate scientific knowledge and sensitize society about the importance of studying and conserving the marine diversity. For this reason, it is urgent to train young Europeans on this challenge, for which didactic materials and specific methodologies are needed.

The concern for the effects of the global change of the ocean that this first curricular block of EduCO2cean material is fundamental for European citizenship in particular and for humanity as a whole. This is because the ocean is a most relevant environment, in which life appeared, and on whose productivity the life of the planet depends. This fundamental environment is undergoing a global change that puts it at serious ecological risk.

Human activities are causing impacts of a global nature. The most signifcant global impacts discussed in this section include the increase in sea level, the decrease in pH of the surface waters of the ocean, as well as an increase in the nutrient inputs to the coastal zone

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All these perturbations are having a global impact on the physical, chemical and biogeochemical processes of the oceans and coasts. The changes produced by these actions derived from human activities are integrated into the concept of anthropogenic global change. These changes are relevant, because they end up affecting marine biodiversity and the ecological structure, as well as the functions, benefits and services of marine ecosystems.

The scientific content related to the challenge of anthropogenic global change in the ocean that was selected for the elaboration of *Didactics of Global Change in Marine Ecosystems*, is summarized in the definition contained in the report of the United Nations Intergovernmental Panel on Climate Change. 2013 (IPCC, 2013), according to which this planetary phenomenon has been evidenced in the oceans by the increase in water temperature, acidification and the rise in sea level (IPCC, 2013).

The EduCO_2cean project includes a research activity model of schoolchildren collaborating with scientists on the effects of global change on intertidal ecosystems where the bivalve molluscs that live in their sediment represent a socio-economic resource relevant to the area, and may be at risk due to the global change. This activity, integrated in the didactic block of acidification, which completes the impact factors of the change in the ecosystems, makes it recommendable to close this first block of global change in the ecosystems with the incidence of global change factors in the intertidal ecosystems.

On the effects of global change on these coastal ecosystems, those aspects of global change that are most relevant in these ecosystems were addressed, and will be taken into account in the scholarly scientific research proposed in the didactic acidification block. That is why in the closing chapter of the didactic material, the effects of the global change that stand out in these ecosystems are discussed, such as the effects of acidification on the calcifying organisms of the intertidal, the increase of mineral salts (nutrients for the primary producers of the intermarela) and the effects of invasive algae species.

This didactic product resulted from the transfer to the didactic of the scientific article entitled “Global Change and Marine Ecosystems” written for the EduCO2cean project by the scientists of the Department of Ecology and Animal Biology of the University of Vigo Emilio Marañón, Mariano Lastra and Cristina Sobrino. A transfer of an article written with the logic of Ecology was made to a didactic product.

The first step in the transfer consisted in the analysis of the internal logic of the article, and its synergies with the curricular logic and with the evolutionary psychology of the young people who will use it. Previously an analysis of the way in which ecology is addressed in the different curricula of the partner countries has been carried out. The contents of Ecology that were collected in the article, experienced a didactic development, a reorganization, an extension and an enrichment of new ones. The other didactic elements were

also added to develop a didactic book, designed with the approach and style of the teaching units.

Bearing in mind the commitment of a complete transfer of the scientific article to the didactics, the comparative study of the situation of marine ecology in the different curricula of the European Union was made. From this analysis it was concluded that *Didactics of global change in marine ecosystems* does not have a natural and simple fit in a single didactic unit of a subject and of an academic level of an educational system. Therefore, this didactic block was written with the idea that the teachers can pick up the parts that may interest them, for their curricular connections with the subjects of secondary education for which they are interested.

Once the content was analyzed at a logical level, keeping in mind the demands of psychological and curricular organization, we moved from a structure of the three sections of the scientific article to a didactic sequence of seven sections designed to be used in an autonomous way and independently as didactic units, but sequenced and organized following the logical - psychological didactic equilibrium.

For the transfer to the didactics it was necessary to incorporate contents of key marine Ecology so that a European scholar of secondary education can understand the content gathered in the scientific article. Among these concepts it was necessary to add the trophic and energy flow aspects, introduced so that they can understand the consequences of global change on productivity. It is necessary in this case to assure them the necessary approximation to the concept of productivity, and its implications in the flow of energy.

To achieve the didactic development of this work, it was necessary to clearly define the didactic objectives and key concepts susceptible to use in any European educational system and that are expressed in the following sections. From these common denominators, the seven key questions were formulated, whose answer with didactic depth to each one of them, requires the study of the didactic unit headed by the headline that contains the statement of that question. These questions are presented to the students before starting the work of the corresponding unit, so that they write the corresponding answer. At the end of the study of the didactic unit headed by that question, the response is recorded again, this time given from the training acquired by the corresponding didactic unit.

Once these initial questions of exploration of previous ideas on the factors of incidence of global change in ecosystems are addressed, two types of activities are carried out, which are activities carried out in a classroom, and which are symbolized by a pencil that contains a number 1; and activities that are performed in a laboratory and symbolized by a flask associated with a number 2.

1 Workbook activities

2 Laboratory experiments

The laboratory practices were designed to address three major conceptual dimensions of anthropogenic global change: convention currents, mixtures of water with dyes of different temperatures, dissolution of bivalve shells in acid, measurement of turbidity with Secchi disk.

Finally, the study on the recruitment of cockles that cease to be larvae and are fixed in the Testal sand was made by the transect method with sampling at the same distance and with the same volume of sand.

INITIAL QUESTIONS

Answer what you know before starting the study:

1) **Are we changing the ocean globally?**
2) **How does global change affect marine ecosystems?**
3) **What factors can limit primary productivity due to global change?**
4) **How does the ocean uptake the atmospheric carbon dioxide?**
5) **What is the current situation of the warming of the ocean and its effects on global change?**
6) **What is the impact of anthropogenic nutrient imputs?**
7) **What other factors of global change affect intertidal ecosystems?**

Concepts

- Climate change concept.
- Climate change impact in sea ecosystems.
- Oceanic productivity and factors involved.
- Biological pump as a capture mechanism for CO_2: Alterations caused by climate change.
- Effects of warming on ocean productivity.
- Effect of anthropogenic nutrients in global change.
- Ocean's acidification during anthropogenic climate change.
- Global warming effects in the biogeochemical cycles of intertidal ecosystems.

Objetivos

1. To acquire the concept of anthropogenic global change and causal factors.
2. To identify the impacts of global change on marine ecosystems.
3. To understand the concept of ocean productivity.
4. To identify the factors that control ocean productivity and the ecological consequences of their alteration.
5. To apply the concept of the biological pump to understand CO2 uptake by the ocean.
6. To recognize the effects of ocean warming on ocean productivity.
7. To understand the effect of anthropogenic nutrients on ocean ecosystems.
8. To understand ocean acidification and its consequences on the biology of the ocean.
9. To reflect on possible future impacts of global warming on biogeochemical cycles in the intertidal zone.

Units

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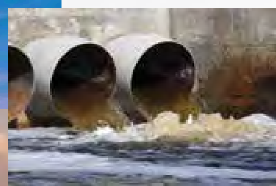
1 Are we changing the ocean globally?



Human activities are causing global impacts such as the warming of the ocean, from which other global impacts derive, among which the increase in sea level, due to thermal expansion and melting, stands out. Both surface water heating and melting lead to an increase in stratification between surface water and deeper water, as will be studied throughout this teaching material.

The stratification, which is produced by differences between the density of the surface water and the deeper one, prevents the mineral salts (fertilizer for oceanic producers), coming from the decomposition of the organic matter and the rocks of the ocean floor, from reaching the surface, which decreases the productivity of ecosystems (decrease in biomass of primary producers from which the entire ecosystem is nourished), as it is going to be studied.

Another global impact caused by human activities, which has an effect on marine ecosystems, is the acidification (lowering of pH) of the surface waters of the ocean. The decrease in the pH of the ocean causes diverse impacts on ecosystems, such as the decalcification of larvae and calcareous organisms, whose shells are affected, due to their dissolution caused by the increase in acidification (pH decrease) of the surface water. This decrease in pH, as will be studied in this chapter, has its origin in the increase in the dissolution of CO_2, coming from the emissions due to the use of fossil fuels. This gas is introduced into the ocean as a result of the interaction of surface ocean water with the atmosphere.

The third major area of global change that is studied with this didactic material is the increase in the contributions of nutrients to the coastal zone, mainly derived from the excessive use of fertilizers. This has diverse effects on ecosystems, as it will be explained later on, especially in relation to the increase of anoxia (loss of oxygen in the ocean), the loss of light penetration capacity, due to excess microalgae of plankton (phytoplankton), and the occurrence of phytoplankton species that produce toxins, as it occurs with the microalgae responsible for red tides (dinoflagellates).

All these human-caused transformations are having a global impact on the physical, chemical and biogeochemical processes of the oceans and coasts, All these human-caused transformations are having. These on-going changes are very relevant, since they end up affecting marine biodiversity and the ecological structure, as well as the functions, benefits and services of marine ecosystems.

1. Fill in the gap that appears before each change with the terms Physical, Chemical, Biogeochemical. Then match that change with the affected factor drawing an arrow. List each arrow with a number. Make a list with the numbers that appear on each arrow associating the explanation of the change.

FACTOR	CHANGE
Temperature	Acidification of the ocean
	Decrease in density
Mineral salts	Nutrient increase
	Rising sea levels
pH	Dissolution of soluble minerals

2. Associate each of the phrases with the following concepts: a) marine biodiversity, b) ecological structure, c) ecological functions and d) services of marine ecosystems. Give examples of each::

- **Different ecosystems**
- **Increase in shellfish activity**
- **Different species**
- **Nutrients for producers**
- **Mineralization of organic matter**
- **Benthic species of the ocean floor**
- **Planktonic species of the oceanic surface**
- **Increase of phytoplankton in eutrophication processes due to excessive accumulation of mineral salts.**

According to the report of the Intergovernmental Panel for Climate Change of the United Nations of 2013 (IPCC, 2013), this planetary phenomenon has been evidenced in the oceans, by the increase in water temperature, acidification and the rise in sea level (IPCC, 2013). Also significant is the increase in mineral salts (nutrients for the primary producers of these ecosystems), by discharges that affect global factors as relevant to marine ecosystems as light and oxygen.

This organism of the United Nations has focused on the oceans one of its major fields of study, since, in addition to occupying more than 70% of the surface of the planet, they regulate the climate, they are a fundamental food base, they release oxygen, they provide great amount of resources, and it is expected that in the future they will be the source of many more. That’s why an important part of the Climate Summit held in Paris (COP21), focused on the problem of the oceans derived from climate change.

3. Look for information on the internet about the last UN summit on climate change and on the IPCC 2013 report.

Bearing that information in mind, answer:

a) What agreements were reached?

b) Which country that signed it has already rejected that commitment? How do you value this fact for the challenge we are addressing?

c) What are the main conclusions about the future of global change in the ocean drawn from the Paris Summit?

In conclusion, these processes of global anthropogenic change are potentially inducing biological responses that affect the balance of marine ecosystems. Among them, they stand out, by the effects that they have on the abundance, the distribution and the activity of populations of species, from the most superficial (planctónicas), to the deepest ones (benthic), the effects of the warming of the ocean, the acidification and eutrophication on distribution. Likewise, examples of impacts on the diversity of communities (set of populations) and the general functioning of the ecosystem are discussed.

The knowledge that is addressed arises from the study of historical series, based on in situ and remote observations, to show changes in the composition of planktonic communities, as well as in the primary production (new biomass synthesis from the fixation of CO_2 through the photosynthesis) of different regions of the ocean. The concepts and processes related to the effect of heating and acidification on the metabolic activity (cellular biochemical reactions) of the populations and communities of different species of plankton, invertebrates and fish, were obtained as a result of a synthesis of several recent experimental studies.

This knowledge that is being addressed in this work, is one of maximum ecological, economic and social relevance; which justifies the effort of their study. The fact of introducing them in secondary schools, in parallel in time with the scientific investigations from which they arise, should be an opportunity for young people to approach the complexity of the challenge and its scientific study. In addition, in this way, high school students are made aware of changes that, due to their global nature, are also evident in their oceanic coastal environments.

That is why school communities are encouraged to apply the knowledge studied here, in the form of scholarly research, inviting scientific communities to be involved with them in their design and development. In this way, we can learn about global change, generating at the same time scientific knowledge about the implications of this challenge in the environment close to schoolchildren. A good example of this proposal may be the one included in the final application part of the next module, which adresses the acidification and completes this first curricular module. It applies the knowledge studied throughout this topic, to help to know over time the possible impacts of global change on a shellfish bank of bivalves of great economic, social and ecological relevance.

4. In this last paragraph it is stated that scientists and secondary school students can collaborate to study data series that allow to know the impacts of global change on intertidal ecosystems, in which shellfish bivalve activities are carried out.

Analyze this information and respond:

a) What is understood in scientific studies by data series?

b) What should be the minimum time to have a series of significant data with value to draw conclusions about the impacts of global change on this type of shellfish resources typical of intertidal estuarine ecosystems?

c) What opportunities can secondary school students have to collaborate with scientists in this type of studies?

d) Can there be any interest for scientists to be involved in this type of studies that oblige them to participate in the formation of secondary school students?

e) Do you see any socio-economic and ecological interest in this type of study? If so, express it, showing your possible level of commitment in a scientific school challenge of this nature.

2 How does global change affect marine ecosystems?

A very productive Icelandic ecosystem, frequently visited by whales

The global change directly affects, as it was seen, both physical and chemical factors such as temperature, pH, salinity and density, which are causing a global anthropogenic change in the ocean.

Therefore, global change must have obvious effects on marine ecosystems, since an ecosystem is a natural system formed by a set of living organisms (biocenosis or population) and the physical environment where they are related (biotope), which includes all types of relationships and interactions between the different elements, both biotic and abiotic, that constitute it.

For this reason, by affecting the global change to abiotic factors typical of marine ecosystems (temperature, density, salinity, light, oxygen, pH ..), affects the whole of marine ecosystems. This is so, because these abiotic factors determine the trophic relationships between the different populations of the communities, with their consequent energy flows and circulation of matter.

These trophic relationships are what make the energy flow through the ecosystem from the biomass obtained by the producers through photosynthesis (primary productivity), to the top predators, through the trophic networks that are established between the different populations of the ecosystem community.

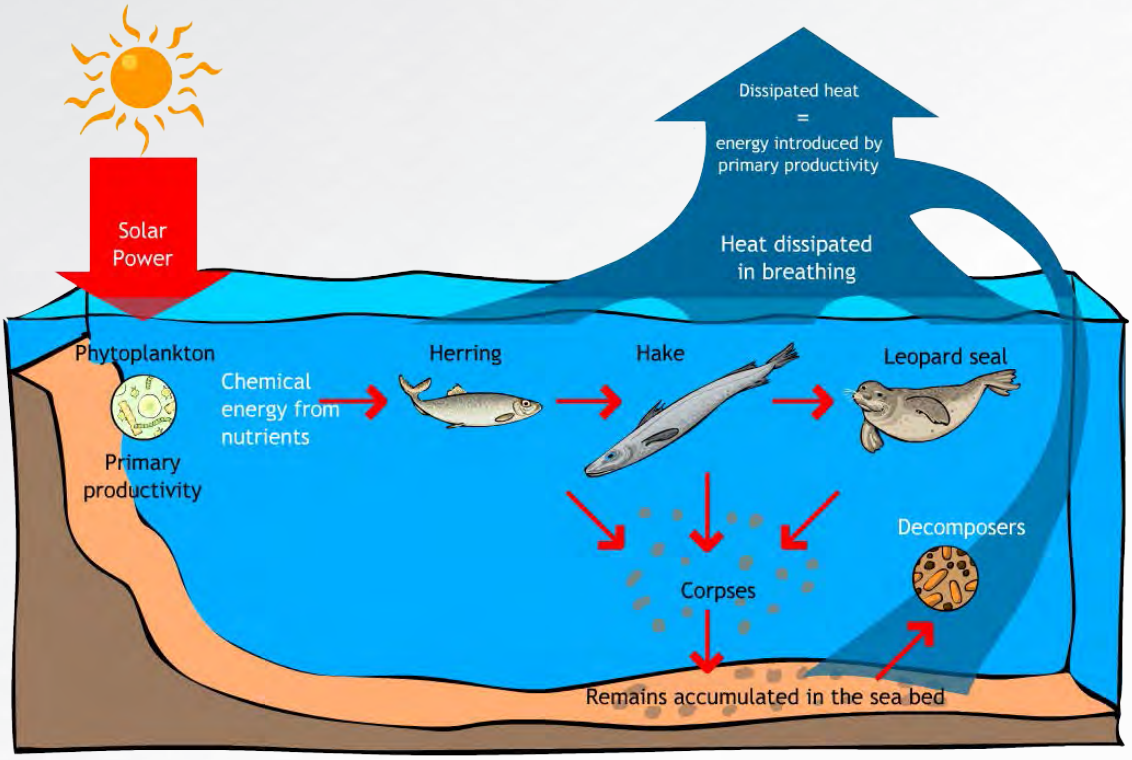


Illustration 1. Energy flow through a trophic chain of a marine ecosystem

The energy that flows in the ingested matter, as it advances through the trophic network, does so in the form of a flow, progressively dissipating energy as heat, which the ecosystem can not reuse. This dissipation as heat is due to the processes of the respiration of the individuals of the ecosystem and to the decomposition of their waste and corpses.

Therefore the energy flows in the ecosystems without returns in the form of reuse, through the trophic relationships, starting said flow of the radiant energy of the sun assimilated, in the form of chemical energy, through the process of photosynthesis that occurs in the producers (primary productivity). In this advance of energetic flow, it gradually dissipates in the form of heat. At the end of its flow, the heat dissipated is equivalent in energy terms to the internal chemical energy of the new biomass formed by the producers (primary productivity) through the process of photosynthesis.

However, the chemical elements move in cycles, given that the organic matter formed by the producers mediating photosynthesis (primary productivity), passes the chemical elements of the inorganic mineral salts to the organic matter. These bioelements return to inorganic matter, when the organic matter is mineralized as a result of the decomposition of remains, waste and corpses from the different organisms of the marine ecosystem.

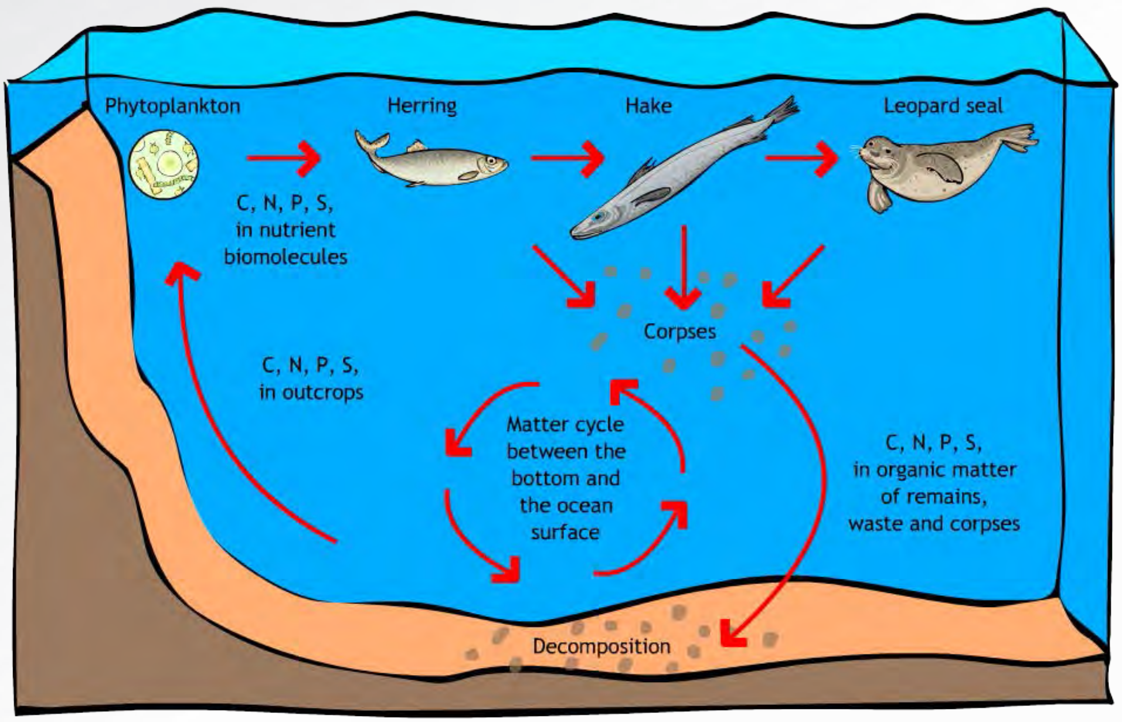


Illustration 2. Matter cycle through a trophic chain of a marine ecosystem

In the oceans, this cycle develops in two spatially differentiated parts. On the one hand, the passage of bioelements to organic matter occurs on the ocean surface, where phytoplankton live. However, the decomposition occurs at the bottom of the ocean, because that is where the remains and corpses are going to be deposited. That is why, in order for this cycle of matter to take place, and therefore marine ecosystems to function, it is necessary that the inorganic matter resulting from the mineralization due to decomposition at the bottom of the ocean rise returns to the surface, as it occurs in the phenomena of coastal upwelling that we will study.

5. Apply the ecosystem concept to answer the following questions:

a) What is the relationship between the concepts of population and community?
b) Give examples of elements of a biotope and of a community or biocenosis of a marine ecosystem.
c) What do the flow of energy and matter cycles of ecosystems have in common and how do they differ?
d) Why does the matter cycle extend from the surface to the bottom of the ocean?
e) What energy transformation activities take place in the flow of energy in marine ecosystems?

To know if a marine ecosystem can be affected by global change, we must know well the time series that allow us to quantify the temporal evolution of the numbers of each of the populations of the community and also the evolution of their trophic relationships.

For this reason it is necessary to study their trophic networks, analyzing them when necessary, in well differentiated trophic chains. These analyses mean having previously clarified a representation that follows routes that the energy contained in food travels through the ecosystem.

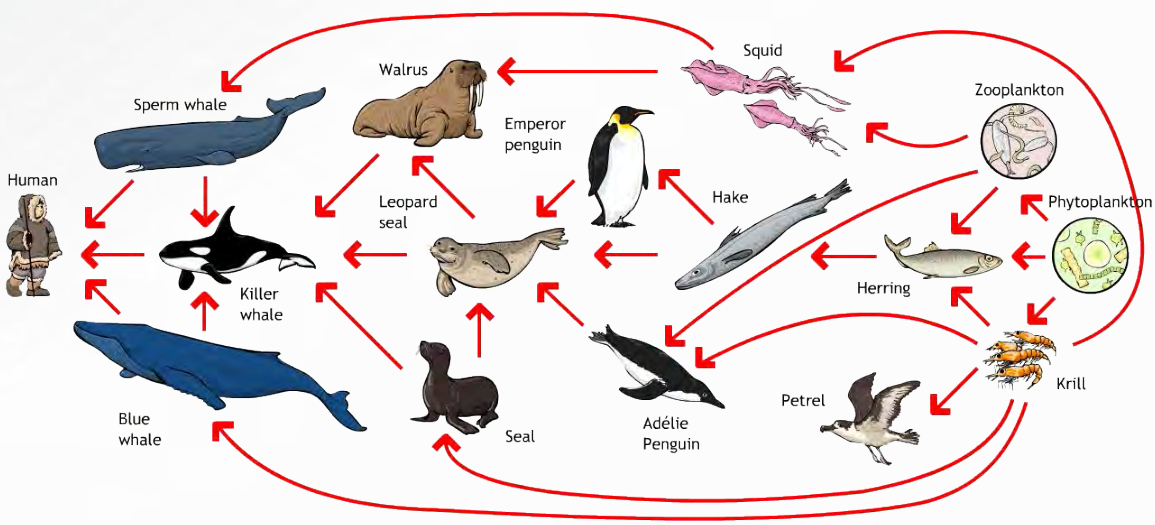


Illustration 3. Trophic network of a marine ecosystem of the Arctic region

In a marine ecosystem, each species can eat very different things and serve as food for different organisms. When a trophic network is being clarified, it may be interesting to follow linear routes of the energy that passes from the populations (set of individuals of a species) that are eaten to those that eat them, and is represented by a linear scheme in which the populations are elements united by arrows that point, starting from the food population, to the population that eat them, which are those that are pointed by the tip of the arrow. In this way, the direction followed by the matter and the energy of the ecosystem that follows that particular route is represented. This representation is known as Trophic Chain.

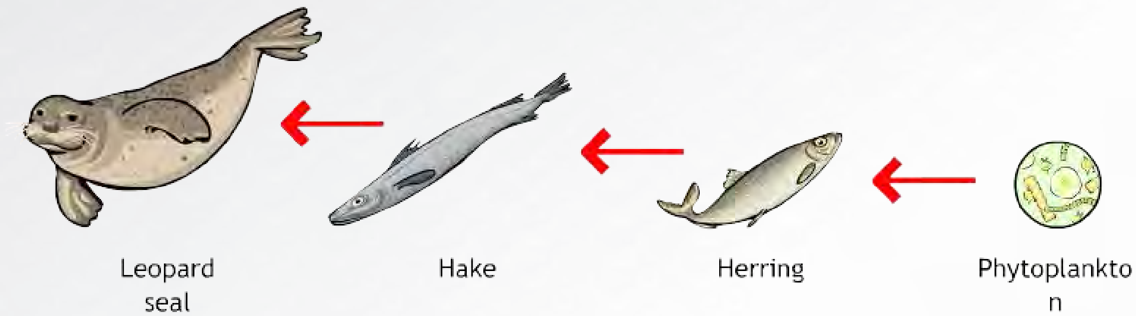
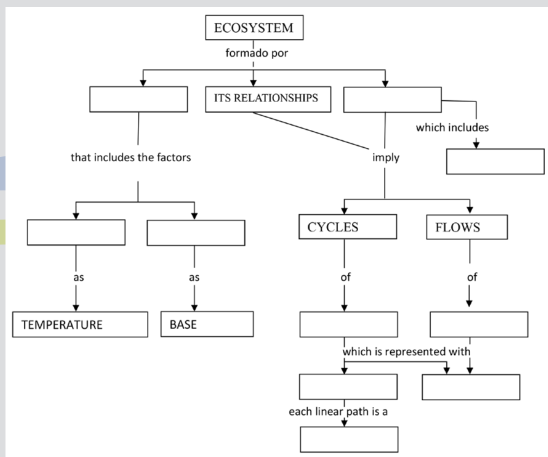


Illustration 4. Trophic chain of a marine ecosystem of the Arctic region

A trophic or food chain is a linear scheme in which each element of the chain feeds on the previous one and serves as food for the next. The representation of trophic chains, intertwined, in which a population can be part of several trophic chains at the same time, is the so-called trophic food web.

6. Complete the missing concepts in the conceptual map referring to the concept of ecosystem using the terms: trophic chain, community, energy, chemicals, trophic pyramids, biotope, trophic, physical networks, populations, matter.



6b. Complete each of the following definitions relating to terms expressed in the conceptual map of the previous activity

- **Community. It is formed by all the .... that inhabit an ecosystem, also known as ....**
- **Population. Set of individuals of the same .... that inhabit the ecosystem and constitute each of the elements of the ....or biocenosis**
- **Trophic food web. They are a network of paths that follows the matter, and therefore its ....able horizon for the nutrition of the species. Each linear path that can be identified in that path is called trophic.................. . Its links are linked with arrows that represent the passage of the energy of the individual that is .... by that to which the arrow points. The individuals to which no arrow points, and from which arrows come out for all are called ...., and those from which no arrow departs, but to them only arrows arrive are called ... .**
- **Trophic pyramid. Representation of .... of energy, in such a way that the base represents the energy assimilated by the ...., through the process of ....Each pyramid which is superimposed on the previous one is located in its center and represents a maximum of 10% because it is the .... which takes advantage of the following ...., because the rest is dissipated in the form of ... . The energy contained in the individuals of the cusp, also called ...., is completely transformed into ...., by the whole of the .... that assimilated in the base the ...., ends transformed in its totality, once it passed through all the .... in ...., and for that reason it is said that a trophic pyramid is a model that represents the .... of ....**
- **Biotope It is formed by the set of factors .... and .... which interact with each other and also with the different .... that form the ....**

Plancton (MECD source, author Rubén Duro Pérez)

In the oceanic food chain and food webs we can distinguish several trophic levels. The first trophic level is made up of producers, among which are the species of microscopic algae of plankton (phytoplankton) that live on the surface of the water. These unicellular organisms are the main transformers of the physical energy of solar radiation into internal chemical energy stored in the carbon bonds of organic matter. In this way, organic matter is produced from various inorganic substances, among which carbon dioxide and N and P mineral salts stand out.

The second level is occupied by the primary consumers, who feed on the producers. The third is occupied by secondary consumers, who feed on primary consumers. Beyond that are the tertiary consumers, such as the shark or the killer whale. The decomposers are in charge of recycling the material.

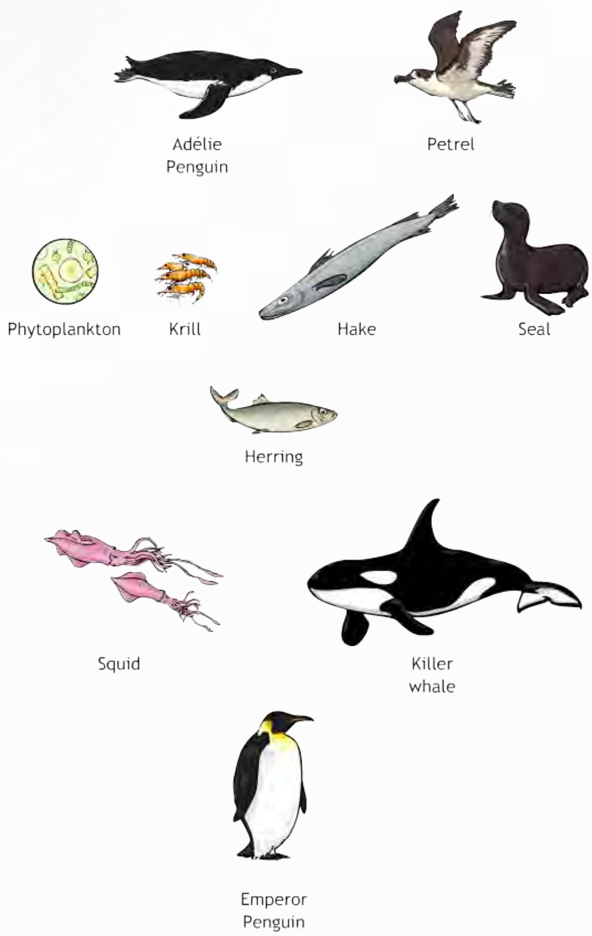


Illustration 5. Images of species to perform activity 7c

7. Look at the trophic chain and the food web (Figure 3) from which the trophic chain was extracted (Figure 4) and answer the following questions:

a) At what trophic level do the phytoplankton, seal, hake and herring of the trophic chain belong respectively?
b) Point out other species of the four trophic levels in the trophic network of Figure 3
c) Name the populations of the image, and with these names organize a trophic network, putting in parentheses, next to each name, the trophic levels it occupies in each chain that you visualize in your analysis.
d) What would happen if phytoplankton disappear in the trophic chain?
e) What would happen if the herrings disappeared?
f) Respond to what is asked in questions c) and d), but placing the species that are asked about in the trophic web of Illustration 3.
g) To represent a matter cycle, what element do we have to introduce?
h) If killer whales were to disappear, who would benefit and who would be harmed? Justify the answer.
i) Would the disappearance of krill be equivalent, more or less serious from the point of view of the flow of energy? Justify the answer
j) How would excessive hake fishing affect the ecosystem?
k) From the point of view of energy cost, what would be more interesting, the aquaculture of herring or hake? Justify the answer
l) If we introduce walruses in these ecosystems, how would the trophic network be affected? Represent two new trophic networks that incorporate that population?
m) In view of what you have reasoned in the questions, do you think that there can be independent trophic chains in ecosystems?

Phytoplankton obtains energy directly from the Sun through photosynthesis, which allows them to form the carbon chains of organic molecules that are the ones which enable its increase in biomass (primary productivity) and the obtaining of energy to perform its vital functions. This energy, necessary for its operation, is obtained by breaking the carbon bonds of the organic molecules that are needed to provide the energy required by vital functions.

The process of breaking chains of C, called cellular respiration, is the same as that which occurs in the cells of the other heterotrophic organisms of the ecosystem, with the only difference that in the autotrophs the carbon chains are obtained by chaining the C from the CO2 of the atmosphere, through the process of photosynthesis, while the heterotrophs have to obtain the carbon chains of the organic molecules that form other living beings, through food.

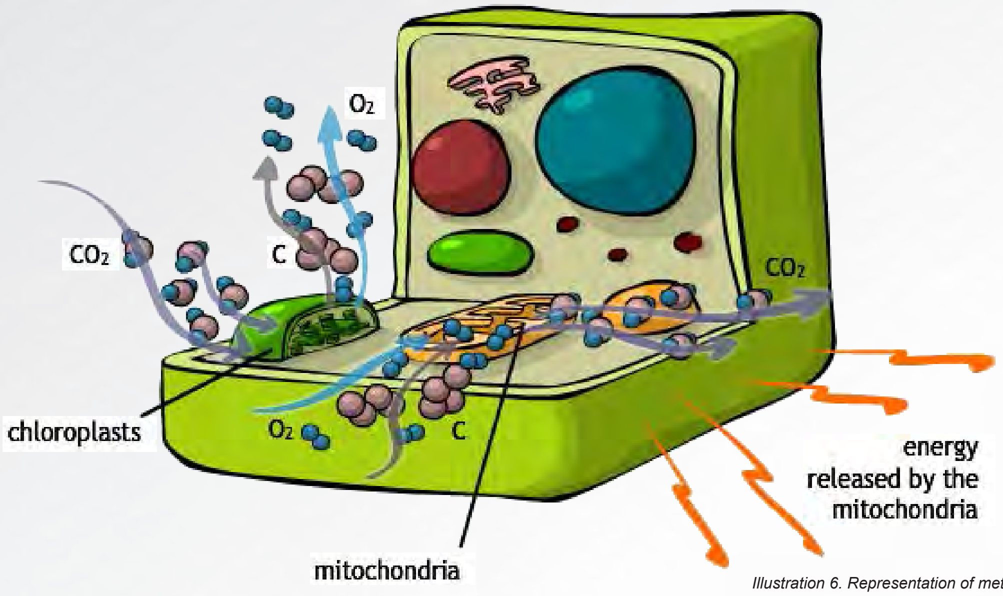


Illustration 6. Representation of metabolic processes of a unicellular phytoplankton organism

In the cells of the different species or populations of plankton, the two processes occur, photosynthesis in their chloroplasts and respiration in their mitochondria. During photosynthesis CO_2 is fixed into chains of organic carbon and in the chemical bonds of those chains the energy obtained by transforming the captured light energy is stored. Water participates in this process, releasing the oxygen that was part of that molecule. The carbon chains that are not degraded by the mitochondria of the plankton cells allow to increase the biomass in which energy is stored for the use of the primary consuming organisms that feed on those unicellular phytoplankton organisms.

The primary consumer heterotrophic organisms obtain energy from the food they eat, contained in the matter that forms the autotrophic organisms that they eat. Secondary consumers obtain energy through the animal matter of primary consumers or herbivores they consume.

In the cells of the heterotrophs, photosynthesis does not occur. But all the cells of living organisms, both autotrophic and heterotrophic, get the energy stored in the carbon bonds of organic matter through cellular respiration. This process, called cellular respiration, that requires oxygen is expressed with the global chemical reaction inverse to photosynthesis:

$$6\,CO_2 + 6\,H_2O \underset{\text{respiration}}{\overset{\text{photosynthesis}}{\rightleftarrows}} C_6H_{12}O_6 + 6\,CO_2$$

8. Look at the trophic network of the ecosystem represented in the figure and complete the table:

POPULATION	SOURCE OF ENERGY	SOURCE OF MATTER	TROPHIC LEVEL
Diatoms			
Copepods			
Herrings	Organic Matter		
Hakes			
Squid		Organic Matter	
Penguin			
Seal			
Whale			
Killer Whale			

The energy contained in this increase in biomass that is available for consumption by marine organisms living from ingesting phytoplankton and other oceanic producers is known as net primary production (NPP). This energy is determinant for the functioning of an oceanic ecosystem, since this is the internal energy of organic matter that, in the end, ends up passing from one organism to another through the trophic networks of marine ecosystems. The more primary production an ecosystem has, the greater the energy that flows through it.

In the unidirectional energy flow of any ecosystem, the energy that reaches a trophic level does not exceed 10% of the energy that reached the previous level. For the graphic representation of that a trophic level only uses around the 10% of the energy available at the lower level and that at the end of this unidirectional flow the 100% of the energy has been dissipated into heat, it is used the trophic pyramide. This pyramide is represented with pillars, which are ordered attending to their trophic level. Each bar represents the percentage of energy which is used by this trophic level, which is proporcionated by the previous level. As these pillars have the same height that available at the level immediately below, and are centered in their midpoints, they are stacked following the order of the trophic level, at the botton it is represented the total ammount of energy assimilated by the producers and at the top, it is represented the energy assimilated by the top predators.

Illustration 7. Trophic pyramid with three links

9. Sort this data and build with them a trophic pyramid of biomass: a whale of 100 tons, 1,000 tons of zooplankton, 10,000 tons of phytoplankton, 142 Eskimos of 70 kg each of average weight .

All the energy whose flow is represented in the networks and trophic pyramids is energy contained in organic matter, and ultimately that energy comes from the energy stored in the carbon chains formed in photosynthesis and that phytoplankton used for cell growth , and that is available for primary consumers in that biomass increase that is known as net primary production (NPP). When this is expressed as the proportion with which the new biomass is produced per unit area, it is called net primary productivity, which results from subtracting from the total energy fixation that producers obtain through photosynthesis, known as gross primary productivity gross (GPP), the energy that the producers eliminate or dissipate in the form of heat in the process of respiration (R).

10. Calculate the losses in the following marine species in the two situations that are quantified in sections a) and b), and also answer to section c):

a) A lobster was weighed on June 21, 2017 and it gave a weight of 2 Kg. It was reweighed on December 21, 2017 and it gave a weight of 2.5 Kg. It is known that this crustacean eats at day 0, 5 Kg of food.

b) A squid of 60 g ate two herbivorous molluscs of 30 g each, increasing its weight after one month to 150 g.

c) In what did they spend the energy that did not affect the weight gain, the lobster and the squid? Justify the answer.

Therefore the net primary productivity (NPP = GPP-R) of a marine ecosystem, represents the real proportion of new biomass of marine producers, mainly of unicellular phytoplankton organisms that is available to the consumption of heterotrophic organisms.

In each trophic link there is a loss of the energy that the individuals ingest in the form of heat, due to the decomposition of the matter that does not absorb in the intestine (waste) and of its expenses due to the emission of heat by the breathing processes .

Therefore, primary productivity is the energy base on which the nutrition of all the individuals that inhabit the ecosystem depends. If the global change affects the key factors of the production of an ecosystem, making it limiting, it will significantly affect its functioning. Therefore, to study the possible effects of global change on ecosystems, it is necessary to study the possible effects on all the factors that may be limiting for the functioning of the marine ecosystem.

11. On an ecosystem in which its primary productivity is decreasing, answer:

a) What factors may be affecting it?
b) Can global change affect those affected factors? Justify the answer
c) How can this decline in primary productivity affect the functioning of the ecosystem?

3 What factors can limit primary productivity?

The main factors that can limit the primary productivity of marine ecosystems are those that affect the concentration of mineral salts that are nutrients, which "fertilize" the surface waters inhabited by phytoplankton, and also those that affect the penetration of light through water so that it can affect these autotrophic organisms.

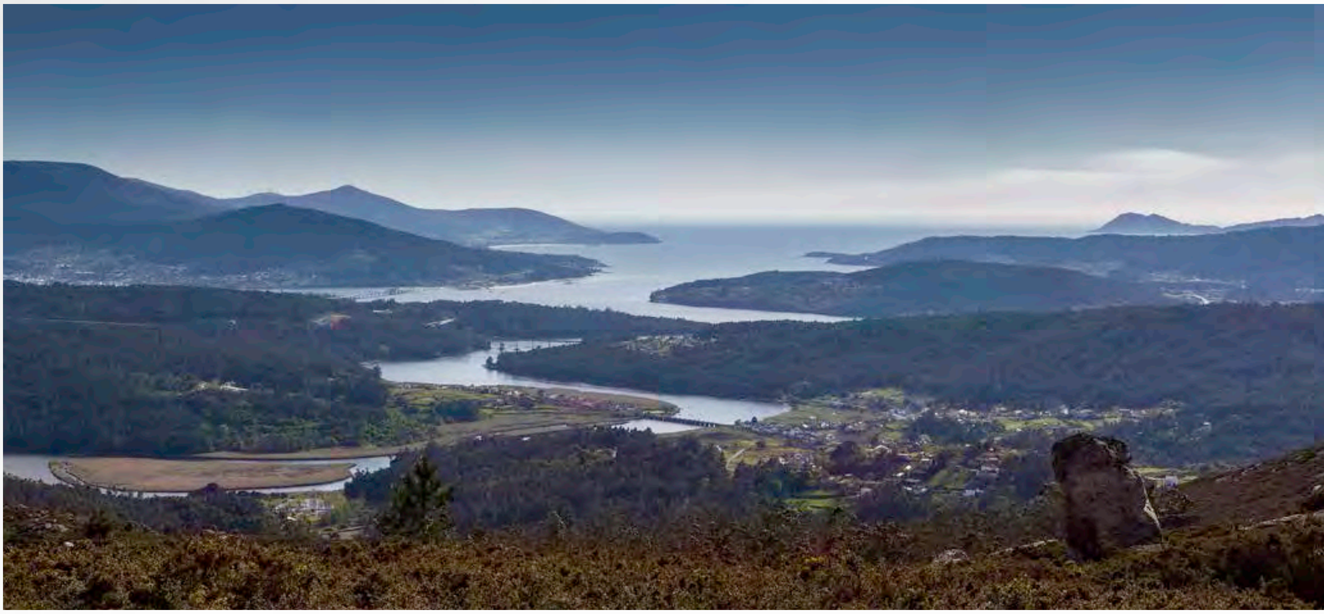
3.1 Factors that determine the access of nutrients to phytoplankton.

The mineral salts that producers need are those that provide the elements that are necessary for the formation of basic elements and that are not part of the chemical composition of the two molecules involved in photosynthesis: CO_2 (C and O) and H_2O of the (H and O). Among these bioelements that nutrient mineral salts have to contribute are nitrogen (N) and phosphorus (P). The N is necessary to form the amino groups of the amino acids that form the proteins and for the formation of the nitrogenous bases of the nucleic acids. P is needed to form the nucleotides of the nucleic acids.

Therefore the nutrients that can become more limiting if the global change prevents their access to photosynthetic marine organisms are nitrogen (in general as nitrate) and phosphorus (as phosphate). We know this because the most productive marine communities occur in places where the concentrations of these nutrients are unusually high.

In the oceans, these locally elevated levels of primary productivity are associated with the input of nutrients from two sources. The first of these sources is the flow of mineral salts transported by the rivers to the estuaries, from where they access the continental shelves, remaining at the disposal of the phytoplankton that lives in the locations of continental shelves that face an estuary. The second source is the ascending marine currents.

Mouth of the river Tambre forming the Muros-Noia estuary.(Author Pedro García Losada)



The marine upwelling currents cause upwelling of nutrients from the ocean floor. It is an oceanographic phenomenon that consists in the vertical movement of water masses, from deep levels towards the surface. These regions with upwelling result in places with very high levels of primary production. The high primary production stimulates the activity of the food chain, since phytoplankton is the basis of oceanic food.

Most upwelling regions are located on the continental shelves, especially in those where winds parallel to the coast or from the mainland predominate, such as the trade winds that blow parallel to the coastline and produce a surface water shift to the open ocean due to the Coriolis Force (which acts diverting the flux to the left in the Southern Hemisphere) on the surface waters of the extensive platforms of Peru. These superficial winds move surface water away from the coast, heated by the incident solar radiation, being replaced by deep cold water that rises up the ramp of the platform, due to the tendency to level the fluids. As a result of

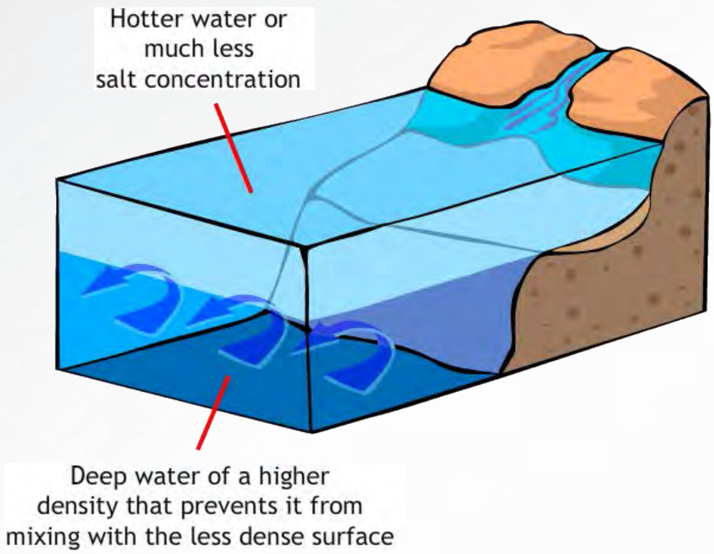


Illustration 8. Representation of the two sources of nutrients

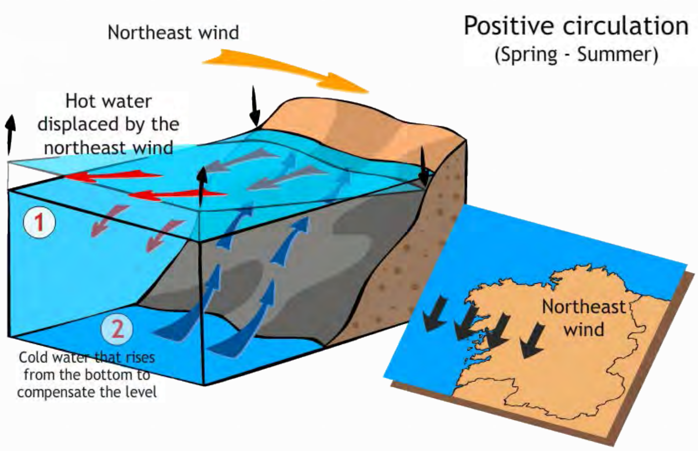


Illustration 9. Representation of the outcrop on the coasts of Galicia with northeasterly winds

this process of rising of deep cold water to level the surface hot water removed, the deep, nutrient-rich cold water occupies the space left by the warm surface water withdrawn by the surface wind running parallel to the coast of continental origin.

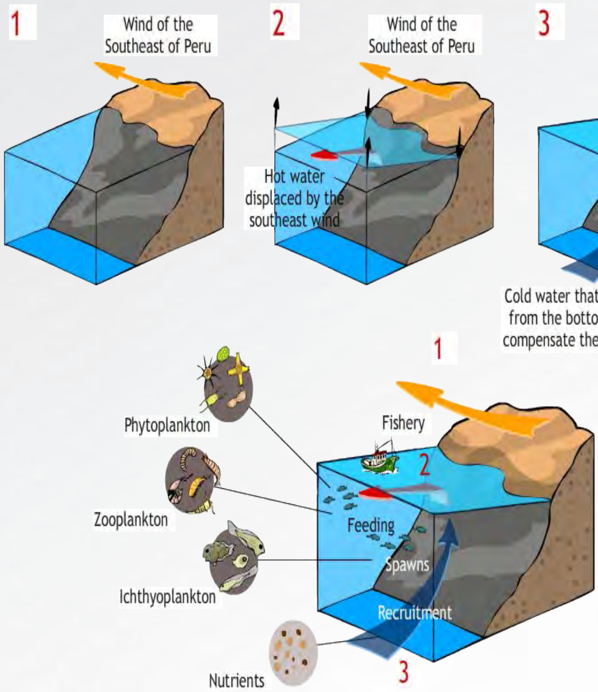


Illustration 10. Representation of the upwelling in the southern hemisphere.

This deep cold water contributes nutrients to that region, which boost the increase of its primary productivity, which is why this emergency process is known as an upwelling. The ramps of the continental shelf favour these processes of ascent of deep waters. Strong upwelling can also occur in regions other than continental shelves, such as in some submarine ridges, as well as in areas of very strong currents.

When the vertical water movement ceases, the hot surface water tends to stratify, especially in very warm areas, forming a thermocline. This stratification is due to the fact that the surface water is of a density that is clearly lower than the deepest. The decrease in the density of surface water stratified by surface heating is due to the expansion of surface water molecules (thermal expansion) when it is heated.

It is in this warm, less dense surface water where the majority of the phytoplankton is located. As this water is not miscible with the colder and denser water, a barrier is formed that prevents access to phytoplankton from deep water, with a high density of mineral salts.

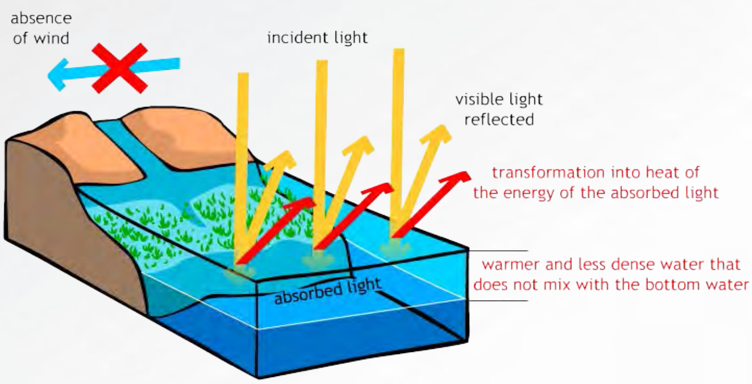


Illustration 11.Stratification process due to wind loss and surface heating

This difference in density can also occur in the ice thawing zones. In this case, the cause of the decrease in the density of the surface water is not its warming, but the entrance to the surface of the ocean of fresh water coming from the melting. This water that enters the surface of the ocean by melting, being fresh water, has a saline concentration clearly lower than ocean water, and is therefore less dense than salty seawater.

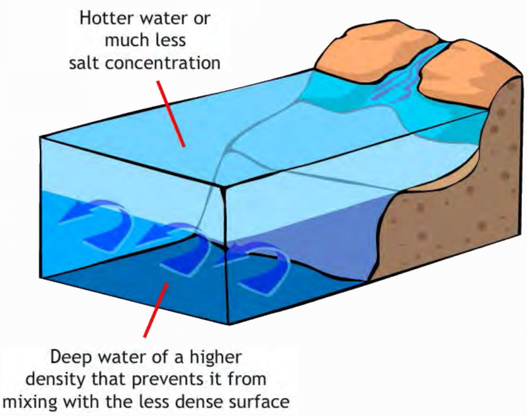
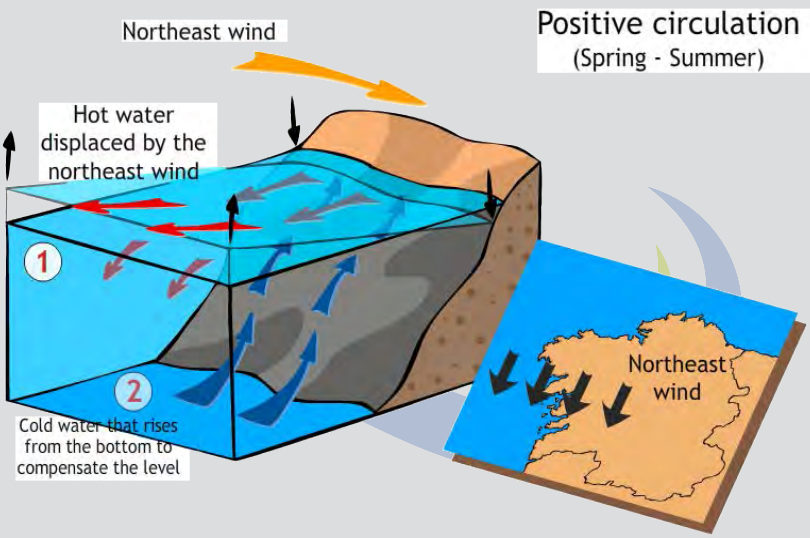


Illustration 12.Representation of the impossibility of access of mineral salts to surface water due to the stratification process.

For this reason, the water coming from the thaw is stratified with the deep water, and also prevents the arrival of mineral salts from the bottom to the surface. In the first case it is said that in the region a thermocline was established and in the second a halocline.



12. Choose which region, 1 or 2, is more likely to have higher primary productivity) Justify the choice.

13. The phenomenon of "El Niño" occurs in periods of time with variable oscillations, which can be between 3 and 5 years, in the Peruvian coasts, and which is one named for the fishermen of the port of Paita, in northern Peru. , because it happened in Christmas times. At that time the trade winds that almost permanently blow from the southeast, from the coast to the ocean cease. When the El Niño phenomenon occurs, the water temperature rises in the coastal water of the region. These changes are attributed to a currentof hot air from the Gulf of Guayaquil (Ecuador).

a) Peru is a country with a large continental shelf rich in fisheries. Will fishing in the area increase or decrease at that time? Justify the answer.

b) Taking into account the geographical position of Peru in terms of latitude, will it be a time of the year of the warmest or coldest? Justify the answer.

c) Describe the situation using two of these three terms: productivity, halocline and thermocline.

2

14. Develop the practice and answer questions:

a) What is the difference in the flow of paperboard cutouts based on the presence or absence of the oil layer?

b) Explain the analogy of oil with ocean water that is experiencing overheating that seeks to establish this practice.

c) What implications can this fact have on the marine ecosystem taking into account the flow of nutrients?

DESCRIPTION OF THE PRACTICE

MATERIAL

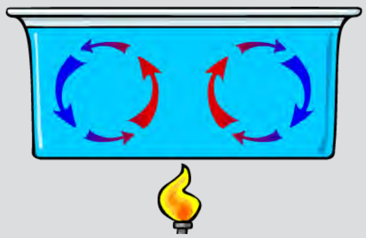
- Oil
- Water
- Heat source
- Cardboard cutouts

PROTOL

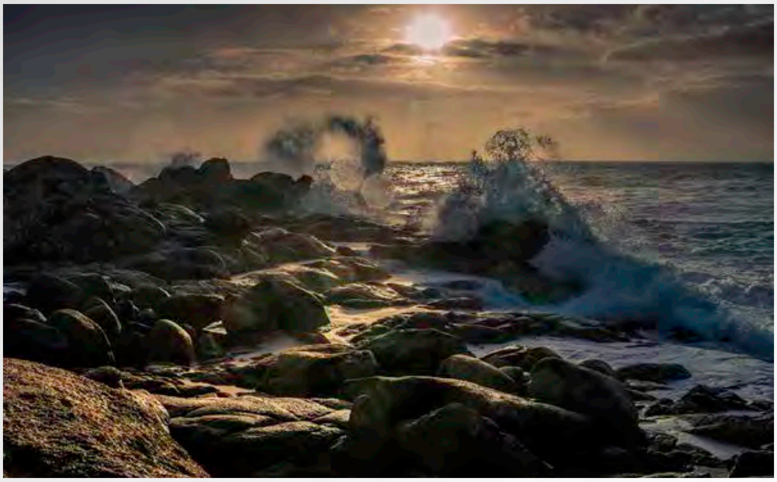
a. We add the cardboard cutouts to the water.

b. We move until we get them deposited in the background

d. Then we will do the same experience but adding a lay of oil on the water. We add the cardboard cutouts an reheat.



3.2 Factors that determine the access of sunlight to phytoplankton



Lira, Carnota (Galicia-Spain). Author Pedro G. Losada

The factors that determine the position of the sun such as latitude or seasonality determine a greater or lesser access of sunlight to phytoplankton. The rays of the sun that reach the surface of the marine ecosystems have a greater or lesser capacity to penetrate according to the sun's inclination.

So when there is more penetration is when the sun is closer to its zenith, and the lower penetration capacity occurs when the Sun is closer to the horizon. Global change does not affect the sun's position, so from this point of view, the global change does not affect the access of light to phytoplankton.

Although the global change has no effect on the position of the Sun, we know that it is influencing the percentage of albedo in the Arctic, due to its effects on the melting of the polar ice cap. This is so because the ice reflects, acting as a huge mirror, most of the incident radiation, while the sea water absorbs most of it.

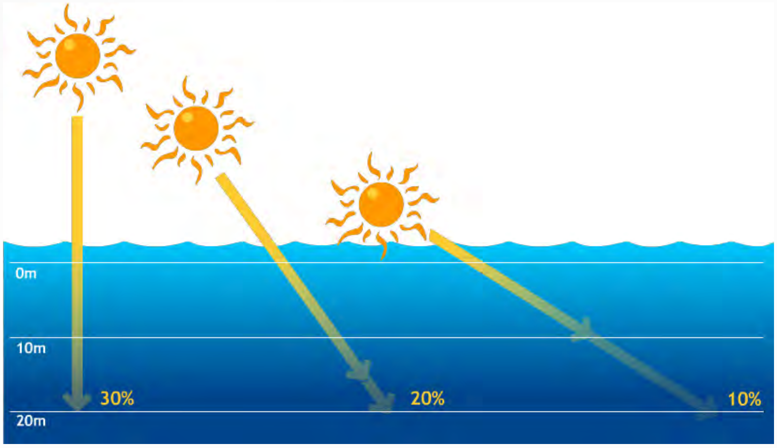


Illustration 13. The more overhead the sunlight is, the greater the penetration capacity it will have

The percentage of energy contained in the radiation absorbed is transformed into the energy emitted as infrared or heat radiation, which contributes to the increase of the temperature in the region. The albedo, or percentage of reflected light, returns all the energy that this percentage of reflected radiation contained, and therefore does not contribute to the warming of the region in which it affected. Only the percentage of sunlight absorbed, whose energy is transformed into heat emitted as infrared radiation, contributes to regional warming.

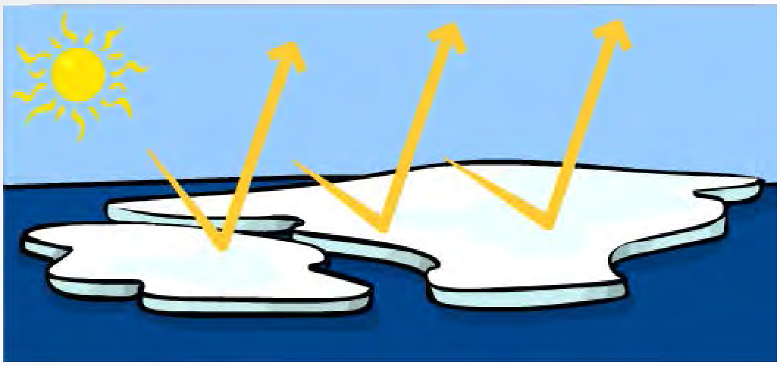


Illustration 14. The ice reflects the totality of the luminous radiation without it being able to contribute to the heating of the frozen region.

As the Arctic melt increases, the percentage of light absorbed increases, decreasing the albedo in that region. That percentage of light, which was previously reflected without contributing to the warming of the region, when it penetrates now into the Arctic water, is absorbed, transforming itself into heat emitted as infrared radiation. The increase in the heat radiation causes an increase in the temperature in that melting zone. This polar regional warming, in turn, accelerates the melting of the ice edges, thus giving rise to a positive feedback, which leads to an overheating of the Arctic region.

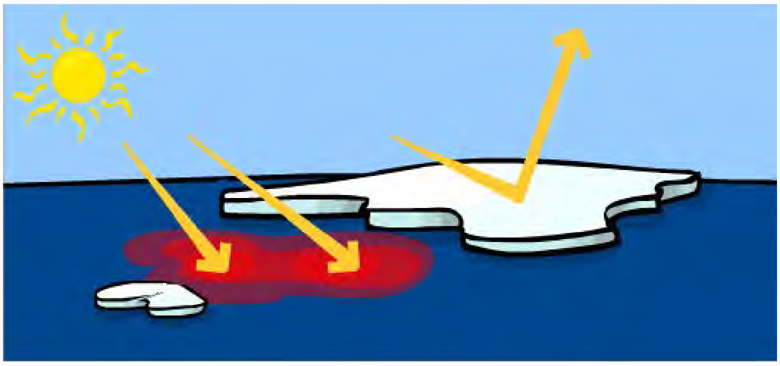


Illustration 15. As the Arctic thaw occurs, the percentage of reflected radiation decreases

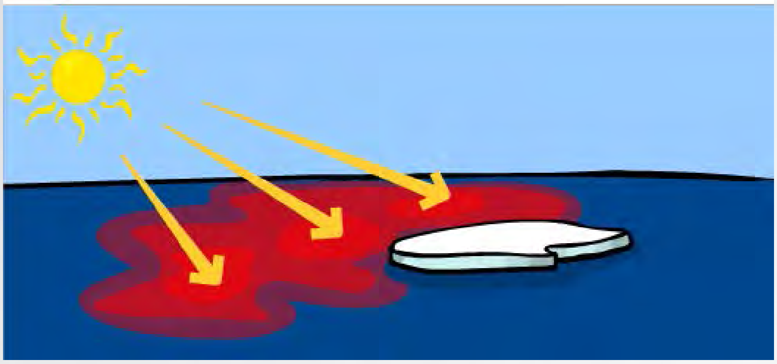


Illustration 16. The radiation that reflected the ice, with the melting happens to be absorbed by the water of the sea, heating the region now

This causes stratification and decreases the speed of marine currents, which carry the heat of the intertropical region, since the movement of these currents depends on the temperature difference. Therefore, as the temperature difference between the Equator and the poles decreases, so do the marine and atmospheric currents responsible for distributing the heat throughout the planet.

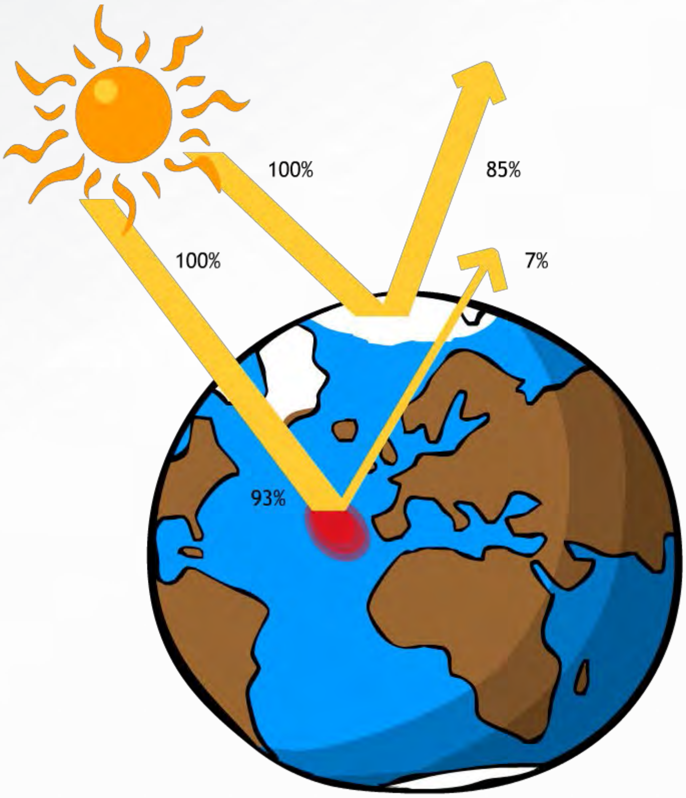


Illustration 17. In the Equator there is more radiation per unit of surface than in the poles, and in addition, since there is no ice, the albedo is much smaller than in the polar region, which determines that the ocean warms more at the level of in the Equator than in the poles, having to carry out the distribution of energy the oceanic currents and the atmospheric circulation

15. What will happen to productivity in these melting zones? Justify your answer.

16. Develop the practice and answer questions:

a) Deduce what color presents a greater albedo

b) It is interesting to reflect on the different adaptations of humanity to the amount of radiation received according to latitude and its demonstrated effectiveness in everyday life. Propose a possible example of some human characteristic that can be related to different levels of radiation according to the latitude or inclination of the solar rays.

c) What are the implications of a reduction in the albedo?

DESCRIPTION OF THE PRACTICE

MATERIAL

- 2 beakers.
- Black paper
- Thermometer
- Focus of light .

PROTOCOL

We will use two beakers, one of them lined with black paper, with the same amount of water at the same temperature. After a few minutes exposed to light we can verify the difference of absorption and, therefore, of temperature.

Another factor on which the penetration of light depends is turbidity, which is a physical factor that depends on the presence of particles that act as agents capable of absorbing or reflecting the light that penetrates. Therefore, the greater the turbidity, the lower the capacity of the light to penetrate.

When the particles abound, a dispersion of the light takes place, which causes that the waters may have different colours. For example, if calcium carbonate is abundant, it becomes milky white, or turquoise blue, and the presence of algae gives it a green colour.

turbid waters (MECD source)

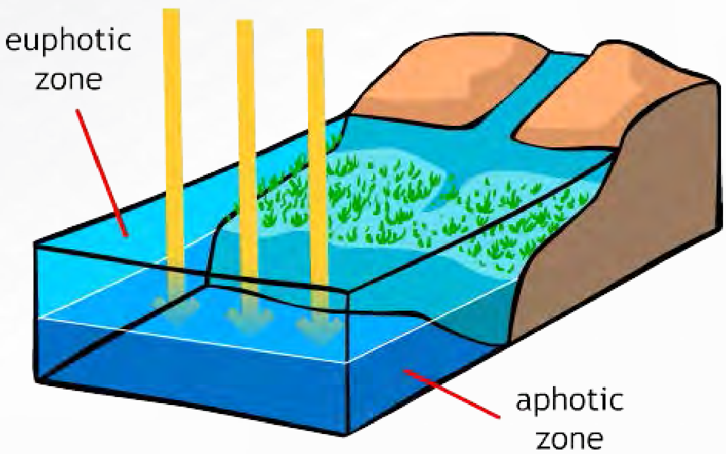


Illustration 18.Representation of the euphotic zone (illuminated surface area) and the aphotic zone (deeper areas without access to sunlight)

The area where the light arrives is called the euphotic zone and this will be deeper when the water is less cloudy. The area where light does not reach is called the aphotic zone. Therefore, the euphotic zone is one in which there are opportunities to perform photosynthesis, while the aphotic zone cannot have any type of photosynthetic activity.

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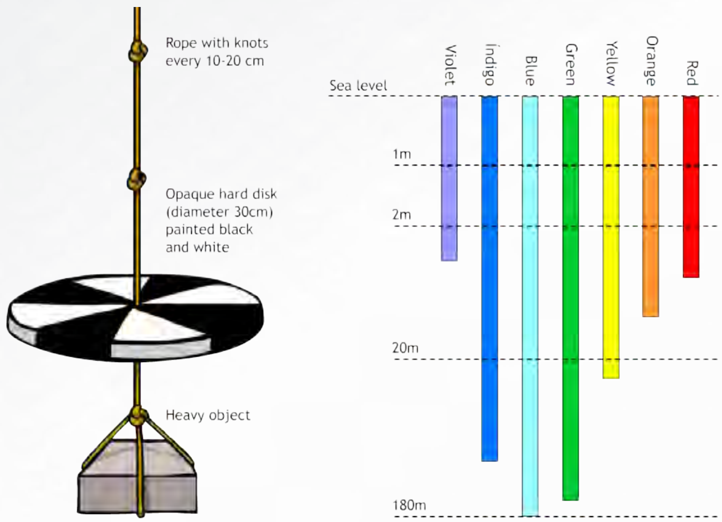
Not all wavelengths have the same ability to penetrate the water column. For example, green and blue irradiance penetrate deeper than the red one. This justifies that the algae of the depths look red, color of the reflected radiation, complementary to the one absorbed. That same reasoning allows us to explain that the most superficial algae are green, of complementary color to the red radiation, of lower capacity of absorption, and absorbed by the superficial algae. To measure this, the Secchi Disk is used.

Illustration 19.Radiation penetration capacity according to the radiation type and Secchi disc, necessary instrument to discover the penetration capacity.



17. Build a Sechi disc with a 30 cm wooden disc, painted according to the dibuno, with a rope that carries a weight at the end, and knots every 10 cm, as shown in the drawing. Once you have it, access a port area or other coastal area with calm waters, one with clear water and one with dark water. Let the disc descend little by little, counting the number of knots that are submerged. Stop the descent just when you stop watching the disc. At that moment the disc has reached the end of the euphotic zone. Calculate the depth, counting the submerged knots. What is the difference in height between the area of clear water and that of turbid water? .

18. The violet light penetrates to little more than 2 meters of depth, and is effectively absorbed by the superficial phytoplankton. The blue light penetrates the most, and reaches up to 180 meters deep, the limit of the euphotic zones in areas of lower turbidity. a) Bearing in mind that our eye captures the visible radiation reflected by illuminated bodies (that which they did not absorb, and therefore complementary to that absorbed), and that the criterion of chromatic complementarity is red as complementary to cyan blue and green violet, what colors will the superficial and deep algae be, respectively? b) Why are not algae found at depths greater than 180 meters? Justify your answers.

Although the euphotic zone has many opportunities for primary production, and in fact where most of the biomass is concentrated, it is also necessary for the euphotic zone to access the nutrient mineral salts.

In general, the least productive areas are found in the open ocean and the most productive, on the shelf, of the supply of nutrient from coastal upwelling and river discharge

Even being the area closest to the continent where the mouths of the rivers have the most nutrients, it is not the most productive area. The most productive areas are located in those regions of the shelf, but at a certain distance from the coast. It is not located in the waters closest to the continent, which are the richest in nutrients, because shelf, especially through the mouths of rivers, and that causes it to be highly turbid. That is why in those waters closest to the continent they have a low penetration of light, and therefore productivity.

That is why it is in the internal shelf where the combination is the best conditions for productivity, because it coincides with a high concentration of nutrients, from the coastal upwelling and continental supply, with a decrease in the turbidity of the water, by previously decanting many of the continental particles.

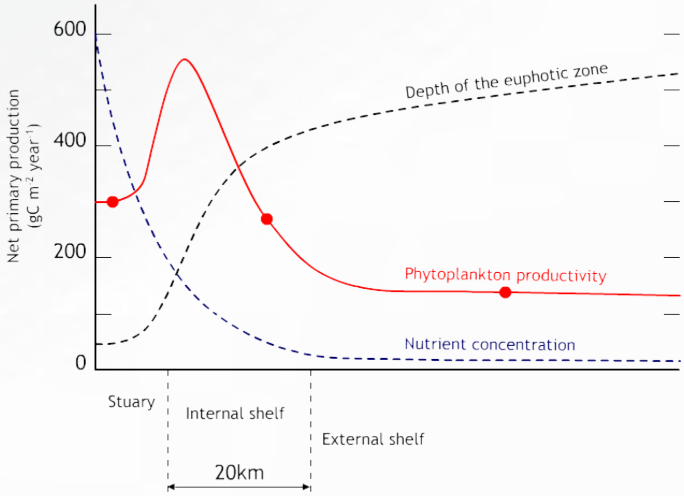
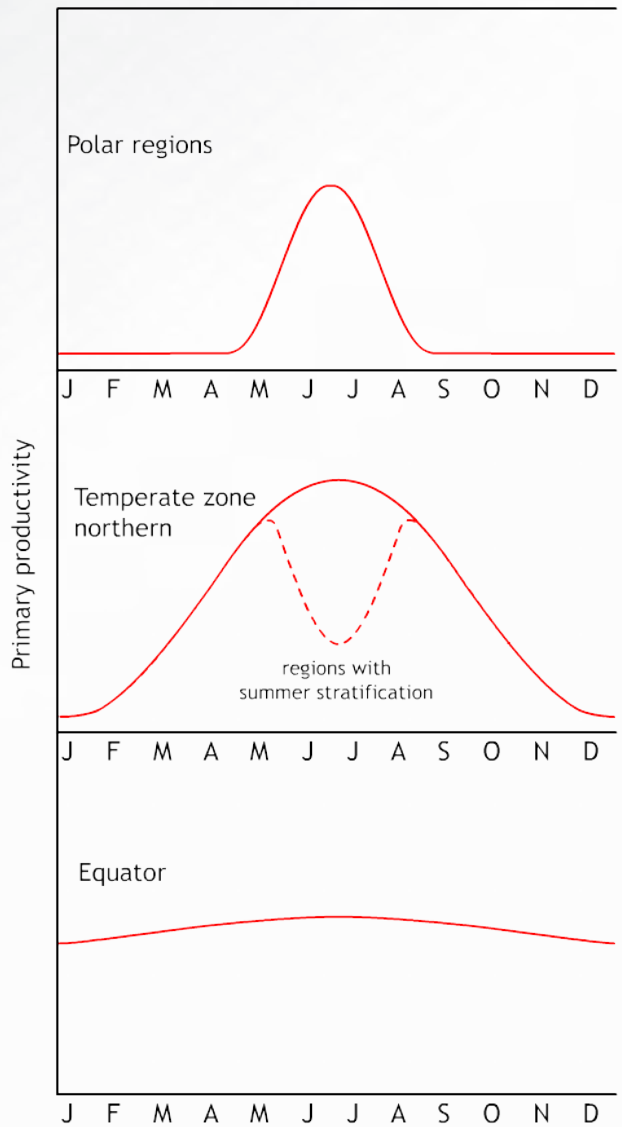


Illustration 20. Graph that relates the productivity and concentration of nutrients in relation to the distance from the coastline (Adapted from Begon, 1995).

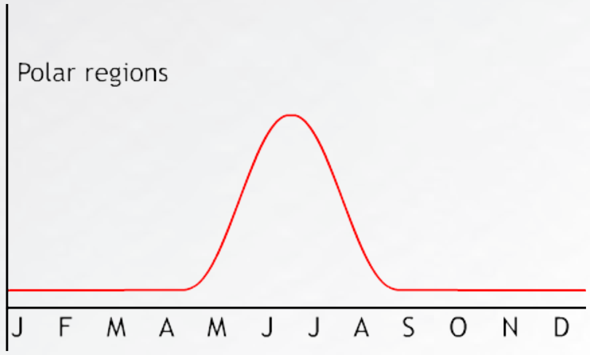
In general, the more nutrient-rich a body of water, the shallower the euphotic zone will be. The masses of water with more nutrients, in identical light conditions, are more productive, so they tend to have higher biomass of phytoplankton that absorbs light to perform photosynthesis, reducing the availability of light at greater depths.

Another factor to take into account in productivity is the number of hours of sunshine, which depends on the latitude and the time of year. From this point of view, we must bear in mind that in the arctic and temperate latitudes, for several months the climatic conditions are harsh. In those times turbulences of the waters are usually generated that force the phytoplankton cells towards deep zones, far from the euphotic zone, which also adds to a significant decrease of radiation in those times and latitudes. In those high latitudes the great limiting factor is sunlight.

Illustration 21. Graph that relates productivity to three latitudes, Ecuador, North Pole and Latitude 50 and the months of the year (Adapted from Begon, 1995).

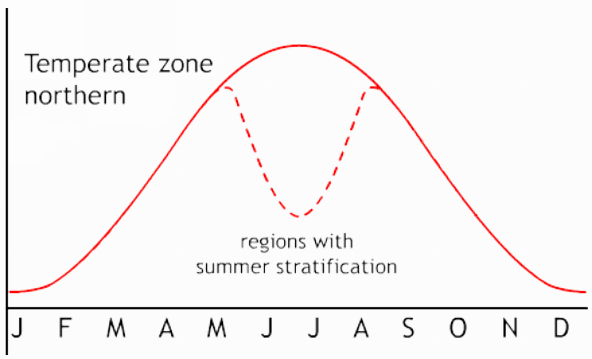


That is why, in these high latitudes, the favorable period for productivity is in the season in which the penetration capacity of solar radiation, the duration of the day and temperatures increase. In addition to those times, the turbulence generated by the wind decreases, facilitating the exposure time of phytoplankton to the sun. For this reason, taking into account that water warming increases the stratification, it is expected that the phytoplankton exposed to sunlight for longer contact with the sun, due to the decrease in turbulence, will increase the primary productivity of phytoplankton in these polar regions in the that the irradiance is the main limiting factor.



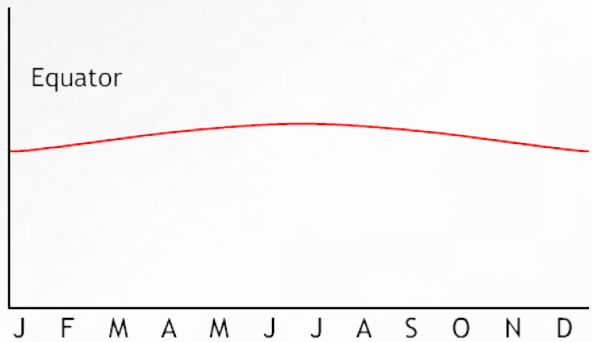
The decrease of turbulence in polar regions, together with the reduction in ice cover, explains the productivity increases that are being measured at the poles, due to the stratification, when for this same reason productivity is decreasing in waters of low latitudes.

The broken line represents how at temperate latitudes, the summertime stratification implicates low production (except if it is an upwelling area or a coastal water with continental nutrient supports). In autumn, the first storms and the heat loss of the surface water implicates episodes of vertical mixing which allow the arrival of nutrients to the photic zone and thus, an increase of the PP. This bloom of the autumn PP is tipically less intense than the spring one.



In the lower latitudes (intertropical zone), production remains practically constant throughout the year, with a maximum that is not very evident in the summer season, and a minimum that is hardly noticeable in the winter season.

However, the maximum values of the tropical oceans tend to be lower than the maximum values of many regions of temperate zones. This is based on the fact that in the tropical oceanic areas the superficial hot water is sufficiently less dense to make it difficult to mix with the deep water, rich in mineral salts, so that the access of mineral salts to the phytoplankton is very limited.



In addition, the abundance of light in these latitudes causes the phytoplankton to deplete the few nutrients they have available very quickly, without renewing themselves, constituting almost biological deserts. It is therefore water with minimal turbidity, because particle abundance is very low, and the concentration of living organisms is minimal. As in addition, in these regions, light has a zenithal shape, the sun's rays reach the ocean's surface at angles close to the vertical, which is why this is not a limiting factor, being in these latitudes the limiting factor access of mineral salts to phytoplankton.

The amount of internal energy stored in the bonds of organic matter synthesized during photosynthesis or gross primary productivity (PPB), is the higher the higher the concentration of phytoplankton. Therefore, as it descends in the euphotic zone, this value decreases, because the penetrating light becomes more limiting.

The depth at which the PPB is exactly compensated, in energy terms, with the respiration (R) of the phytoplankton, is known as the compensation limit. Below that level the PPN disappears. Therefore, the compensation limit determines the lower limit of the euphotic zone. The greater the concentration of surface nutrients and light radiation, the greater the increase in phytoplankton biomass, and the energy expenditure in respiration, which determines a low depth of the euphotic zone.

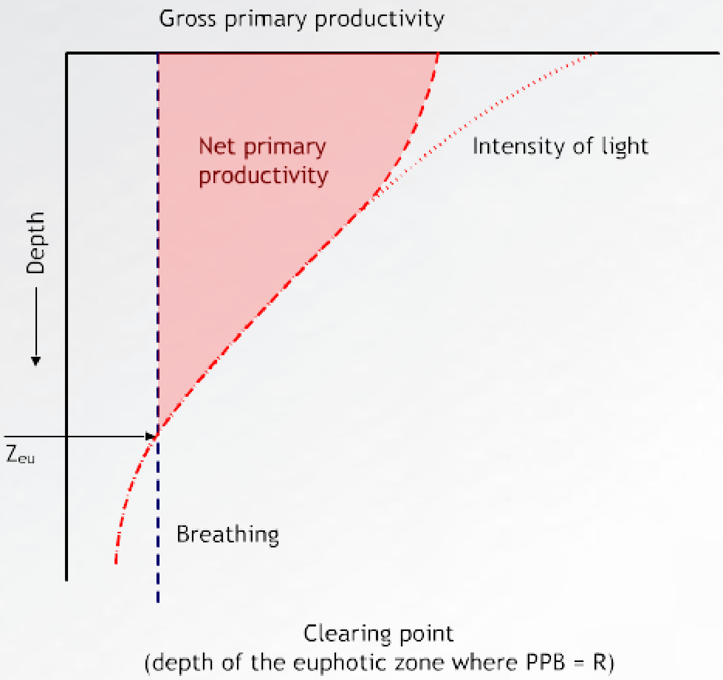


Illustration 22. Limit of the euphotic zone marked by the equivalence of primary productivity with breathing. Adapted from Begon

19. In a given ocean region, the annual average of gross primary productivity was calculated and the result of 0.55 g of dry matter / m2 / day was obtained. Knowing that this organic matter is used in 53% of respiration, calculate the net first productivity of that oceanic region

20. n a given ocean region, the annual average of gross primary productivity was calculated and the result of 0.55 g of dry matter / m2 / day was obtained. Knowing that this organic matter is used in 53% of respiration, calculates the net first productivity of that oceanic region.

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

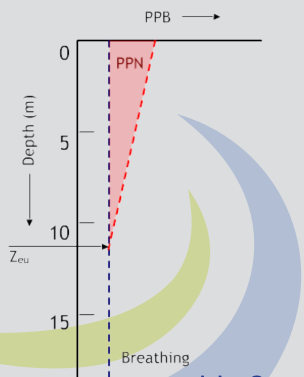
21. Look at the photographs of an open ocean region and a fjord (glacial valley invaded by the sea) and answer:

a) Cover the open ocean chart with the graph referring the relationship of its productivity with depth, covering the table.

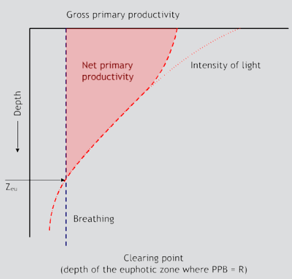
FOTO	GRAPHIC

b) Compare the two regions in light penetration capacity and abundance of phytoplankton.


foto 2



graphic 2



graphic 1


foto 1

The distribution of the productivity of the different planetary oceanic regions follows a studied pattern and depends mainly on the latitude, the climate in the region and the proximity to the coast. As the climate is changing, so do these patterns, causing variations in productivity, with obvious effects on their marine ecosystems. .

Rebordiño. Muros (Galicia-Spain). Author Pedro G. Losada

4 How does the ocean take up the atmospheric CO_2? The biological pump.

Marine phytoplankton make about half of the photosynthesis, or primary production, that takes place on Earth each year. For this you need the energy coming from the sunlight. That solar energy needs it to transform CO_2 into organic molecules.

Therefore, in addition to sunlight and mineral salts, phytoplankton need CO_2 in order to obtain the carbon skeletons on which organic matter is structured, and in whose carbon bonds the internal chemical energy obtained by transformation of luminous energy through the process of photosynthesis is stored.

CO_2 is a gas that forms part of the atmosphere with a volume concentration of 0.04%, and from the atmosphere it can diffuse into oceanic water, especially in windy areas. But in addition to this CO_2 that diffuses to the ocean from the atmosphere, in oceanic waters this gas is released from the cellular respiration processes of marine organisms and from the decomposition of organic matter that occurs in the oceanic waters themselves. That is why its distribution and access routes of CO_2 to phytoplankton are diverse.

Phytoplankton contribute to oceanic CO_2 uptake and it is produced a distribution by the different transfer routes among the different levels between which this gas moves. For this reason it is necessary to study the relationship of global change with the distribution of carbon dioxide.

22. Answer the following questions:

a) From what inorganic molecule comes the C that forms the organic molecules?

b) Where is the energy of the organic molecules contained? From what other source of energy was it obtained ?

c) Which can be the sources of C that are chained by phytoplankton?

The relationships with productivity are obvious, because phytoplankton requires constant direct contact with carbon dioxide to make the carbon chains during the process of photosynthesis. Those carbon chains obtained in photosynthesis are the contribution of vital energy for all cells. That is why it is said that organic matter obtained in the process of photosynthesis, constitutes the food chain in marine ecosystems, on which depends the existence of important biological resources such as fisheries.

The carbon dioxide that accesses the euphotic zone will be captured by the producers, especially the phytoplankton, to be used in the process of photosynthesis. In turn these organisms and all other living beings will release it through cellular respiration processes. From that capture the carbon of the CO_2 to form organic matter can follow the path of the ecosystem's trophic network. Through this trophic path, these chains end up being made available to the decomposers of the depths, which release the chained carbon atoms, giving rise again to this gas.

The food chain itself becomes part of the transport pathways of carbon in the ocean, which in part of the carbon pathways in the oceans, this element is chained in the organic molecules that form the living material. These chains ultimately originate through the process of photosynthesis, which makes it possible to obtain biomass from the producers, mainly phytoplankton, to which this gas must reach in sufficient quantities to meet the photosynthetic needs. If for some reason these routes were altered, the primary productivity (PPN) that the ecosystem needs for the energy flow it needs could be affected.

Part of the increase in phytoplankton biomass (PPN), due to the increase in cellular organic material produced by phytoplankton during photosynthesis, is used as food by consumer organisms, such as zooplankton, and another part is decomposed, mainly by the action of heterotrophic decomposing bacteria, to give rise again to inorganic nutrients. Decomposition and respiration remove the carbon from the trophic pathway and leave it as CO_2 gas, which, following the oceanic access routes to phytoplankton, can enter the trophic network again.

23. Complete the table related to the three access routes of CO2 to phytoplankton

VÍA	PROCESS
1.- Superior aerial	
2.- Trophic	
3.- Respiratory	
4.- Decomposition	

24. If the ocean increasingly diffuses carbon dioxide due to the emissions produced by the use of fossil fuels, what will happen to the level of accumulation of this gas in deep waters?

25. How can the rise in temperature of sea water affect its capacity for carbon dioxide accumulation? Justify your answer.

But both dead phytoplankton cells and faecal pellets produced by zooplankton and other organisms tend to sediment to deep water, which causes a vertical flow of organic carbon down from the ocean surface to the ocean floor. As this organic material is sedimented, the action of bacteria and other heterotrophic organisms transforms it again into CO_2, Part of that carbon dioxide could rise in waters affected by upwelling, sharing in this case the routes of ascent of the mineral salts that rise from the bottom. But not all the ocean floor has access to these roads, so that a part of the CO_2 that follows the trophic path accumulates in deep waters over time scales of 100-1000 years. The time-scale is important because after hundreds of years, all the deep ocean is renovated in a way that CO2 from the botton waters becomes again in contact with the atmosphere.

This process, mediated by the plankton, of CO_2 capture in the form of organic matter on the surface and its subsequent transport to deep waters is called the biological pump. The existence of the biological pump is responsible for most of the vertical gradient of inorganic carbon dissolved in the ocean, which contributes to the regulation of CO_2 levels in the atmosphere and therefore in the climate.

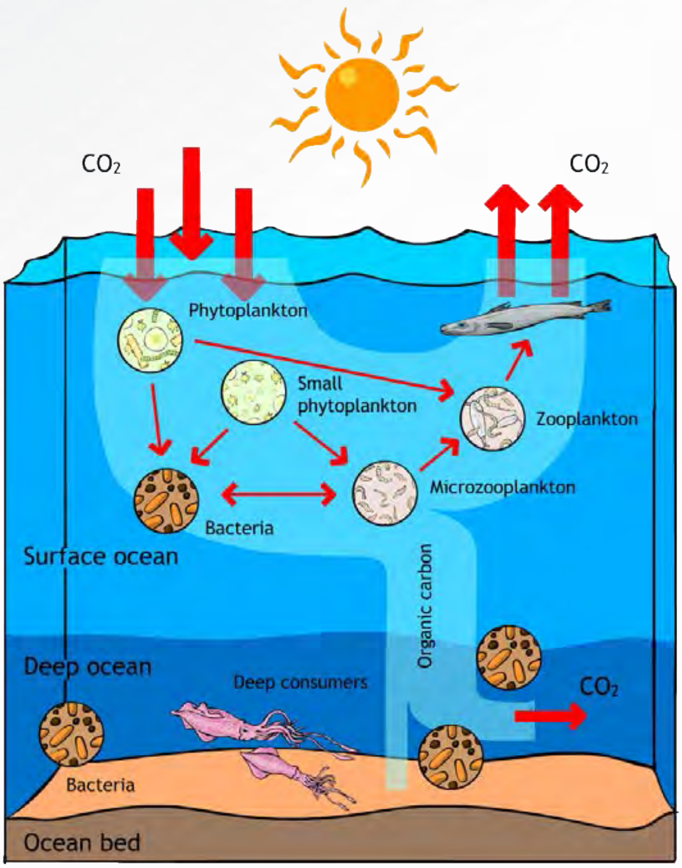


Illustration 23. Representation of the Biological Pump model (Adapted from Chisholm SW (2000) Nature 407, 685-687).

The biological pump is affected by the emission of greenhouse gases (GHG), the origin of global warming. The emission of these gases increases progressively in the last two decades. It seems that there has been a slowdown in recent years of economic crisis in the industrialized countries, but has never come down.

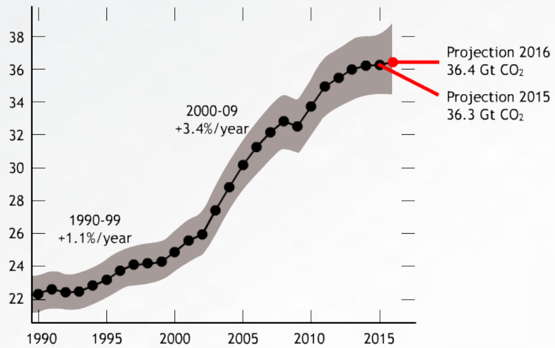


Illustration 24. Graph that shows the increase of GHG emissions since 1990

The rising CO_2 concentrations cause an increase in the so-called 'solubility pump', which represents, which represents the fact that the CO_2 is dissolved in the surface cold waters (as in the North Atlantic) which finally get sink, transporting the CO_2 to the bottom of the ocean and this way, eliminating more than a half of the emitted greenhouse gases (GHG). The solubility pump and the ocean's uptake of CO_2 are enhanced by the action of the phytoplankton and the biological pump, which contribute to reduce the concentration of CO_2 in surface waters. But even so, in the region approximately of 47% of the GHG gases accumulate in the atmosphere, contributing to global warming. In recent years, 34 Gt of CO_2 are being emitted, of which 16 GT accumulate in the atmosphere causing the increase of GHGs, with the consequent increase in global temperature. The concentration of CO_2 in the atmosphere undergoes a seasonal variation in the manner of sawtooth, because in the autumn and winter the decomposition of the organic matter of the loss

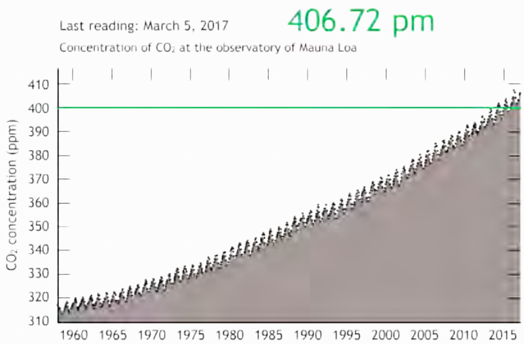


Illustration 25.Graph of the increase of the CO_2 emissions from the middle of the last century in which the seasonal variations can be appreciated with maximums in autumn and minimums in spring..

of the leaves of the deciduous trees predominates (the majority of the continental mass is in the Northern Hemisphere) which increases CO_2 levels and in spring and summer carbon fixation predominates in the growth of the leaves, leading to less CO_2 in the atmosphere.

This graph with seasonal maximum and minimum, in the form of saw teeth, should follow a horizontal trend. Since the last major glaciation (20,000 years ago) CO_2 levels in the atmosphere had remained relatively constant at a concentration of approximately 280 ppm. However, with the advent of the Industrial Revolution, CO_2 levels started to increase. This is so, because we are opening a new way out of carbon into the atmosphere, injecting carbon into the atmosphere, which was separated from it by the fossilization process, through emissions from the use of fossil fuels. That graph could have a much steeper slope if the oceanic biological pump were blocked.

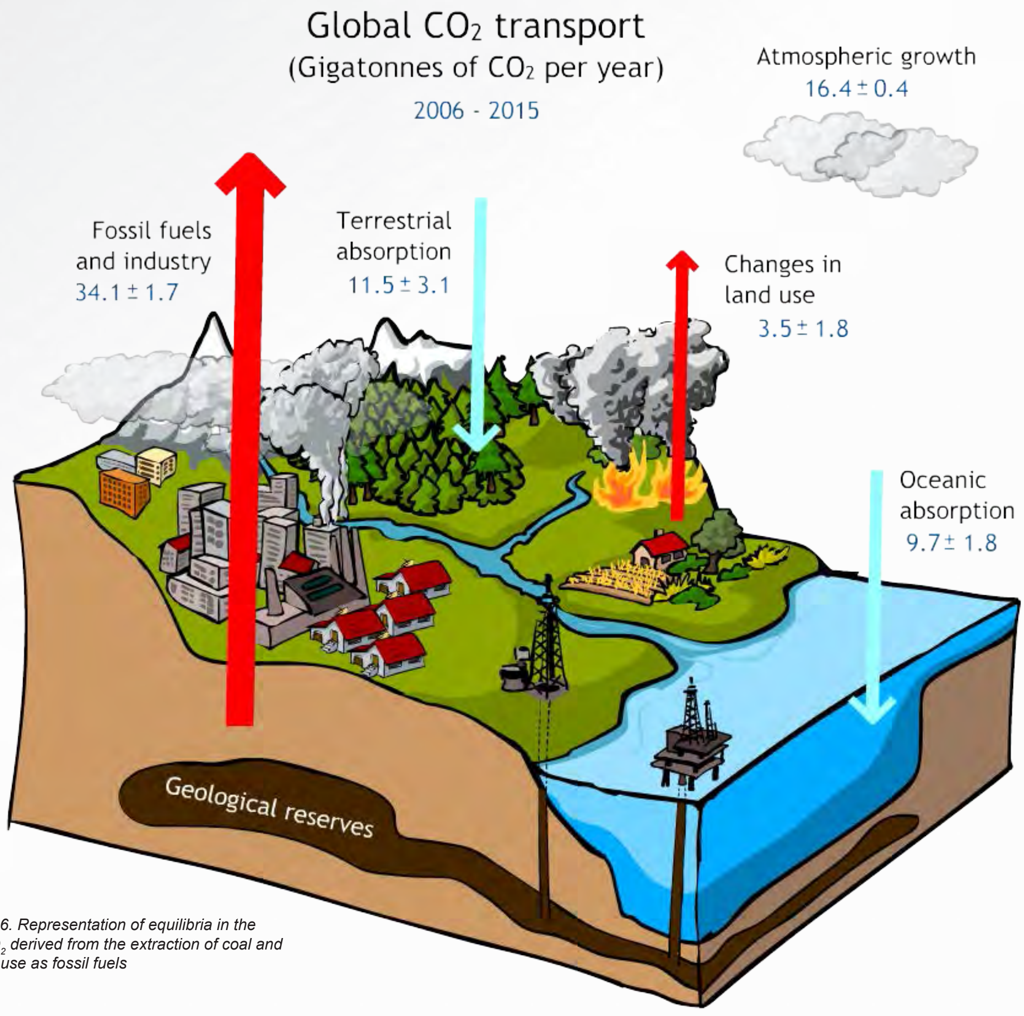
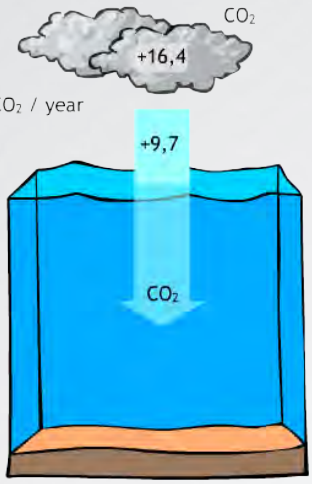
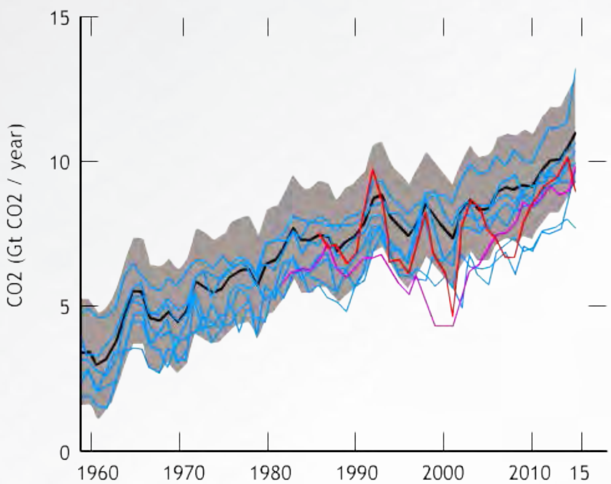


Illustration 26. Representation of equilibria in the levels of CO_2 derived from the extraction of coal and oil and their use as fossil fuels

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



This increase that is influencing the activity of the solubility pump, because there is more carbon dioxide in the atmosphere, so, its uptake by the ocean will increase. It has been proven that the C sink of the ocean progressively increases from 9.7 Gt CO_2 in the 2006 average to 11 GtC / year in 2015. This is why the pump is in good working order and the changes that the global change may make to it occasionally. , that if interrupted, there would be a positive feedback of this global environmental problem.



Representation of the incorporation ocean uptake of CO2 during the period 1960-2015

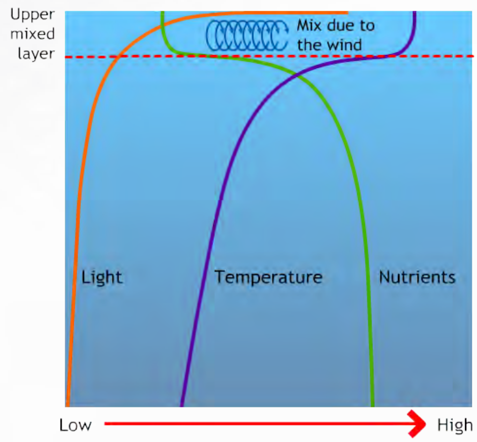


Illustration 28. Representation of the stratification process due to the formation of a thermocline that hinders the access of nutrients to the surface and the necessary mixing processes that the biological pump needs to introduce CO2 into the bottom (Adapted Chisholm SW (2000) Nature 407, 685-687).

The anthropogenic carbon dioxide harboured in the ocean already exceeds by 50 times the carbon dioxide present in the atmosphere. But its concentration is not uniform, because it is maximum in the cold waters of the North Atlantic due to the fact that the carbon dioxide solubility increases as the temperature decreases, where the mixture of deep and superficial water facilitates the operation of the biological pump and minimum in those of maximum stratification, which highlights the relationship between the biological pump and the global anthropogenic change in the ocean. Therefore, if the ocean tends to stratify with global change, this will weaken the functioning of the biological pump and there will be an increase in global warming.

As it has been explained, especially in warm areas, surface water reaches a higher temperature, and the subsequent expansion process decreases its density, as we have already seen. This temperature difference is known as thermocline, which determines that the difference in density is a barrier that hinders the arrival of nutrients to the illuminated layer and decreases the operation of the biological pump, which decreases productivity.

Therefore, as also explained in the previous section, the ecosystems of tropical and subtropical regions, where the thermocline is more marked and persistent, are characterized by a low amount of plankton, and therefore primary production. On the other hand, in regions where greater turbulence (generated by wind or tides) weakens the thermocline and allows vertical mixing and the arrival of deep, cold, nutrient-rich waters and a good functioning of the biological pump , there is a high abundance of phytoplankton and an intense biological productivity.

Therefore, the stratification of the oceanic waters implies a weakening of the biological pump and the access of nutrients to the phytoplankton. That is why this process, increased by global change, is decreasing productivity. But at the same time, when the operation of the biological pump is interrupted, the entry of carbon dioxide into the ocean decreases, increasing the levels of anthropogenic CO_2 in the atmosphere, which means an increase in global warming, which leads to a greater oceanic stratification. that continues to enhance the problem and decrease productivity

26. How is the fact that the waters of the intertropical regions, having high levels of insolation, are not very productive?

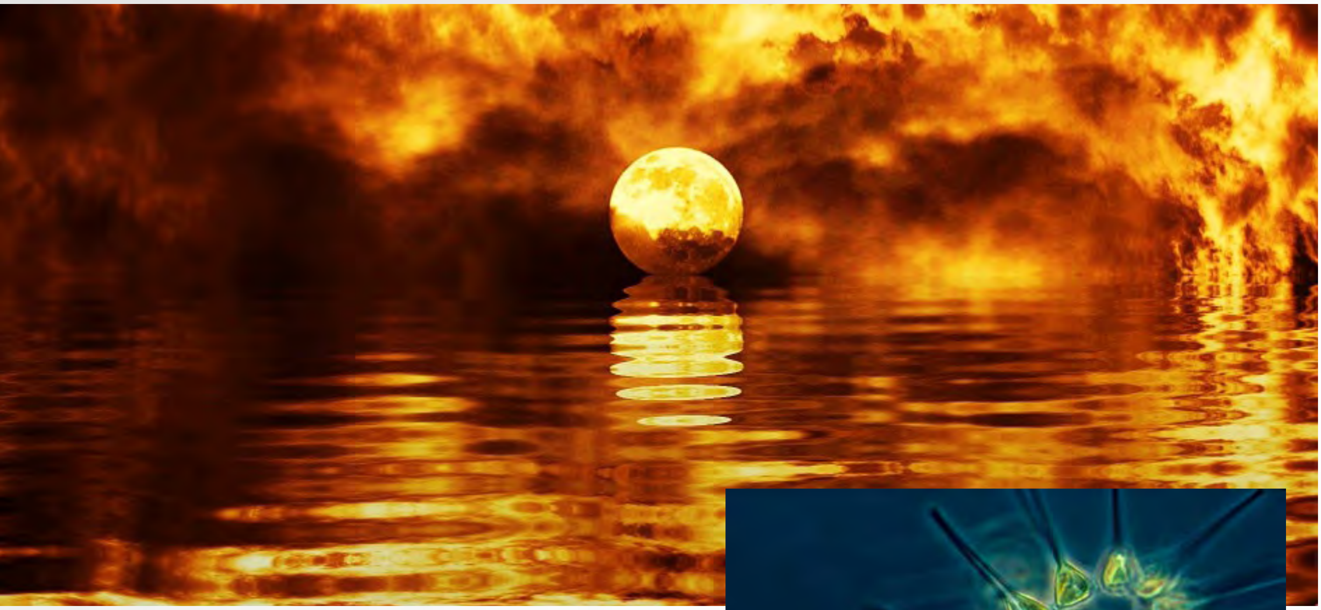
a) Assuming that the oceanic waters included in the tropics are not very productive, how do we explain Peru's fishing wealth?

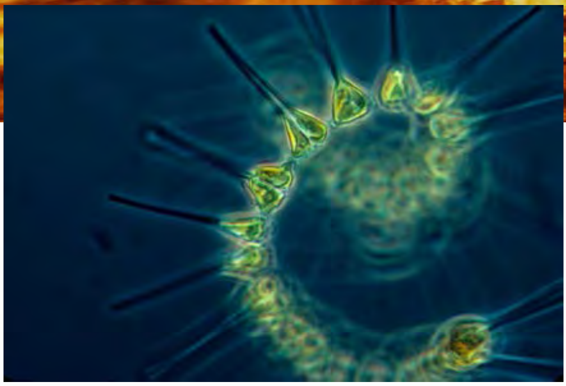
b) Compare the concentration of carbon dioxide in the Central Pacific and the North Sea. How are they different? What are the causes of these differences?

c) Does the thermocline facilitate or hinder the operation of the biological pump? And the access of nutrients to plankton? Justify your answers

d) What are the expectations of global warming about the operation of the biological pump? And vice versa? Justify your answers

5 What is the current situation of the warming of the ocean?





According to the 2013 IPCC report, the increase in temperature has resulted in an increase of 0.85 ºC between 1880 and 2012. In addition, almost the entire planet has experienced an increase in temperature. The average temperature of the surface of the ocean has behaved in these terms, and has risen to the same extent as the increase in global temperature, 0.7 ° C since the beginning of the twentieth century, although in certain regions there have been increases of up to 2 C.

This increase in temperature has resulted in an increase of 0.85 ° C between 1880 and 2012. In addition, almost all the ocean regions of the planet have experienced an increase in temperature.

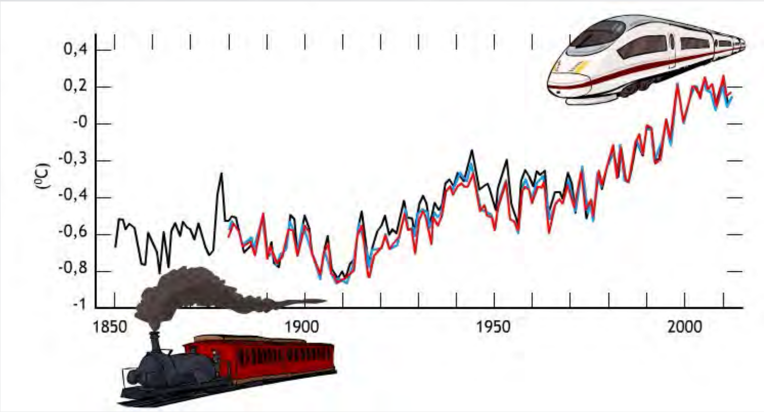


Illustration 29. Graph of combined warming land and sea. It is estimated at 0.85 degrees centigrade between 1880 and 20012, edited with the photo of the old train pointing to 1880

The heating of the atmosphere, in turn, has led to an increase in the heat content of the ocean between 1955 and 2010. If we take the values with good representativeness, we have to start the series of data in 1971. This series exceeds 45 years, evidences an increase of global temperature in surface of 0,11 ºC per decade, and that in the water column up to 700 m, supposes an increase of 0.015º C

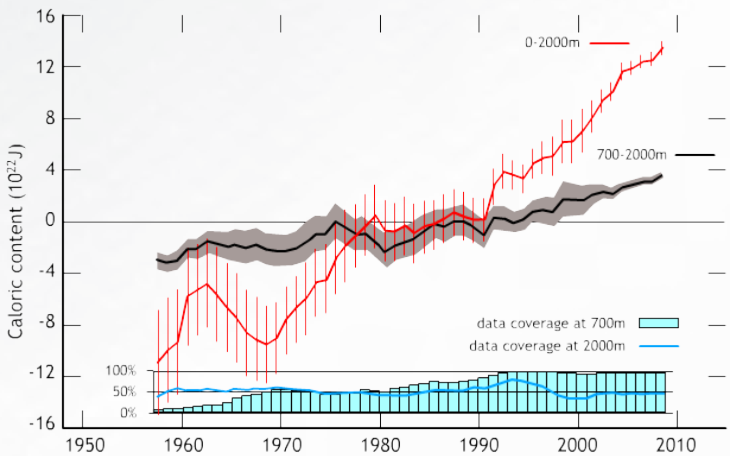


Illustration 30. The warming of the ocean has been since 1971 of 0.015 degrees centigrade per decade in the upper 700 meters

The oceanic warming detected in the 1971 -2010 series, although widespread, is not uniform in magnitude. This reaches its maximum magnitude in the Atlantic, and in all of them, it is higher in the Northern Hemisphere than in the South. It also presents significant latitudinal differences, higher in middle and lower latitudes than in high polar and subpolar latitudes. Pattern that is reproduced in the different oceans.

This warming is not only superficial. It also extends, although to a lesser extent to the lower layer to 700 m. The heating of the 700-2000 m layer represents one third of the total ocean warming. Therefore, the increase in heat content accelerates in the upper layers, which is what justifies the trend in the increase in stratification.

Therefore, the ocean is warming globally, affecting stratification and patterns of plankton distribution. These changes show the effects of global anthropogenic change on the productivity of the oceans, affecting key factors of their productivity, on which the flow of energy through their trophic networks depends.

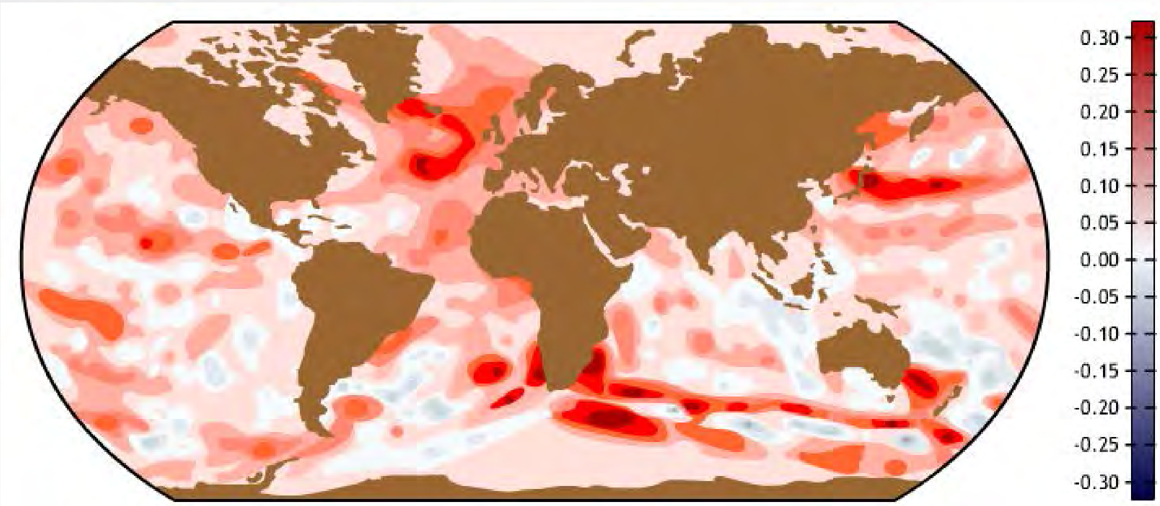


Illustration 31.World map with variation of ocean temperature (0-700m) between 1971 and 2010

27. Responde a las cuestiones relativas al calentamiento global del océano:

a) Which is the reason why the surface of the ocean gets warmer than the deeper areas?

b) Does it explain any consequences of the change in plankton distribution over ocean ecosystems?

c) What effects does the stratification have on the abundance and distribution of plankton?

5.1 Effects of global warming on the distribution and abundance of plankton.

The warming of the surface ocean affects the distribution and abundance of plankton directly, because temperature is a fundamental determinant of metabolic activity and the growth of organisms, and indirect, because the intensity of the thermocline hinders the supply of nutrients from the ocean floor to the surface.

The relevance of the plankton in the functioning of the oceanic ecosystems motivated diverse investigations to know the answers of the plankton to the climatic change. This type of research has the challenge of obtaining observations in extensive ocean regions, and over long enough periods of time.

One of the contemporary investigations that faced these two challenges was the Continuous Plankton Recorder (CPR) research program. It is a program that has generated and continues to generate a wealth of data on abundance and diversity of plankton in the North Atlantic. The CPR uses automatic samplers, installed on commercial vessels, which continuously collect plankton samples that are then examined in the laboratory.

Photograph of the stern part with trawl systems to collect data from the plankton (CSIC source)

One of the clearest effects of climate change on marine plankton detected by the CPR is a modification of phenology (chronology of life cycles). In most species, annual peaks of abundance tend to occur at an earlier date.

For example, in the phytoplankton species Ceratium fusus the annual maximum abundance was recorded, on average, 30 days earlier during 1990-2000 than during 1960-1970.

Ceratium fusus

However, in some species a delay in the seasonal maximum of abundance has been detected. These changes in phenology occur independently in different species, which can cause decoupling between trophic levels and therefore affect the transfer of energy along the food chain.

The second characteristic pattern of the response of species to climate change, also observed in terrestrial ecosystems, is the migration of distribution ranges to higher latitudes during periods of warming. The CPR data showed that the distribution of diatoms and dinoflagellates, two of the most important phytoplankton groups, spread farther north during the warming period observed in the Northeast Atlantic during the four-year period 2004-2008, compared with the study made in the four-year period between 1984 and 1998.

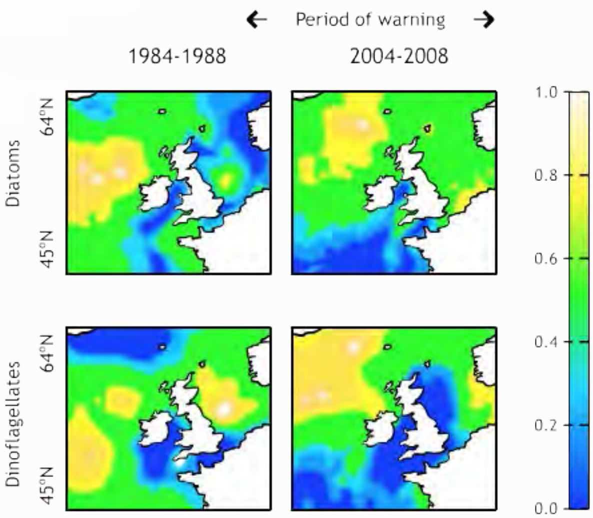


Illustration 32. Normalized abundance of diatoms and dinoflagellates in the northeastern Atlantic during different periods between 1959 and 2008. Figure by Chivers et al. (2017) Nature Comm. 8, article no 14434

A study published by Richardson in 2008 shows that, similarly, the typical species of zooplankton of warm waters have extended their distribution to latitudes farther north, while the species of subarctic communities have restricted their latitudinal range.

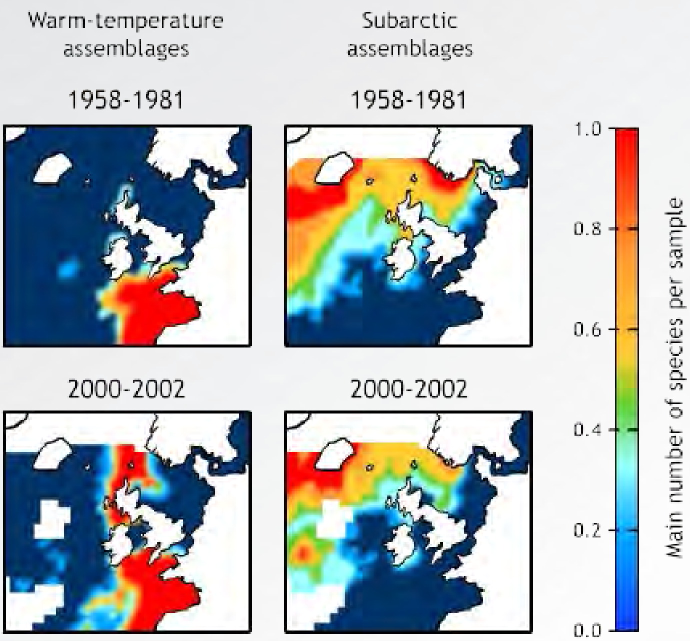


Illustration 33.Abundance of zooplankton species belonging to warm water communities and subarctic communities during different periods between 1958 and 20002. Figure by Richardson, A.J. 2008. ICES J. Marine Science, 65.279-295

These changes in the distribution surfaces and their geographical location, show a change in distribution with temperature, following the logic of warming, as there is a shift towards colder waters of the North. But it is also observed that in general, the observed rates of displacement in the distribution ranges of the planktonic species are smaller than the speed of change in temperature, suggesting that the plankton species possess a certain capacity to adapt to changing conditions. . On the other hand it was also observed in these studies that the speed of change in the distribution depends on the species, so different groups of plankton show different rates of change in their distribution limits.

26. Responde a las cuestiones relativas a la distribución del plancton:

a) Which explanation would you give to relate these changes of temperature with the changes of distribution?

b) How can these changes in the distribution of plankton affect the location of fishing areas with a broad history such as that of the Gran Sol bank?

5.2 Consequences of surface ocean warming on marine primary production

If, as we have seen, the increase in the surface temperature of the ocean is affecting the distribution and abundance of plankton, as marine primary productivity is carried out mainly by this group of microalgae its maximum exponent, we can also expect that the warming of the surface ocean is affecting to marine primary production.

In addition, temperature is an environmental variable of critical importance in biology, mainly because it affects the speed of the enzymatic reactions that control metabolism. Within a favorable temperature range, within limits that do not affect the inhibition of enzymatic activity, the metabolic activity of organisms tends to increase exponentially with temperature, if other factors are not limiting.

However, in the case of primary production carried out by phytoplankton in the ocean, it has been found that the stimulating effect of the increase in temperature disappears when there are conditions of strong growth limitation due to lack of light or nutrients, such as it has already been seen in the previous chapters.

The most important consequence of surface ocean warming on marine primary production is due to indirect mechanisms, through which temperature affects the supply of resources such as light or nutrients. Thanks to the surface color measurements of the ocean using sensors on board satellites, it is possible to determine the phytoplankton abundance (since a higher concentration of phytoplankton makes the colour of the water greener) and therefore estimate the global marine primary production along time scales ranging from days to decades.

This type of data, obtained by satellites, has shown that, when the surface waters are warmer and, therefore, the thermocline is more accentuated and fewer nutrients reach the illuminated layer, primary production tends to decrease. This decrease in primary production, as a consequence of warming, is observed in temperate and tropical regions.

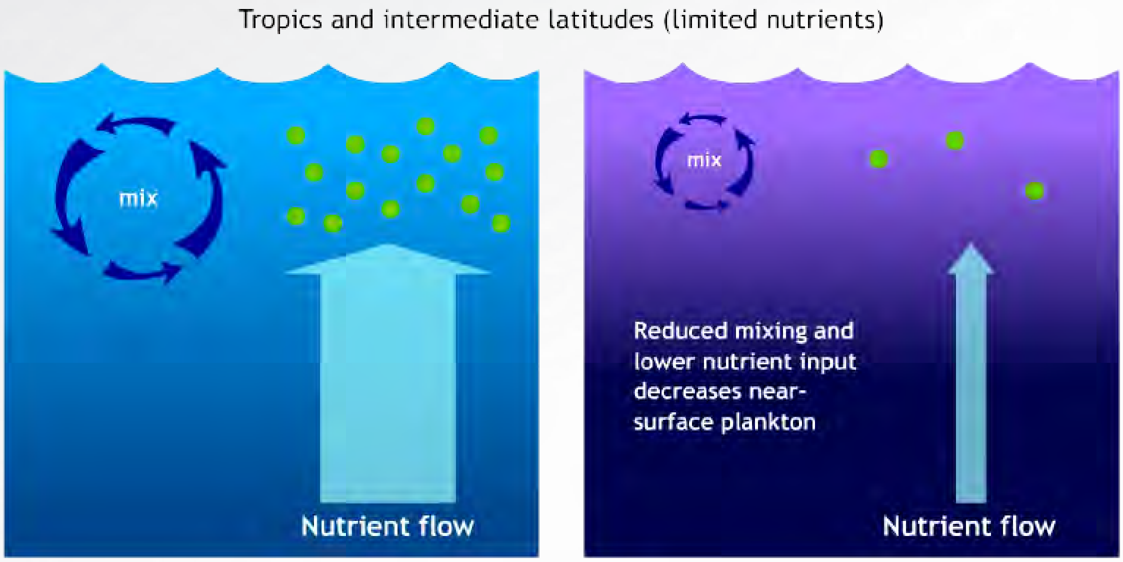


Illustration 34. In the temperate and tropical zones surface heating, which implies stratification, with the consequent thermocline, decreases the supply of nutrients from deep waters, and therefore decreases productivity.

The tropical zones in which the productivity is decreasing coincide with the areas of greatest increase in stratification, which is explained, as has already been explained, by the difficulty that stratification poses for the access of nutrients to the surface from the deep waters.

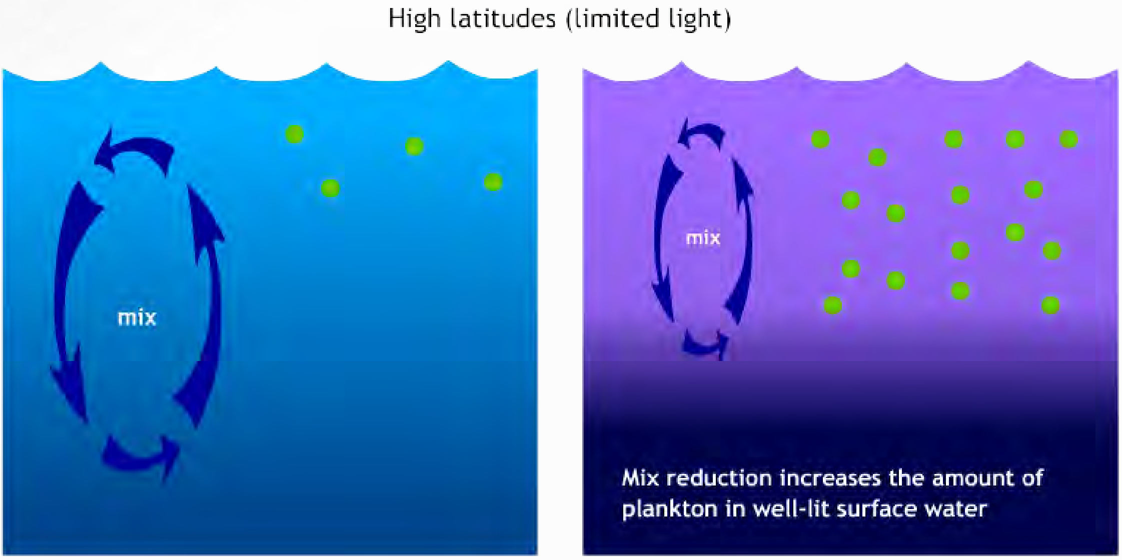
However, in the ocean of high latitudes, where stratification is also increasing, as in the Arctic Ocean, primary production is favoured. This is because the smaller mixing as well as the smaller ice cover, allow a bigger ammount of light to penetrate in the water column.

This hypothesis is based on the fact that, as it has already been explained, in the polar areas there is intense turbulence, which cause the mixing of surface water with deep water to be more intense than in other oceanic regions. That is why phytoplankton are forced to descend to depths where there is no light (aphotic zone).

In these conditions of high mixing intensity, the growth of phytoplankton is often limited by the lack of light. Because of the scarcity of light in these latitudes and its low capacity to penetrate, due to the horizontality of the angle of incidence, it is necessary to add the short time of stay of the plankton in the surface, where it could accede to the radiation, because the turbulence incorporates it fast to deep zones.

In this context, a warming of the surface water of the Arctic, which is also accompanied by a decrease in salinity due to the access of fresh water from the melting of the ice, will reduce the intensity of vertical mixing in the water column. Under these circumstances, the exposure time of phytoplankton to light will increase, which will lead to a higher rate of primary production.

Illustration 35. In the polar areas the plankton is limited by the lack of light, because there is less incidence and penetration capacity. To this limitation is added the fact that with the mixture due to frequent turbulence, the plankton descends to depths those that the light does not reach. Therefore, the stratification favors the increase of time of exposure to light, with the consequent increase in productivity.



But due to the smaller extension of the polar regions with respect to the temperate and tropical zones, the global effect of this mechanism of increase of primary production will be comparatively modest.

Data obtained from satellites also show that the extent of subtropical and warm regions, characterized by very low abundance of phytoplankton, is gradually increasing in all oceans.

According to some studies, this expansion of the subtropical gyres leads to the progressive decrease of the global biomass of phytoplankton. For the whole ocean, available mathematical models predict a 5-15% decrease in global primary production and CO_2 uptake by the biological pump by the end of the 21st century.

27. Perform the stratification simulation using the materials indicated, and following the protocol, and answer the two following questions:

a) How could the effects of climate change, such as the increase in global temperature and the melting of sea ice, affect the vertical structure of the water column?

b) What would be its consequences?

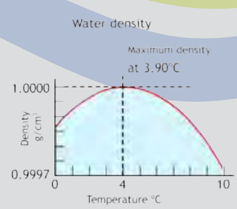
DESCRIPTION OF THE PRACTICE

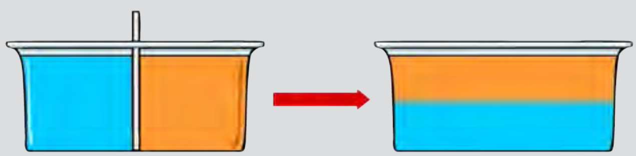
MATERIAL

- **Rectangular tank with a dividing wall**
- **2 beakers**
- **Food dyes or paints of 2 different colors**
- **Water**
- **Ice**

PROTOCOLO

1. Fill a beaker with cold water and the other with hot water
2. Add a few drops of food colouring in each glass (each one of different colour)





6 What is the role of the contributionsof anthropogenic nutrients in the context of global change?

Marsh of the Ebro Delta

The contributions of anthropogenic nutrients, mainly nitrogen, to the ocean have increased more than a factor of 10 since the Industrial Revolution, as a consequence of the synthesis of fertilizers and the burning of fossil fuels.

The main increase in nutrients comes from chemical compounds with nitrogen, a limiting mineral nutrient that is not obtained at the natural rate at the speed necessary to maintain the current population, since it is estimated that one third of the current population requires nitrogen obtained in an industrial manner.

This limitation to which we would be forced without nitrogen fertilizers was already implicit in the theory developed by the British economist Thomas Malthus (1766-1834) (Foto de Malthus) during the beginning of the industrial revolution, according to which the rhythm population growth responds to a geometric progression, while the rate of increase of resources for its survival does it in arithmetic progression. Undoubtedly, the needs of this type of limiting nutrient would behave according to this model, if it were not for the chemical industrial production of this type of fertilizers.

Thomas Malthus (1766-1834)

Although the chemical reaction to obtain ammonia, from which nitrates and nitrites can be obtained is a reaction with a significant percentage of its reactants in the atmosphere, nitrogen (N_2) and hydrogen (H_2), is a very little facilitated reaction, and that in nature it depends on certain types of microorganisms capable of breaking the triple bond of N_2.

However, this reaction was achieved in a technological way in the last century, and consists of reacting nitrogen and gaseous hydrogen to produce ammonia. The importance of the reaction lies in the difficulty of producing ammonia at an industrial level. Although about 78.1% of the air that surrounds us is molecular nitrogen, (N_2), this diatomic gas molecule is very stable, and relatively inert, due to the triple bond that keeps the two nitrogen atoms tightly bound together.

In the first decade of the twentieth century research was developed that served as the basis for obtaining nitrogen from the air and producing ammonia, which when oxidized forms nitrites and nitrates. These are essential in nitric acid (HNO_3) and fertilizers such as ammonium nitrate (NH_4NO_3). This process was developed by the scientists Haber and Bosch (foto dos dous científicos) were awarded the Nobel Prize in Chemistry in 1918 and 1931 respectively, for their work and developments in the application of technology at high pressures and temperatures.

Fritz Haber (1868-1934) was born in Breslau, Kingdom of Prussia (now Wroklaw in the Silesia region, Poland). He was a German chemist awarded the Nobel Prize in chemistry in 1918 for developing the synthesis of ammonia, important for explosives and fertilizers. He has also been described as the "father of chemical warfare" for his work on the development and deployment of dichloro gas (formerly chlorine) and other poisonous gases during the First World War.

Carl Bosch (1874-1940). He was a German chemist and engineer awarded the Nobel Prize in Chemistry in 1931 for his work on the synthesis of ammonia.

The first great impulse of this industrial process took place during the First World War for its use in explosives. This solution was sought to overcome the lack by Germany of this chemical compound, given that the supply of Chile was controlled almost 100% by the British.

As the reaction is very slow, it is accelerated using a catalyst whose composition highlighted iron (Fe_3^+) and the necessary industrial processes were developed to achieve high pressure conditions (between 150 and 300 atmospheres) and high temperatures (400-500ºC)) until reaching a yield of 10-20% in the reaction:

$$N_2 + 3H_2 \leftrightarrow 2NH_3$$

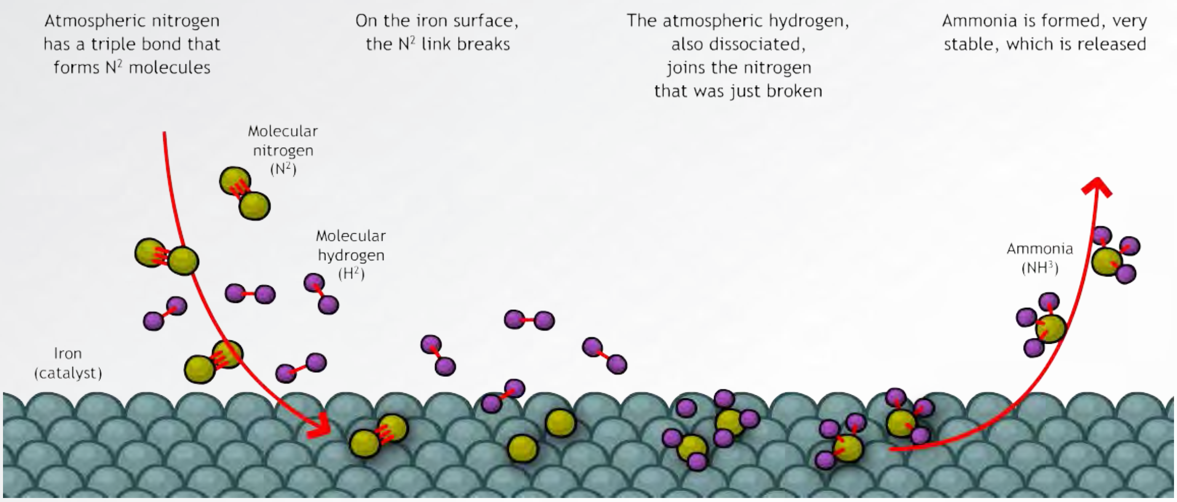


Illustration 36.The Haber-Bosch process where the nitrogen in the air is converted to ammonia by an iron catalyst.

The fertilizers thus obtained allow more than a third of the world's population to be fed because it allows artificially replacing the high extraction of nutrients from the soil by the agriculture and livestock that is needed to support the world's population.

However, the use of these fertilizers obtained in an industrial way, implies that they are used excessively, exceeding a lot the fertilization that is done with them to the requirements of agriculture and livestock.

This misuse of fertilizers produces numerous environmental problems due to the erosion and runoff of nutrients to layers and bodies of water, the most emblematic being eutrophication. In this way the contributions have multiplied by more than 20, which accelerates the natural cycle significantly since the onset of the industrial fixation of nitrogen.

This increase in the supply of nutrients, due to the use of fertilizers, which if not incorporated in this artificial way, would be limiting, prevents, until now, the nitrogen from being the limiting factor. Therefore, if these industrial processes did not exist, there would not be the production of cereals that makes possible the exponential increase that the human population of the planet is following.

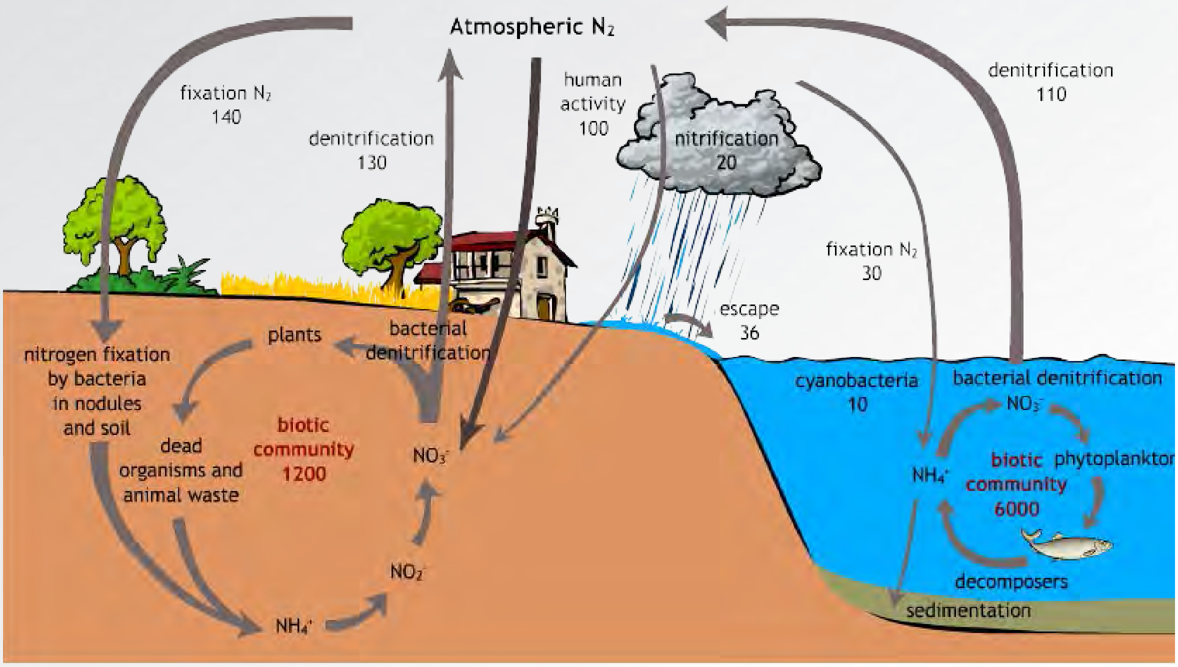


Illustration 37. Cycle of nitrogen

28. Answer the following questions:

a) If we know that a third of the current population could not be here without the industrial production of nitrates, and that the use of nitrates is contributing to global change, write a personal assessment of the past, present and future of inorganic fertilizers.

b) Explain the imbalances in the nitrogen cycle that has led to the use to our present days of the possibilities of this process, and relate it to the main consequences.

c) Was the problem of nitrogen limitation due to population growth present in the Haber and Bosch investigations? Justify your answer.

The result of this contribution of anthropogenic nitrate supplements leads to an important increase in primary production with important consequences on the composition, structure and dynamics of the ecosystem.

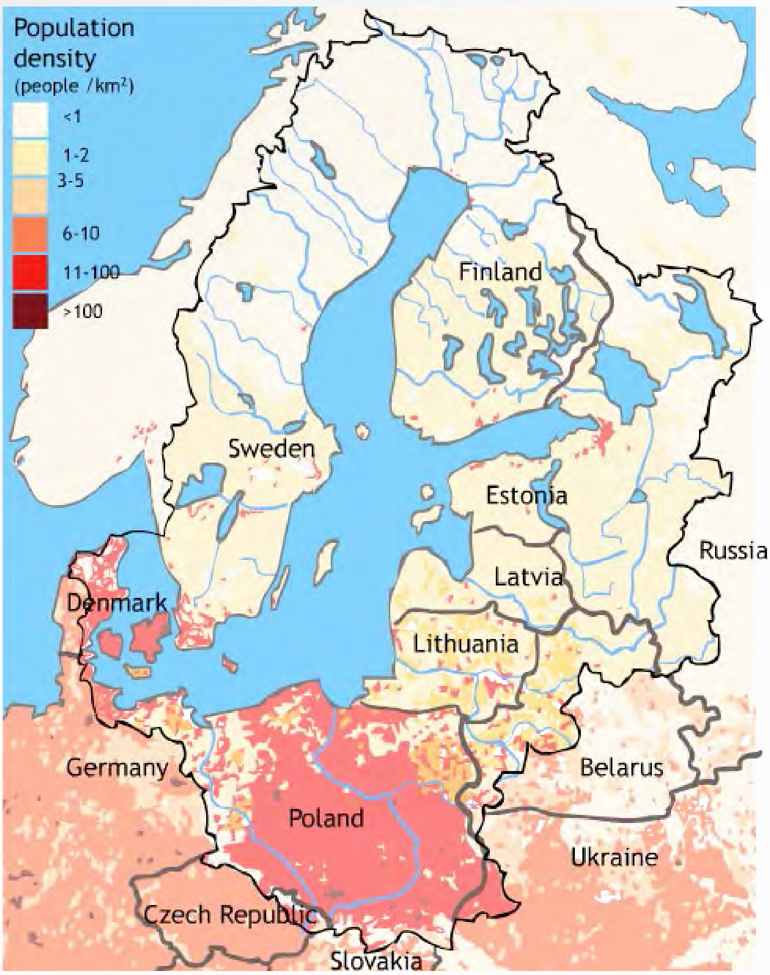
The excessive increase in productivity in aquatic ecosystems is called eutrophication, which tends to favor the proliferation of phytoplankton. With this increase, species with harmful effects usually proliferate. But eutrophication is often harmful, from the point of view of the productivity of aquatic ecosystems, because it will prevent the access of light and oxygen to aquatic communities.

The word Eutrophization comes from Greek and can be translated as well-nourished, although there is no single, globally accepted definition of marine eutrophication. According to the Marine Strategy Framework Directive (EU 2008), eutrophication is a process due to the enrichment of water by nutrients, especially nitrogen and / or phosphorus compounds. This increase ends up leading to an increase in the phytoplankton biomass and the primary production of algae, which, as it is going to be exposed, leads to changes in the balance of organisms; and degradation of water quality. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and / or the sustainable provision of goods and services (EU MSFD JRC Report 2010).

Eutrophication is a phenomenon of global anthropogenic change in the ocean, because it is present in almost all large marine ecosystems, although this phenomenon is more evident in marine lagoons and bays, and in small, closed seas, with discharges important, as in the Baltic Sea.

Panoramic of the Baltic coast in the Polish city of Gdansk.

To explain the relevance of eutrophication in the Baltic, we must bear in mind that it is a drainage basin that covers an area of approximately 1 670 000 km^2 that drains into a sea of 415 000 km^2 of surface area. This basin is a drainage area that is densely populated, with more than 85 million inhabitants living in 14 industrialized countries. In addition, particularly in the southern part, there are many areas dedicated to intensive agriculture, based on the consumption of industrial fertilizers, which emit large amounts of nitrogen compounds (ammonia, NOx) into the sea, which are triggers of important eutrophication processes. This process of eutrophication in the Baltic reflects very well the repercussions on this type of environmental impacts that industrial development based on the Haber - Bosch process implied, since from the beginning of the XX century the Baltic sea has changed from a sea of clear oligotrophic water to a strongly eutrophic marine environment.



38. Map of population density in countries bathed by the Baltic Sea

29. Answer the following questions:

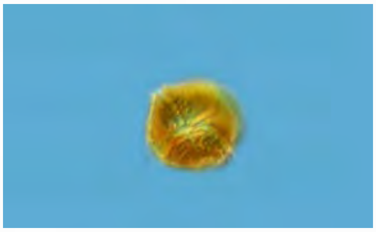
a) What percentage of the drainage area occupies the surface of the Baltic? Will the same proportion occur in the Atlantic?

b) What does it mean that the Baltic changed from oligotrophic in the early twentieth century to eutrophic now? What were the causes of that change?

c) How can you explain that the Baltic has increased eutrophication so much since the Second World War?

d) Where will the average eutrophication be greatest, in the Baltic or in the Atlantic? Justify your answer.

Among the effects of the eutrophication of the oceans, we can mention the red tides. This phenomenon, called harmful algal bloms, consists on episodes where algae grow out of control, decolorating the water. An example of these algae is the group of dinoflagellates are unicellular algae which produce toxins with toxic effects, such as diarrheals or even more serious, as may be the case of paralyzing effects. It is for this reason that they close the extraction in the mollusk filter parks, as is the case of the mussels, during these periods of explosion.

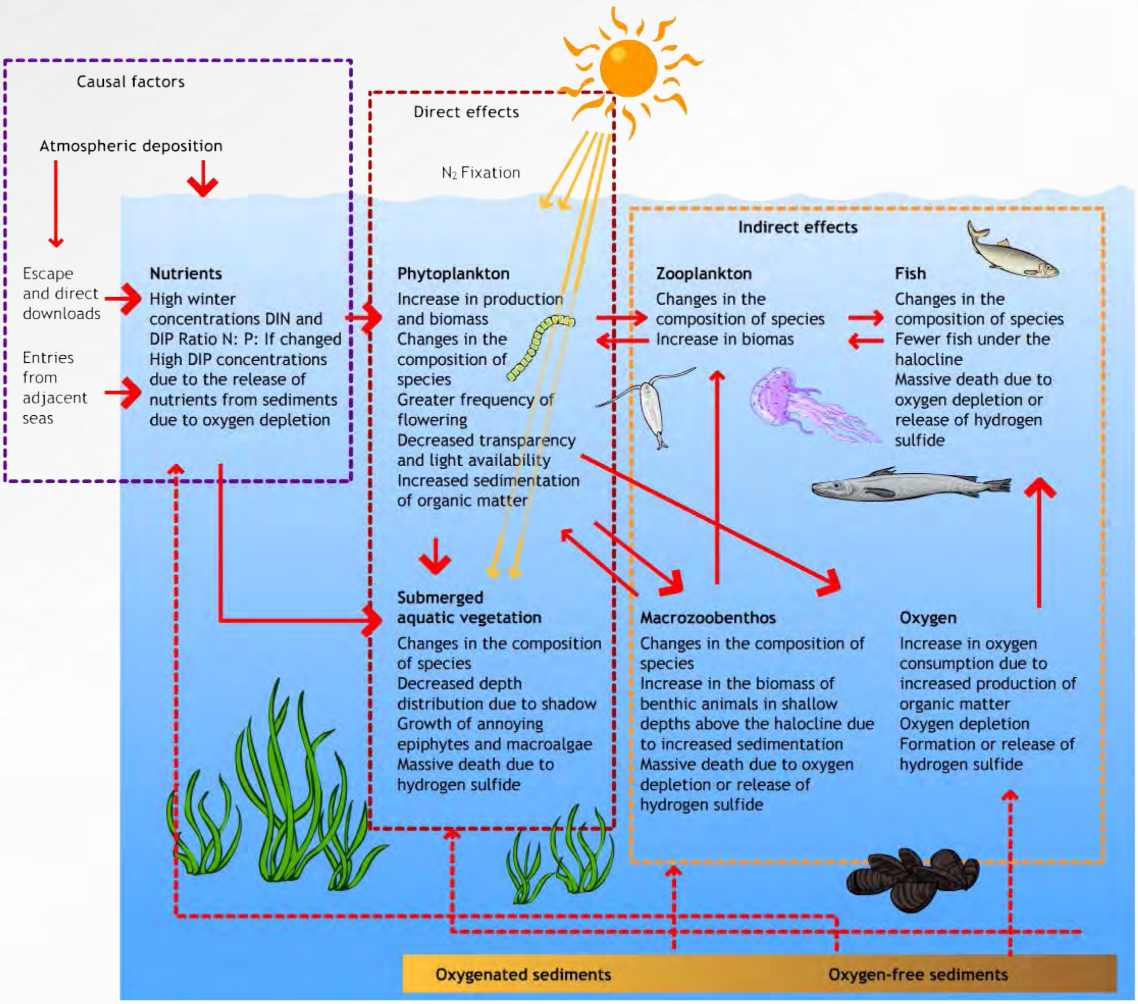


Red tide (image on the right Source: Ibero-American Agency for the diffusion of Science and Technology), caused by the unicellular algae of the dinoflagellates group (top image, source: MECD, Author: Antonio Guillén)

In general, the bloom of algae that occurs during eutrophication causes a cloudiness that prevents the light from penetrating to the natural limit corresponding to the euphotic zone of this oceanic ecosystem. As a consequence, the depth in which oxygen-producing photosynthesis is possible decreases significantlly

In addition, the excess production of organic matter by phytoplankton that occur in these eutrophication processes, cause a clear increase in the deposit of organic matter, from the cellular mortality of the plankton on the sediments.

39. Effects of eutrophication in the ocean (Adapted from Ærtebjerg et al. 2003).



The subsequent degradation of this material by consuming organisms requires an oxygen expenditure and, as a consequence, the extension of coastal waters with low concentrations of dissolved oxygen (hypoxic zones) has increased during the last 50 years, especially in adjacent regions to densely populated areas. The progressive decrease of the oxygen concentration in the hypoxic zones restricts the abundance and activity of the animals and, in extreme cases, can lead to the occurrence of anoxia.

2

30. Do the practice and answer:

a) In what more clarity is achieved in the tube? Justify your answer

b) In which place and with concentration of fertilizer is more clarity obtained in the tube? Justify your answer

c) What factors affect the eutrophication according to the experiment? Justify your answer.

DESCRIPTION OF THE PRACTICE

MATERIAL

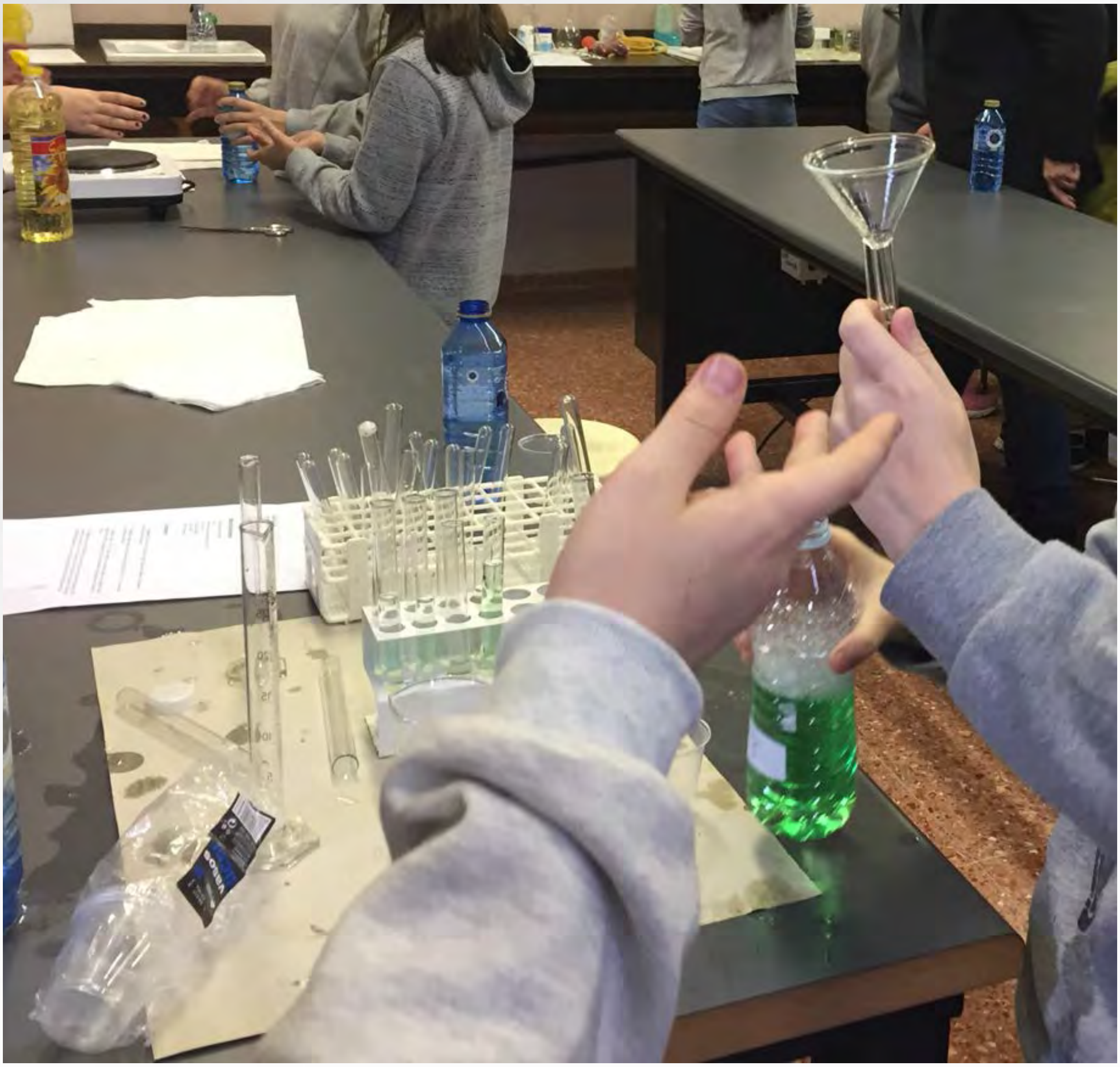
- **6 test tubes.**
- **Inorganic fertilizer: nitrates and phosphates.**
- **Cultivation of the microalgae *Chlorella sp.***

PROTOCOL

Three test tubes are placed as a control and they are filled with 10 mL of distilled water. Next they prepare and label other three tubes as a 10% solution of fertilizer (nitrates and phosphates) and finally three other tubes as a 20% fertilizer solution (nitrates and phosphates). Once the nine test tubes are laid out, 10 drops of the Chlorella sp microalgae culture are added. Each tube is stirred to mix it homogeneously. One tube of each type is placed in a very bright place, another of each type in a medium illumination place and, finally, one of each type is placed in a dark zone. The tubes are left for five days in an illuminated place and we will observe the changes produced day by day.

1

31. Propose urgent interventions that contribute to solving the environmental imbalances detected, from the point of view of agricultural, domestic and industrial use, taking as reference the uses, emissions and treatment of wastewater.



7 What other factors of global change have an impact on intertidal ecosystems?

Shellfish activity in the intertidal of Testal, in the Ria de Muros-Noia (Author: Pedro G. Losada

The intertidal ecosystems are of particular relevance due to their biodiversity, which in many cases leaves us with diverse resources, such as shellfish bivalves, which will focus on the application of the study of this didactic material and that corresponding to acidification. The unit on acidification concludes with the description of the experience developed in the shellfish bank of the intertidal of Testal (Noia-Galica-Spain), to close the didactic scientific content on the global change in the marine ecosystems of the EduCO2cean project.

In these ecosystems, problems of stratification due to surface heating and eutrophication that affect their productivity that have been analyzed in the previous chapters have a special impact. But here acidification is also having a special impact, to which the EduCO2cean project dedicates a study unit, due to its uniqueness. These two units will complete the scientific - didactic proposal on the global change of this project.

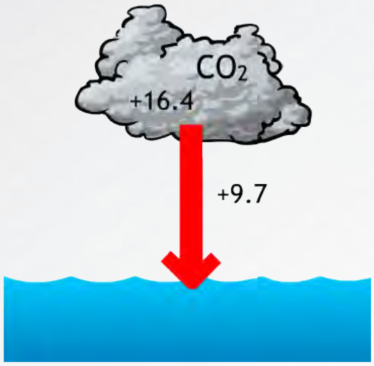
The decision to dedicate a unit to acidification, which closes with scientific intertidal school research, justifies not going too deeply into this factor of global change in this unit, to do so in the specific unit of acidification. But if it is addressed with its outstanding incidence in this type of intertidal ecosystems, because it is a very relevant factor in global change, and also because it has a clear impact on the scientific school research experience incorporated at the end of the acidification unit and selected to apply the two units in an integrated way.

Organization of a school investigation in the intertidal of Testal, in the Muros-Noia estuary. (Author: Pedro G. Losada).

For this reason, in this chapter 7 the effects of the determinants of global change that are still to be studied will be addressed, focusing on intertidal ecosystems, especially in relation to the shellfish resources of the group of bivalve molluscs, object of study in the research school scientist with whom the acidification unit is closed.

Therefore, in this last chapter of this unit the global change factors that have not been dealt with in the previous sections are collected, with their special relevance in the intertidal ecosystems that contain shellfish banks of bivalve molluscs. These factors included because they were not treated before and because they have a clear incidence in the intertidal ecosystems are: acidification, alteration of the biogeochemical cycles and introduction of allochthonous specie.

7.1 Acidification and its special relevance in intertidal ecosystems .

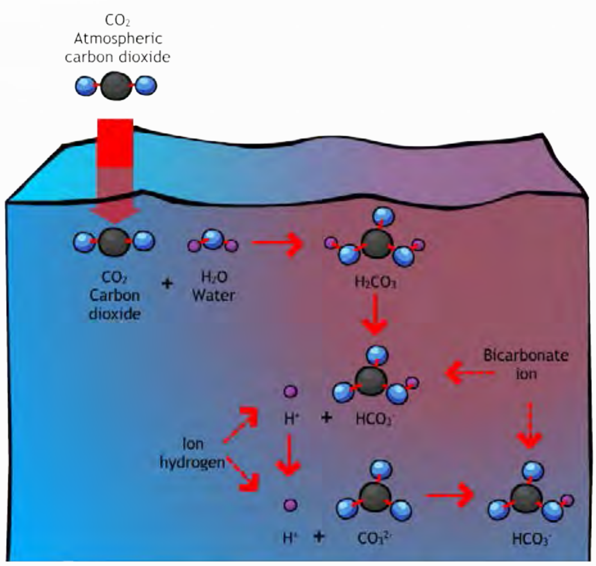


40. Quantification of the diffusion of CO_2 from the atmosphere of the ocean

The atmosphere and the ocean are in continuous interaction across the ocean surface, and in that interaction, diffusion of the gases from the atmosphere to the ocean water occurs.

That is why, from the Industrial Revolution, with the increase in the amount of CO_2 produced by man and discharged into the atmosphere, mainly due to the use of fossil fuels, cement production and changes in land use, including among these, deforestation, has caused that over time the surface of the ocean has already absorbed approximately a third of human CO_2 emissions every year.

When atmospheric CO_2 dissolves in the ocean, it reacts with water molecules and produces carbonic acid (H_2CO_3). Most of this acid dissociates into hydrogen (H^+) and bicarbonate (HCO^{3-}) ions. Consequently, the increase in H^+ decreases the pH and also decreases the concentration of carbonate ion (CO_3^{2-}):

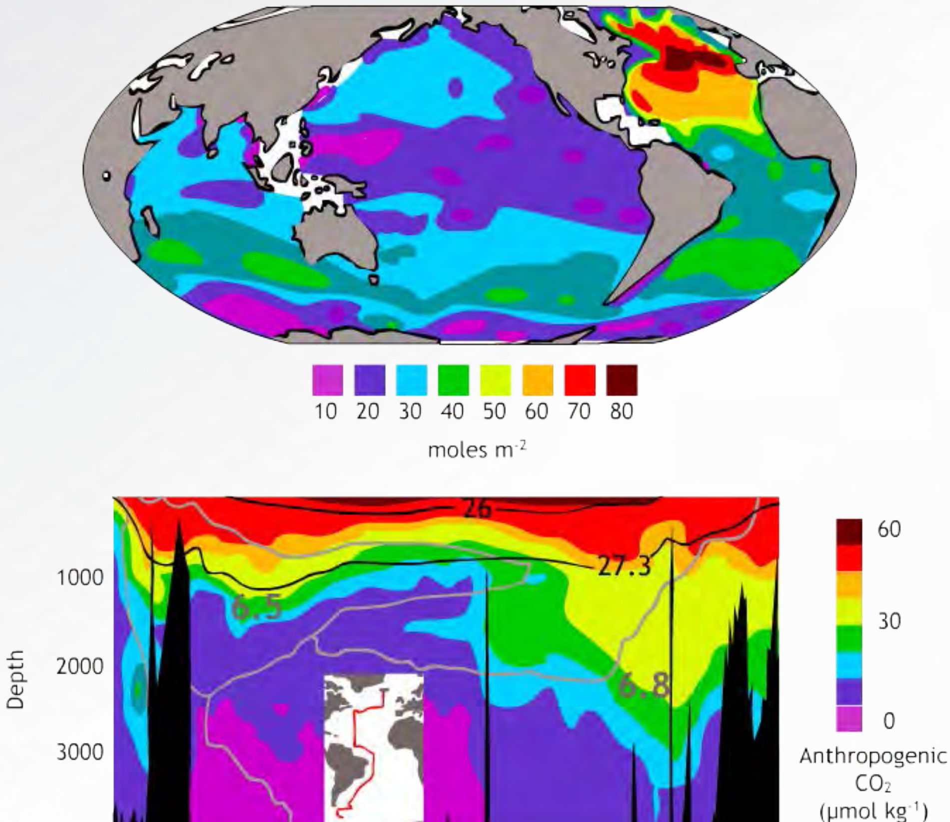


41. The ocean is enriched with CO_2 and becomes more acidic

Currently scientists have a sufficiently broad and detailed record of measurements to conclude that the uptake of anthropogenic CO_2 by the ocean has decreased the pH of seawater since pre-industrial times.

This change, which occurs on a global scale, is called ocean acidification, although what is happening, in most of the ocean, is a decrease in basicity, given the slightly basic nature of the ocean environment. This acidification is greater where more CO_2 diffuses, and this diffusion is greater in the North Atlantic. In turn, latitude also influences depth diffusion.

42. CO2 levels in the ocean



Oceanic acidification affects mainly calcifying organisms, which form shells or skeletons of calcium carbonate ($CaCO_3$). There are numerous species of calcifying organisms in very diverse taxonomic groups, such as phytoplankton, zooplankton or marine invertebrates such as mollusks, crustaceans, sea urchins and corals. As the pH decreases and the concentration of CO_3^{2-} decreases, it becomes more difficult for these organisms to develop their exoskeletons or shells.

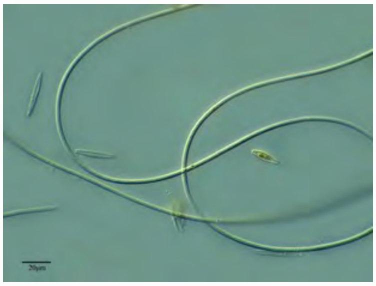
The decrease in calcification leads to a softening of its outer covering, which can lead to decreased growth, greater vulnerability to potentially stressful external factors, deformities and increased mortality. Acidification can also affect different structures of noncalcifying organisms, both calcareous, such as fish otoliths, as well as tissues and vital organs, affecting processes essential for the development of the organism and the population such as orientation and reproduction. However, the increase in CO_2 seems to benefit some autotrophic organisms such as phytoplankton or green algae, which are able to efficiently regulate their metabolism to take advantage of the high concentrations of CO_2 present in the environment.

Decalcification process of a mollusc for 45 days in acidic oceanic water

The effect of the increase of CO_2 on marine phytoplankton has been studied extensively, as it is the main photosynthetic organisms that sustain the biological pump and therefore contribute to the sequestration of CO_2 and the regulation of the atmospheric concentration of CO_2. Among the different variables studied, the number of experiments focused on the analysis of the effect on photosynthesis, respiration and the growth of phytoplankton stand out. The results show that the response varies depending on the species and also between experiments carried out in the laboratory under controlled conditions, or carried out in the natural environment without regulation of environmental factors.

The studies, based mainly on experiments of manipulation of the concentration of CO_2 under controlled conditions in the laboratory, show some significant trends according to the functional group of phytoplankton studied. For example, in coccolithophores, a group of calcifying phytoplankton whose cells are coated with $CaCO_3$ plates or coccoliths, acidification does not affect growth, abundance or photosynthesis, although it does decrease calcification.

Diatomaceous algae colony



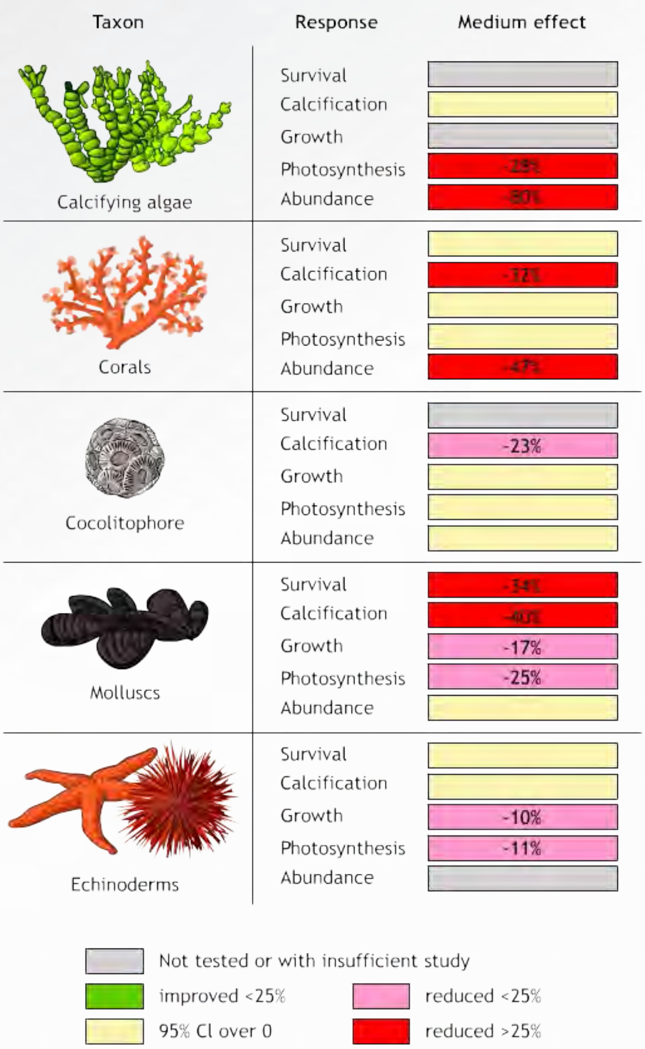
On the other hand, in diatoms, an important group of primary producers on a global scale with a silicic exoskeleton that is not affected by acidification, the increase in CO_2 stimulates production and growth.

32. Answer the following questions:

a) In view of the levels of CO2 diffusion in the Atlantic, in which regions can we expect more acidification? Justify your answer

b) Does the rise in water temperature increase or decrease the acidification?

c) Acidification is a different impact to global warming, both impacts of global change in the ocean, what coincidences can we find between the origin of both impacts on the global change in the ocean?



Most marine animals can tolerate very low pH values during their adult stage. However, in general they are more vulnerable to acidification during the initial stages of their life cycle, such as eggs or larvae, in which they lack a developed system of internal pH regulation.

The larvae of bivalve molluscs like that of the bivalves of the molluscs of the intertidal ones: cockle, clam or mussel, which are important resources with economic impact, show a significant decrease in the development of the shell and in the survival of the individuals under conditions of elevated CO_2.

The trends show that both CO_2 emissions of anthropogenic origin to the atmosphere and the decrease of pH of the ocean will continue during the rest of the XXI century, intensifying the acidification of the surface waters of the ocean, where most of the marine organisms develop their life cycle.

43. Groups of organisms affected by ocean acidification

Surface waters, especially in intertidal shellfish banks, are important for the economic and social development of human beings. In them acidification has special relevance because it reduces the recruitment of mollusks with carapace by affecting the acidification to the development of their larvae in their swimming phage phase as trocóforas larvae. That is why acidification is expected to reduce the recruitment of bivalves because this impact decalcifies the larvae.

33. Do the practice and answer:

a) What happens to the shell that is introduced in acid? Justify your answers

b) When the size decreases, how is the process affected? Justify your answer

c) What happens when the temperature increases?

d) Bearing in mind that the larvae of mollusks of shellfish interest are small and calcareous, what two factors of global change are affecting it? How does these factors affect the resource? Justify your answer

e) What other marine organisms can be affected by this phenomenon?

DESCRIPTION OF THE PRACTICE

MATERIAL

- 1 beaker.
- chlorhydric acid with a commercial scholar concentration.
- bivalve shells.

PROTOL

With the corresponding safety equipment (lab coat, glasses and gloves), in a flask with hydrochloric acid we will dissolve the shell of a calcareous organism (such as *Cerastoderma edule*), thus simulating the effect of ocean acidification on calcareous organisms and trying to deduce the consequences of it. Next, another effect of anthropogenic global change is integrated: the increase in the global temperature of the ocean. We will put another flask with hydrochloric acid to the fire and we will dissolve a ground shell, seeing as the speed of the reaction increases as the temperature increases and therefore, the shell dissolves faster.

34. Answer the following questions:

a) Make a list of seafood species that are marketed in your area that may be affected by acidification.

b) Investigate the economic and ecological importance of these species and report on the future implications of acidification on both areas.

Algae deposited by currents and tides

7.2 Effects on the biogeochemical cycles in intertidal media.

The presence of large amounts of organic matter deposited on the shoreline by currents and tides is common on all coasts. In medium and high latitudes, these materials are visible over the intertidal range and consist mainly of macroalgae from the rocky substrate, or vascular vegetation from marine grasslands (*Zostera sp, Posidonia sp*) and marshes (*Juncus sp, Spartina sp*).

Marshland in Noia (Author Pedro G. Losada)

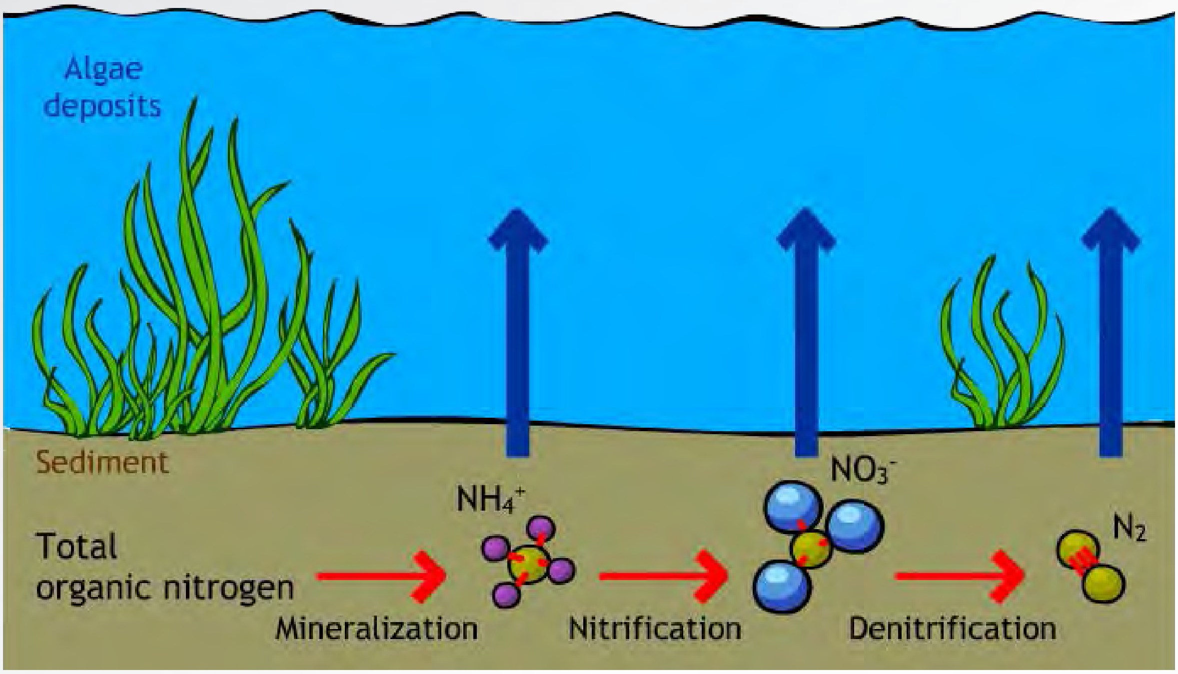
From the ecological point of view, these contributions function as generators of numerous processes associated with the decomposition of biomass, its consumption, the community's metabolism and the supply of habitat. For example, the recycling of algae washed up on beaches is the origin of interesting biogeochemical processes, such as decomposition and mineralization processes that cause the release of nutrients (inorganic N and P, with the consequent release of CO_2).

Those responsible for carrying out these processes are both invertebrate organisms, mainly arthropods, and the microbial community, whose metabolism can be aerobic (with release of CO_2) or anaerobic (with release of CH_4 y H_2S).

Z Muddy intertidal zone (Author: Pedro G. Losada)

35. In ecosystems where eutrophication and temperature increase, can we expect more or less decomposition of organic matter?

One of the key elements for marine productivity that are released in the final stages of the decomposition of organic matter is the N. This is released at the end of the decomposition of organic matter in three different forms: ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-).



44. Mineralization process in intertidal sediments

Mineralization is the process by which decomposing activity, fundamentally bacterial, transforms organic matter into ammonium (NH_4^+). Bacterial mineralization continues in a process called nitrification, which transforms ammonium into nitrite and nitrate.

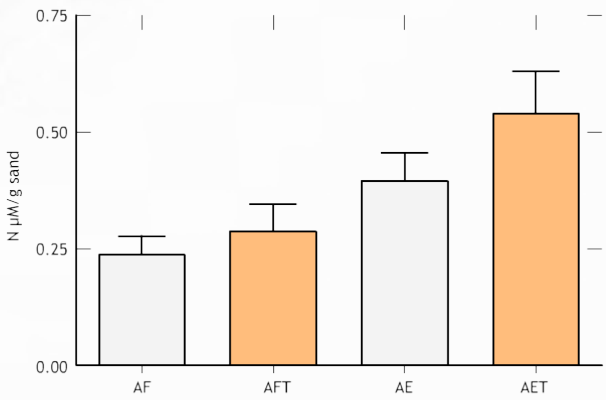
Both ammonium, nitrite and nitrate are easily assimilated by primary marine producers in general and by phytoplankton in particular, as the main responsible for ocean productivity. Under anoxic conditions, nitrates in turn can give rise to molecular N (N_2) through a process of anaerobic decomposition of organic matter called denitrification

Once the organic matter is decomposed, the inorganic N and other nutrients such as phosphorus in the form of phosphates (PO_4^{3-}) are released into the sediment, being incorporated into the water column by the action of waves, tides and currents. Given that all these processes have to do fundamentally with the bacterial metabolism, it is foreseeable that climate warming will cause changes in the rates of remineralizing activity and respiration, which will result in increases in the release of inorganic N and P to the marine environment and CO_2 to the atmosphere.

Recent experiments conclude that the increase in temperature accelerates the decomposition and processing, through different consuming and degrading routes, of the organic matter deposited. In its most optimistic predictions, the Intergovernmental Panel for Climate Change (IPCC) foresees temperature increases in western Europe around 0.5 ° C for the next decades.

Studies of manipulation of the natural environment carried out so far reveal that a temperature increase of 0.5 ° C will stimulate the release rate of inorganic N by more than 20%. As regards the effects of heating on respiration, a similar increase in temperature will increase the release of CO_2 by 7% for materials recently supplied by the donor ecosystems (rocky, marshes, etc). When this biomass remains a more or less prolonged time in the water column before being deposited on the coast, the release of nutrients (both N and P) and the emission of CO_2 can increase between 10 and 20% because of the increase of temperature, due to the greater bacterial proliferation of decomposing tissues.

45. Effect of temperature on the remineralization of the N medium concentration of inorganic N in sediment under patches of algae at environment temperature and heated to 0.5 degrees centigrade. AF: fresh algae ; AFT: fresh algae with increased temperature; AE: partially decomposed algae (1 week in water column); AET: partially decomposed algae with temperature increase



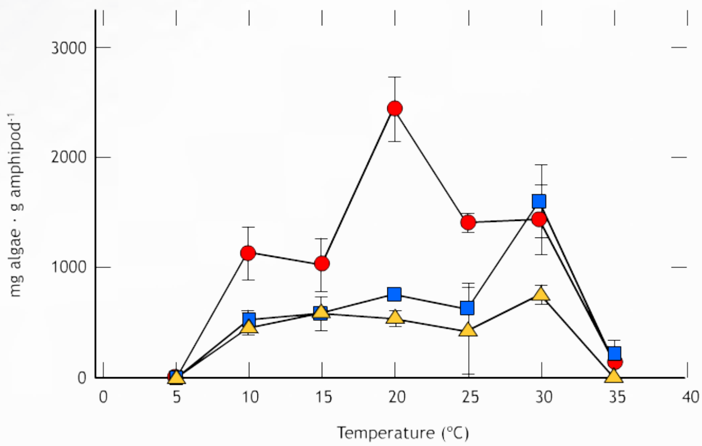
36. Answer the following questions:

a) How can the incidence of ocean warming affect eutrophication and the mineralization of organic matter on the coast?

b) Can these processes of incidence of climate change on coastal organic matter have an impact on global warming itself? Justify your answer.

In the intertidal environment, many species use macroalgae deposits as a source of food and shelter. In fact, most of the biodiversity of the sands depends on the presence of deposits of algae or marine plants supplied by the ocean. Within these materials there are complex trophic networks in which various levels of primary consumers and predators are intertwined, whose last representatives are birds or mammals of great ecological interest whose survival depends on the availability of prey linked to the stranded algae deposits.

The effect of climate change on fauna will have an immediate impact on the processing of macroalgae or any type of consumable material deposited on the coastline. As an example, the speed at which herbivorous species consume intertidal algae depends to a large extent on variables such as air temperature, humidity degree, rainfall, etc. In general terms, humidity increases the consumption rate by herbivores and bacterial mineralization. The temperature also increases the speed at which these materials are consumed, but within an optimum range that can vary depending on the species and its stage of development.



46. Effect of temperature on the consumption of algae. Consumption rate of the Talltrus Saltator antipode on the macroalga Saccorthiza Polyschides at different temperatures for different age classes (length of the animal). Circles- 3-8mm; squares- 8-11mm; triangles 11-14mm (Lastra et al., 2014)

In many cases, the consumed resource does not depend directly on the algal biomass but on the microbial community formed by bacteria and fungi that develops on the surface of the tissues of the algae and that facilitate the degradation of the cellulose walls of the plant tissues. The increase in temperature will lead to an acceleration of the consumption of any type of organic matter deposited on the coast, which in turn will increase the rate of excretion, respiration and the general metabolism of the community.

36. **Answer the following questions:**

a) How does the warming of the ocean affect the amount of algae that accumulate on the coast?

b)

7.3 Introduction of non-native species.

An undesirable side effect of the increase of the temperature in the coastal ecosystems of temperate zones will be the arrival of species from warmer latitudes, which can alter the organization of the autochthonous communities. These exotic species can be both primary producers (for example, macroalgae) and consumers of any trophic level. When these species maintain a reduced presence, they do not usually cause significant effects on ecosystems.

Algae of the genus Sargassum, invaders in the waters of Galicia

But when they have great capacity to compete for resources and space, they proliferate in large numbers and are able to compete effectively with the native populations, sometimes displacing them to extinction; in these cases they are called invasive species. The arrival of these invasions can cause changes not only in the biota but also in the metabolism of the ecosystem, the transfer of energy and the cycles of matter. The intertidal of Galicia are being invaded by genera such as Sargassum and at the same time the *Laminaria* or the *Sachorriza* are leaving these coasts to colonize others in which they practically did not exist, as in the North of France.

37. How does the warming of the ocean affect the amount of algae that accumulate on the coast?

FINAL REFLECTIONS

Once you have developed the study related to each question, answer again to the initial question:

1) **Are we changing the ocean globally?**
2) **How does global change affect marine ecosystems?**
3) **What factors can limit primary productivity due to global change?**
4) **How does the ocean uptake the atmospheric carbon dioxide?**
5) **What is the current situation of the warming of the ocean and its effects on global change?**
6) **What is the impact of anthropogenic nutrient imputs?**
7) **What other factors of global change affect intertidal ecosystems?**

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