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Ocean Under Global Change: From Science to School

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ABSTRACT

This article includes a methodological proposal in which students collaborate with scientists in order to establish a significative series of data to know the impacts of Climate Change on a shellfish bank which represents the main socio-economic motor in a costal population of more than 14000 habitants live. This proposal explains the theoretical background of the experience as well as the teaching strategy through laboratory practices which allows the students to act as efficient scholar scientists on this type of collaborations with research teams. Also described is the practical application of this knowledge on an investigation allowing for the beginning of a temporal series of data about the situation regarding the collection of cockles (*Cerastordema edule*) to understand how Climate Change can affect this valuable economic resource in Galicia – Spain. This applied scholar science is described ending with the analysis of data through our accumulation of graphs and the creation of our conclusions. Through our conclusions we have found the necessity of carrying on the kind of studies in the following years remarkable both, before and after, the recruitment campaign in order to obtain conclusions about possible adaptations of the duration of the recruitment period to Climate Change. Via our pedagogically obtained conclusions, we have found interest in this type of proposal to be valuable for the acceleration of the incorporation of these contents to the syllabus due to the urgency of the arrival of this knowledge to society.

Keywords: scholar science, global change, laboratory practices, scientific method, change investigations, science – technology – society

INTRODUCTION

This article proposes a practical approach to new ways of teaching and learning about Global Change in the Ocean. The pedagogic relevance of the described and analyzed experience is remarkable due to the fact that anthropogenic global change is one of the greatest global challenges which frontier science has to face.

Thus, when dealing with the curricular experience of a scientific knowledge on its own development which has not had time to be introduced in the scholar syllabus yet, we are facing a pedagogic singular challenge with a high innovative potential.

On the other side, the urgency of this challenge requires an immediate introduction into the school science so that students not only acquire the curricular abilities on this subject, but that they can also act as agents who make aware, disseminate and educate our society about this issue. Such a learning role requires a high compromise and a prominent role on the part of the student, offering him encouraging opportunities at the same time that allows the school to act as a bridge between science and society, so that citizens become aware

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and involved with the solution of this problem which, because of its high impact, asks for an urgent and global implication.

This approach leads us to pursue the goal of making students competent in communicating the challenge in outdoor classes by using laboratory practices and simulation models. This is why in this article we will present the procedures to carry out these demonstrations and the reflections in which the students must incur, in order to have data, justifications and scientific conclusions at their disposal to be able to explain this global change to citizens by using public modern expositions about global change.

In order to reinforce the motivation and the scientific training, a research is addressed, creating a community in which scientists and students take part, in order to put into practice research methodologies which are key to study the possible impacts of global change in the recruitment of common cockles (*Cerastoderma edule*) at the main shellfish bank for this bivalve in Galicia.

Therefore, we present throughout this paper new ways of learning and teaching so that the pupils can collaborate with the scientists in the processes of research and dissemination of the most relevant and urgent knowledge to achieve their thorough and fast implication in the challenge of the global change in the ocean. To achieve this model, Climántica's own methodologies were followed in the context of the participation in the strategic European Alliance for innovation and cooperation and the exchange of good educative practices EduCO2cean-Erasmus+, trying to find a balance between reason and emotion, and between scientific rigour and playful spirit.

The article is structured in three parts: theoretical grounds, laboratory practices and simulations, and finally, an investigation in the Testal's shellfish bank. The theoretical ground is approached starting from the great dimensions of global change: 1) global warming, stratification and its effects on the loss of primary productivity, 2) pH drop in the ocean and 3) eutrophication and its effects on the loss of oxygen in the ocean. The laboratory practices deal with the three great conceptual dimensions of the anthropogenic global change: convection currents, water mixing with different colourants and temperatures and the dissolution of bivalve seashells in acid. Finally, the study of the recruitment of common cockles which abandon their larval form and get fixed at Testal's sand was carried out by the transect method with data collecting at equal distance and with the same volume of sand.

THEORETICAL GROUNDS

The ocean is one of the most relevant environmental assets in the Earth: life first appeared there and the productivity of the planet depends on it. This exceptional environmental ecosystem is suffering a serious global change which puts it at a serious ecological risk.

Between the most influencing factors for this global anthropogenic change, three main aspects become remarkable due to their impacts on productivity and because of their negative implications in the energy flux at marine ecosystems. These three impacts are: 1) ocean warming and their stratification, 2) Ocean acidification and 3) Eutrophication and anoxia at the existing oceans.

The theoretical framework for this article is approached from the standpoint of the science of anthropogenic global change and we pursue the introduction of these kind of global challenges in process of study and thus part of frontier science, in the school syllabus using the own methodology of Climántica's project.

Justification Based on the Science of Global Change

Among other impacts, human activities are causing an increase in the temperature with global impacts such as the rise of the sea level and its acidification (pH drop) in the surface water or the increase in the nutrient supply to the sea shore.

The combination of these types of impacts is affecting globally the physical, chemical and biogeochemical processes in the oceans and shorelines, changes that are summed up in the concept of anthropogenic global change. These modifications are relevant because they affect the marine biodiversity and the ecological structure, as well the functions, benefits and services of the marine ecosystems (Marañón, 2017).

The scientific content related to the challenge of the anthropogenic global change in the ocean which has been selected to be transferred to the scholar syllabus in the didactic proposal collected in this article, is the one which is summarized in the definition for Climate Change from the report of the Intergovernmental Panel on Climate Change by the United Nations from 2013 (IPCC, 2013). This report states that this global phenomenon has been become evident in the oceans because of the rise in the temperature of the water, the acidification and the rise of the sea level (IPCC, 2013). It is also relevant the increase in the amount of mineral salts (nutrients for the primary producers of this ecosystem) because of the impact of these spills on ecological aspects such as light or oxygen, which implies remarkable reductions in the depth of the euphotic zone and remarkable anoxia in certain oceanic zones.

All these processes linked to the anthropogenic global change are potentially inducing biological responses in marine ecosystems which can lead to significant impacts on physical-chemical properties, biodiversity, structure and energy flows from the ecosystem.

This is why this article deals with the transfer to the syllabus of the effect of ocean warming, acidification and eutrophication on the distribution, abundance and activity of the populations of planktonic and benthic species. For this purpose, new learning formulas are sought, which allow the incorporation of such an effervescent science about a new challenge of global nature.

In addition, we try to approximate students to scientific methods, such as sampling by using the transect technique with samples equidistant and of equal volume, to generate significant data series which allow us to know over time the effects of these impacts on the diversity of bivalve populations in one of the main shellfish banks in Galicia.

Stratification due to the ocean warming and biodiversity loss

One of the three major changes which might potentially lead to global change is the loss of productivity from the stratification derived from ocean warming. Stratification is produced because the surface water heats up due to global warming. Surface water heating causes a decrease in density due to thermal expansion. This way, a thermocline is established and it marks the separation between two masses of water with different temperatures, and therefore with different densities, which prevents the water from the lower layers from reaching the surface.

The currents which cease to reach the surface are those ascending sea currents which come from the bottom where the rocks are and the organic matter breaks down, so the important amount of mineral salts which fail to reach the surface, would suppose an important contribution of nutrients needed by phytoplankton organisms, which are the main primary producers of the ocean.

That is why these regions with rises of deep waters to the surface are places with remarkable high levels of primary production. High primary production stimulates the activity of the food chain, as phytoplankton is the basis of ocean food.

However, with stratification, the rises cease and in those regions take place a decrease in the concentration of phytoplankton on which hinges the entire energy flow of the ecosystems of these affected regions**.** That is why stratification involves a decrease in primary production, which implies the loss of ocean biodiversity at the general level.

Ice melting and its impacts on productivity

The rays of sunlight which reach the surface of marine ecosystems have a greater or lesser capacity to penetrate according to the inclination of the sun. Thus, there is more penetration when the sun is in a zenithal position and the lower penetration capacity takes place when the sun is closer to the horizon.

Although global change has no incidence in the greater or lesser penetration capacity, as this depends on the position of the sun, it is indeed influencing the overall change in the percentage of albedo, due to its effects on the thawing of the Arctic polar ice cap. This is so because the ice reflects, acting like a huge mirror, most of the incoming radiation, while the sea water absorbs most of it, transforming its energy into infrared or calorific radiation, which contributes to the increase of the temperature in the region.

By increasing the thaw of the Arctic due to global warming, the percentage of albedo decreases, enhancing the percentage of penetration and absorption of light in the ocean, thus raising the temperature of that oceanic region. This polar regional warming causes, in turn, an acceleration of the melting of the ice edges, thus giving rise to a positive feedback, which is leading to an overheating of the Arctic region. This process of stratification, due to the increase of temperature produced by the decrease of the albedo in the regions of polar thaw, is subjected to a positive feedback because the fresh water of the surface which originates from the thaw has a significantly higher density than ocean salt water, making the mixture difficult.

However, in polar regions it is being discovered that the effects of stratification do not have the same incidence on the decrease in productivity that the stratification in low latitudes. It is even anticipated that there may be slight increases in productivity in these zones because in these high latitudes.

The prediction of increased productivity in the poles is based on the fact that in the polar oceanic latitudes the mixture by turbulence is very high, which makes the availability of light even more limited for phytoplankton, which when descending ceases to have access to this little solar radiation. If the water is stratified, it increases its exposure to sunlight which is the greatest limiting factor in these ecosystems.

This type of forecasts is based on research such as the Continuous Plankton Recorder (CPR) Research Program, which employs automatic samplers installed on commercial vessels, which continuously collect samples of plankton that are subsequently examined in the laboratory (Marañón et al. 2017). The data of the CPR show that the distribution of diatoms and dinoflagellates, two of the most important groups of phytoplankton, has extended further north in the warming spell observed in the Northeast Atlantic during the period 2004-2008 (Chivers et al. 2017).

The decrease of the pH of the ocean

The atmosphere and the ocean are in continuous interaction through the oceanic surface and in that interaction, the diffusion of gases from the atmosphere into the ocean water is produced. Therefore, from the Industrial Revolution on, with the increase in the amount of CO2 produced by humanity and poured into the atmosphere, mainly due to the use of fossil fuels, the production of cement and changes in land use, including the deforestation (Marañón et al. 2017), all this has caused that with the passage of time, the surface of the ocean absorbs approximately one third of the human emissions of CO2 each 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 is dissociated into hydrogen ions (H^+) and bicarbonate (HCO_3^-). Consequently, the increase of H^+ decreases pH and also reduces the concentration of carbonated ion (CO_3^{2-}):

$$\underset{\text{carbon dioxide}}{CO_2} + \overset{\text{water}}{H_2O} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \overset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-} \rightleftharpoons \overset{\text{hydrogen ion}}{H^+} + \underset{\text{carbonate ion}}{CO_3^{2-}}$$

This change, which is produced at a global scale, is called oceanic 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 higher where more CO2 diffuses, and this diffusion is greater in the North Atlantic.

Ocean acidification affects mainly the calcifying organisms, which form shells or skeletons of calcium carbonate ($CaCO_3$). In this group we find organisms whose larval decalcification can be an important barrier for its development. This is the case of the bivalve of commercial interest involved in this study (*Cerastaderma edule*).

Eutrophication and Anoxia in the context of the global change of the oceans

The contributions of anthropogenic nutrients, mainly nitrogen, to the ocean have increased in more than a factor of 10 since the Industrial Revolution, as a result of the synthesis of fertilizers and the burning of fossil fuels (Marañón et al. 2017).

This increase in the nutrient input is called eutrophication. The word eutrophication comes from the Greek and can be translated as well nourished, but it does not exist a globally accepted definition for marine eutrophication. According to the Marine Strategy Framework Directive (EU 2008), eutrophication is a process due to the enrichment of water in nutrients, especially nitrogen and/or phosphorus compounds.

This increase in nutrients tends to promote the proliferation of phytoplankton and often favours species with harmful effects. The amount of microalgae which accumulate in the plankton becomes so high that it impedes the penetration of the light, reducing, in many cases, significantly the depth of the euphotic zone, and makes more difficult the diffusion of the gases.

Eutrophication also stimulates the production of organic matter by phytoplankton, much of which is deposited on sediments. The subsequent degradation of this material by consumer agents requires an oxygen expenditure and, as a consequence, the extension of coastal waters with low dissolved oxygen concentrations (hypoxic areas) has increased in these last 50 years, especially in regions adjacent to densely populated areas. The progressive decrease in the concentration of oxygen in the hypoxic areas restricts the abundance and activity of the animals and, in extreme cases, can lead to the appearance of anoxia.

Foundation from the Framework of the Didactic Methodology and the Context

The urgency that the challenge dealt with in this article will influence the awareness of the public requires the transmission of a didactic approach which allows the transfer of the frontier science, which is in full elaboration, directly to the school syllabus, and from there to our society, cutting back in years the date in which the conclusions drawn from these investigations are introduced into the school curriculum. To achieve this, the methodological proposal was supported by two design principles of the Climántica project (Sóñora, 2011), most used by this project in its experimental curricular proposals, involving experimental laboratory and field classes:

1) Secondary school represents an effective bridge between science, technology and society to make the public fully aware of the urgency of this challenge. Students can collaborate with scientists to help them with data collection while scientists provide students with the scientific knowledge through direct contact with them but also through teacher's training.
2) The urgency of this challenge makes the scholar community responsible for taking control of concepts, procedures and attitudes to be able to, from a very young age, give strong and determined answers to this problem. This is why it is urgent that this school science has a strong presence in the syllabus. However, the incorporation of this new scientific field into the official syllabus is much slower than the urgency of this response requires.

The didactic approach, which is based on these principles, is aimed at involving a school community in an investigation in order to know which factors affect the fixation of the larvae of *Cerastoderma edule*, when they change from the planktonic swimmer form to the bivalve morphology one, which settles down in the intertidal sand where it will remain for the rest of its life.

To facilitate the transfer of this school science to the society, it was chosen for the investigation the shellfish bank of this species with a great commercial relevance for Spain, which has a turnover of millions of euros every year with this resource. the choice was made on the basis of the design principle of the Climántica project, according to which, the resources subjected to change impacts and with a great socio-economic relevance, must be selected.

The shellfish bank in which the experience was developed is located in Testal beach, in Noia (Galicia-Spain). Support for its development was obtained from the Strategic Alliance for Innovation and Cooperation in good educational practices *STS Education Models to Transmit to Society the Challenge of Global Change in the Ocean (EduCO2cean)* approved and financed by the European Union in the announcement for the Erasmus 2016: Project Reference: 2016-1-PT01-KA201-022952

The group of students was defined by following another principle of action of Climántica for this area of the school science destined to give educational answers to the climatic change. This selection consists of making proposals to all secondary school students, in the area of the resource to study, to collaborate with researchers, under their direction, to obtain relevant information for science and society. Some volunteer students may join the school group, devoting both school time as well as extracurricular time.

In this case a group of 70 students aged between 14 and 16 years was formed. These students received training from their teachers as well as from scientists. All the training was developed on the scientific reflections arisen from the performing of laboratory practices referring to each of the fields which are collected in the previous subsection. These are the practices which are described in section 3.

The school training process ended with an explanation of the ecological research procedures which were applied in the beach research phase. At the end of the training, 20 task teams were formed with a minimum number of 3 students and a maximum of 4. Each team was given all the necessary materials to develop the part of the research described in section number 4.

The foundation of these ecological techniques applied on the beach is based on the technique of samplings of interstitial fauna, based on transect, with sampling at regular distances and identical volumes of sediments, as exposed in section number 4.

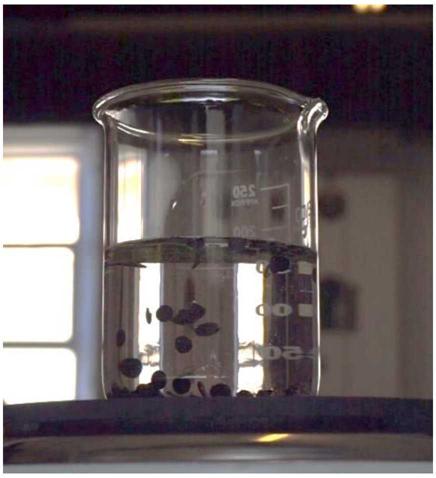


Figure 1. Photograph of the practice of ocean stratification carried out at the International Youth Campus of Climántica. It represents the rise of nutrients from the ocean floor to the surface

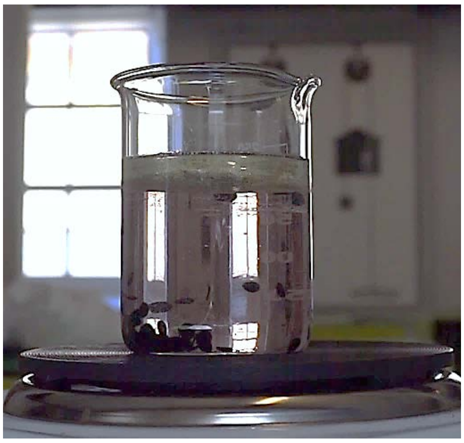


Figure 2. Photograph of the practice of ocean stratification carried out at the International Youth Campus of Climántica. It represents the impossibility for the nutrients to rise the surface

DESIGN ON PRACTICES OF ANTHROPOGENIC GLOBAL CHANGE

Practice on ocean stratification

Objective: To simulate the process of oceanic stratification and to discuss what ecological implications this phenomenon has on aspects such as productivity or biodiversity.

The practice is divided in a first part of assimilation of concepts on the flow of nutrients in the ocean and the importance of phytoplankton as a basic pillar of the marine ecosystem and a second part in which the process of derivative stratification will be visualized as a result of ocean warming.

In the first part of this experience the rise of nutrients from the ocean floor to the surface waters, where the phytoplankton, which is the basis of the aquatic ecosystem food chain is found, is simulated through convective flows. In the first place, a bucket is filled with water and placed on the fire. Then, the cardboard clippings, which will simulate being the nutrients, are submerged**.** The warmer water from the bottom is then displaced and surfaces, thus observing a convective movement which simulates the rise of nutrients from the ocean floor (**Figure 1**).

Then, to assimilate the implications of a change in the density of the medium in the ascent of nutrients, a layer of oil is added to the bucket with water and it is observed how the cuts of cardboard, which represent the nutrients, cannot penetrate in the surface layer of oil (**Figure 2**).

In the second part of this practice the stratification of the water mass is simulated, stratification due to the difference of densities which is created by the thermal expansion of the surface water and we will discuss

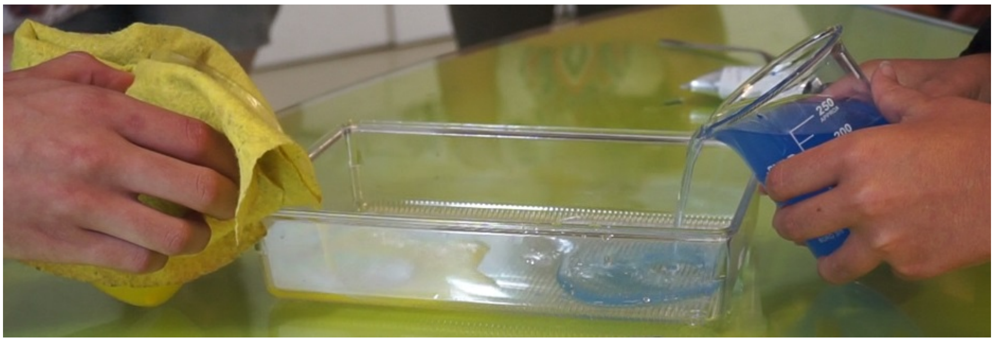


Figure 3. Photograph of the practice of ocean stratification carried out at the International Youth Campus of Climántica

Figure 4. Photography of the pole thaw practice held at the International Youth Campus of Climántica

its implications by making analogies with the first part of the practice. To do this, we will dye with different food colouring a bucket with hot water and another with cold water. Then we will pour both into a tank and thanks to the colour provided by the colorant, we will observe how the stratification process is produced due to the difference in existing density (**Figure 3**).

Once the process is assimilated, students are supposed to make analogies with the first part of practice and must able to understand the implications which this process has on the rise of nutrients from the ocean floor and thus, deduce the consequences it may have on ocean productivity. To do this, it is interesting to analyze how other phenomena derived from climate change, such as the thawing of the poles, can affect this process and thus conclude, finally, how in the middle latitudes this process of oceanic stratification will imply a decline in productivity while at the highest latitudes it may imply even a small increase of the same, as explained in paragraph 2.1 (Behrenfeld et al. 2006).

Practice on the Thawing of the Poles: Arctic and Antarctic Models

Objective: To understand the implications of the melting of the poles in the increase of the sea level, in the increase of the ocean temperature and in the modification of the productivity.

To represent the Arctic and Antarctic thaw model, a rock base which simulates the continent is placed in two buckets and water is added so that both cuvettes have the same level of water. In the case of the Arctic model, the ice cubes are placed floating on the water, whereas in the case of the Antarctic model (like Greenland and mountain glaciers), they are placed on the rocks. This way, we will observe how the thaw of the Arctic, which presents floating ice, does not produce variation in the sea level, while the thawing of the Antarctic actually does, since it presents continental ice. Finally, the phenomenon of the melting of the poles must be related to the oceanic stratification (and the consequent modification of the productivity) and to the increase of the global temperature of the ocean due to the reduction of the albedo (**Figure 4**).

Practices on Ocean Acidification

Objective: To understand the process of ocean acidification resulting from the dissolution of anthropogenic CO_2 in marine water, as well as its implications for the ecosystem.

The practice is divided into two parts: a first part in which we will make the acidification of the medium and a second part in which the effects of this process will be observed, integrating also how other aspects

Figure 5. Photograph of the phases of the practice of ocean acidification carried out at the International Youth Campus of Climántica

Figure 6. Photograph of the practice of ocean acidification carried out at the International Youth Campus of Climántica

consequence of the climate change have an influence as for instance the increase in the global temperature of the ocean.

First, an acid-base reaction is performed to obtain the CO_2 that subsequently will be dissolved in water. To do this, vinegar (acetic acid) is introduced in a bottle and sodium bicarbonate is put inside a balloon. Then the mouth of the globe must be placed in the mouth of the bottle and, after this, we allow the sodium bicarbonate to fall on the vinegar, firmly holding the balloon to the mouth of the bottle to observe how it swells due to the rise of CO_2**.** Once we have the CO_2 inside the balloon we will let it dissolve in the water of one of the flasks with the help of a straw leaving the other flask with water as a reference. (**Figure 5**).

After dissolving the CO_2 in water, we will add to both flasks the blue of thymol (or in its defect we can use the resulting liquid after boiling a beet for about 5 minutes) to check the decrease of pH (acidification) produced after the dissolution of CO_2 in one of the flasks.

Once students have understood the process and the chemical reactions by which ocean acidification happens, we will move to the second part of the practice in which we will introduce the consequences of this process for the ecosystem.

With the corresponding safety equipment (lab coat, laboratory glasses and gloves), in a flask with highly concentrated hydrochloric acid we will dissolve the shell of some calcareous organism (e.g. *Cerastoderma edule*), simulating the effect of ocean acidification on calcareous organisms and trying to deduce its consequences for the organism. Another effect of the anthropogenic global change is then integrated: the rise in global ocean temperature. We will put another flask with hydrochloric acid to the fire and dissolve a ground shell, observing how as the temperature rises, the speed of the reaction increases and therefore, the shell dissolves faster (**Figure 6**).

Practices on Eutrophication

Objective: To understand the process of eutrophication due to the enrichment of water in nutrients and its relation with the anoxia and the reduction of the depth of the euphotic zone.

First of all, at the beginning of the didactic proposal, three tubes are set up, acting as a witness. They must be filled with 10 mL of distilled water. Three other tubes are prepared and labelled as a 10% solution of manure (nitrates and phosphates) and finally three other tubes as a 20% solution of manure (nitrates and phosphates). Next, we will add 10 drops of the culture of the microalgae *Chlorella sp*. Each tube is stirred to be mixed equally. The tubes are left for five days in a well-lit place and we will observe every day the changes brought about. In addition, it is possible to add the light availability as a variant.

SCHOOL RESEARCHERS ON COCKLE AND GLOBAL CHANGE

Object of the School Research and Biology of the Species

The training of the students in the fields, described in this article, was applied in a school ecological study destined to initiate a series of data of densities of *Cerastoderma edule* in the shellfish bank of Testal in Noia (Galicia-Spain). The investigation was proposed as the beginning of a series which will be repeated over the next few years, at the same moment, before the beginning of the closed season, in the last week of shellfishing, just before the beginning of the recruitment or passage from a larva swimmer to a cockle which will take place in the sediment.

Cerastoderma edule is a bivalve mollusk with a rapid growth, short life and a high reproductive capacity which forms very dense populations in estuaries and sea inlets because it withstands quite wide ranges of temperature (3-20 °C) and salinity (10-36).

This bivalve needs to live in areas visibly affected by tides and this is why it appears in the Baltic Sea and the Mediterranean Sea. It is distributed throughout the entire European Atlantic coast. It is buried in the first four centimeters of sludge-sandy and sandy sediments, preferably at the lower levels of the intertidal although it can appear from the infralitoral areas to the upper intertidal.

It is a filter bivalve which feeds mainly on phytoplankton and resuspended microphytobenthos. The seawater enters by the inhaling siphon and is retained by the cilia of the gills.

In the Galician estuaries it reproduces from March to July-August and the first recruits of the year can already appear in the sediment of the shellfish grounds at the end of March, although in the shellfish ground of study they are not usually placed in the sediment until the beginning of April. That is why the shellfish season extends until the end of March, when the study was carried out.

Fertilization takes place in the water column; the embryonic development lasts 48 hours at the end of which it hatches a trochophore larva swimmer. Over the following 48 hours, a veliger larvae, which already has a bivalve shell, is developed. After 2-4 weeks of pelagic development, when the larvae reach 250-350 µm, they head towards the sediment and at this point, the recruitment occurs. After fixation and metamorphosis it becomes a juvenile.

It is called recruitment as the result of subtracting the settling and metamorphosing larvae and early post-settling mortality. After fixation and metamorphosis, it becomes a juvenile. Smaller recruits tend to look over the middle mesolitoral, and as they grow, they descend towards the low mesolitoral

Methodology of the School Scientific Research

Formulation of the hypothesis

To situate the students in the context of collaboration with scientific communities, they were made partakers of a hypothesis, which intentionally was selected as false, to motivate the students' reasoning in the search for conclusions. This decision was therefore made to compel them that, given the evidence of falsehood of the hypothesis, they had to face with the need to formulate a new hypothesis, with the consequent consequences on the design of the research.

The hypothesis that it was departed was that in the banks shellfish the cockles are distributed evenly regardless of the level of the tide and the size of the animal.

To verify the hypothesis, it was necessary to study the spatial variability in the recruitment and the structure of sizes of the cockle between tidal levels in an intertidal shellfish bank. This is why the transect sampling methodology used in Ecology was applied, which allows the same volume of samples to be obtained at regular distances (**Figure 7**).

Figure 7. Photography of the shellfish bank were the investigation took place

Figure 8. Location of the two itineraries in the intertidal or litoral

Sampling design

Two metric tapes were extended parallel to the coastline, one in the lower mesolitoral (once it came down from the tide) and another in the middle mesolitoral (when the tide was still dropping). In each transect, each 25m, we will mark with a wooden stake a sampling point (20 for each transect = 500 m of transect). The starting coordinates of each of the transects were taken (**Figure 8**).

Figure 9. Foreground with students marking a sampling square at the sampling point assigned to it

Figure 10. A team of 3 students extracting the volume of sand (25 cm x 25 cm x 25 cm) from a sampling point

At each sampling point, an area of 25×25 cm is marked. With the help of a shovel, sand was collected to a depth of 5 cm and was placed in plastic buckets conveniently labeled with pencil in tracing paper labels as it was a raining day.

Taking sieves to sieve with water

Once the volume of sand (25 cm x 25 cm x 25 cm) was collected (**Figure 10**), it was put into a bucket.

Each bucket was moved to the seashore where their content was sieved through a series of different opening meshes, with the help of seawater in order to eliminate the sediments. After this, every shells were removed so that only alive mollusks were left (**Figure 11**).

Figure 11. A team sieving the volume of 25 cm x 25 cm x 25 cm from a sampling point

Figure 12. (a) A team measuring and writing the obtained data. **(b)** It is represented with an L the only length used for this investigation

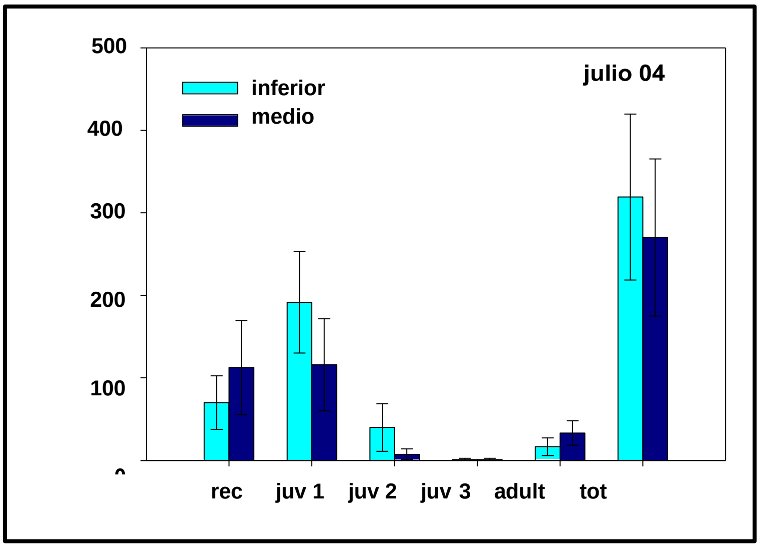
Table 1. Table which was used to write down the data and the results

Transect	Point Nº	
	1 or 2,	**Spats:** equal or less than 4 mm: Nº
Medium or	… or 20	**Juveniles group 1**: from 5 to 10 mm Nº
Low		**Juveniles group 2:** from 11 to 16 mm: Nº
		Juveniles group 3: from 17 to 20 mm: Nº
		Adults: larger than 20 mm: Nº

Once sieved, individuals were deposited in trays with their label to be measured with a gauge, writing the obtained data (**Figure 12(a)**). For this study we used just the maximum length represented in the **Figure 12(b)** with an L. These data were written own in a record sheet with a pencil, never with a bullpen.

Data analysis

Each group left the beach with two data tables (**Table 1**), one for each sampling, so that the table identifies whether the data corresponds to the middle or lower intertidal (first column). It is necessary to indicate the number of the sampling point that corresponded to the group in that transect (second column). The third column contains five rows. Each row shows, by descending order size, the different sizes classes, to indicate the number of individuals in each of the classes that appeared in the sampling point whose data is collected in that table.



Graph 1. Graphical model chosen to express the results extracted from the data analysis

Table 2. Table of results with the absolute frequencies in the 5 kinds of sizes in the infralittoral (blue in Graph 2) and in the low mesolitoral (red in Graph 2)

Transect	Spats	Juveniles 1	Juveniles 2	Juveniles 3	Adults
INFRALITORAL	0	0	60	289	237
LOW MESOLITORAL	2	6	64	277	402

After completing the table, the students moved to a computer room at the secondary school IES Virxe do Mar, which was the coordinating school of this scientific-school research.

In order to obtain the results an Excel table was designed with the collaborative tools of the project. Each group incorporated its data from the five categories for each of its two sampling points in the two transects.

This collaborative Excel was designed to integrate all the data in each category and in each transect. Once the edition of the graph was activated, a graph was built following the methodology of the Ecocoast project, from the Coastal Research Group of the Department of Ecology of the University of Vigo, who was lent to direct the transfer of its scientific methodology to this pedagogical project.

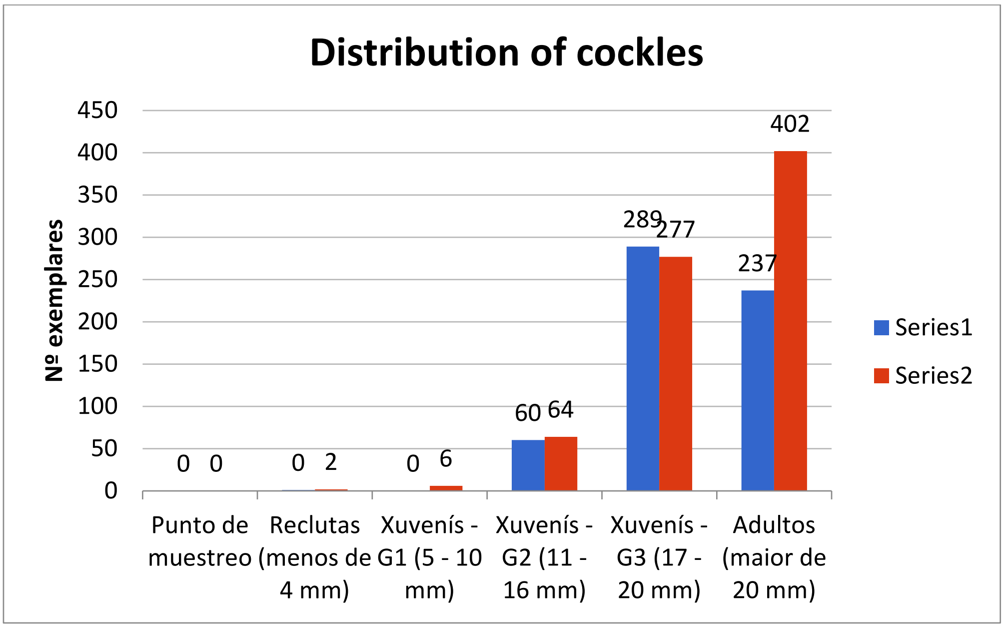
With data from the excel file we represented the results in the simplest graphic display which this group uses to express their data. This representation was selected because it is the simplest one which can be used in the scientific methodology. In **Graph 1** it is possible to visualize the model that is followed for the graphic expression of the results, which allows to show the abundance of the different size classes in the two levels of tide.

Results

Once each group loaded the data into the collaborative Excel, the global data expressed in **Table 2** were obtained.

Graph 2 shows the results from **Table 2** to facilitate the development of the reflections and discussions which lead to the conclusions of this school research.

In the infralittoral there is not any spats while in the low mesolitoral there are some spats, but in absolute frequencies. Thus, the smallest individuals are not present in the infralittoral and they are present, with low significance, in the low mesolitoral.



Graph 2. Representation of the frequency of each age class in the infralitorial (blue) and in the low mesolitoral (red)

The graphical representation of the results shows that there are only significant frequencies of the three classes of higher sizes.

In the three classes with significant presences there are only significant differences between the two transects in the group of adults (bigger than 20 mm). There are only significant differences between the two transects in the adult class, which are more abundant in the low mesolitoral. In the infralittoral there were 237 adult individuals and the low mesolitoral there were 402 individuals.

In relative percentage terms, the frequencies of the two upper classes of juveniles practically have no differences between the low mesolitoral and the infralittoral. However, in adults, from the total which appeared in the two samplings, 63% were found in the low mesolitoral and 37% in the infralittoral, being the size very similar (in the order of 20 mm) and smaller in relation to the cockle that is usually commercialized.

Discussion

The discussion was organized in a colloquium with the participants, in which the summary video of the activity was projected and a colloquium was developed with the graph from the conclusion of the video. In that colloquium, the cockle's behavior when the larvae ceased to be swimmers was exposed.

Among the main aspects of the biology of the species that were exposed in the discussion, it is remarkable that the recruitment is produced in the upper part of the littoral, above the average low mesolitoral. As individuals increase in size, they move towards the lower part of the coast, being, when they become adults, able to incorporate towards the part which is permanently covered, where the individuals of larger size are located.

It was also mentioned that recruitment is not usually produced until the beginning of April, which is why the shellfish campaign is suspended at the end of March. This study was held on the last day of the shellfish campaign of that year, on 27 September 2017.

At the time of the year in which the study was conducted, the cockle larvae are still in the water column. However as shown in the data of table 2 and represented in **Graph 1**, in the low mesolitoral there are some spats and juveniles. That is the area that corresponds to recruitment, which could indicate a recruitment of premature individuals. This is why this aspect was identified as strategic to continue in samplings of successive years, in case it was an aspect to take into account in the adaptation of the periods of prohibitions to climate change.

The appearance of larger cockles in remarkable superior frequencies has to do with that they are cockles which have been recruited the previous year. The maximum frequency of adults has been related to the fact that this is the normal size, or the most frequent one, for the one-year cockles, which were recruited at the end of the previous year's campaign.

The most discussed aspect was that the adult cockles are more frequent in the low mesolitoral than in the infralittoral, while cockles use to descend towards the low mesolitoral as they grow. There were students who related this with the position that corresponded to the most frequent size of a one year cockle, and that when they were larger, they would descend to the lower mesolitoral. The interest of scoring adult sizes in the next sampling was indicated.

The other explanation which aroused, on the grounds that when they were sampling in the low mesolitoral they met shellfish catchers, and they were working in the upper limit of the water. Based on this observation, it was thought about the possibility that when looking for the cockles at low tide, in the sand covered with water, there could be a bigger extraction of adults in the infralittoral, which could justify that, as seen in table 2 and in the graph, adults in this area of contact with water at low tide, are 37%, standing 63% the low mesolitoral ones. In the discussion of this comparison, it was proposed the interest to make samples before and after the shellfish collection period.

The results showed that the hypothesis given to the students was incorrect. The design opted for a hypothesis that motivated and gave meaning to the work, but it was interesting because it was necessary a reformulation that facilitates the obtaining of the conclusions. That was done in this discussion, and the reformulation process was the basis for the statement of the paragraph of the conclusions.

CONCLUSIONS AND PEDAGOGICAL IMPLICATIONS

Conclusions Drawn from the Discussion on Scientific-School Research

It is necessary to reformulate the hypothesis that was proved not being true because the position in relation with the tide and the size have influence.

It is convenient a new sampling prior to the start of the shellfishing season in order to verify if the difference in density between the medium and lower mesolitoral environment is due to shellfishing or is related with a distribution pattern characteristic of the biology of species.

Pre or post shellfishing season samplings should be done every year to track the effects of climate change such as parasite *Martelia cochillia* which invades banks as the water temperature rises.

It should be studied whether recruitment is anticipated by climate change when some individual appears in the lower mesolitoral which may be indicative of this advancement. These scientific-school series can demonstrate this type of needs of regulating the cycle to give answers to global change: recruitment anticipation, times of increased red tides…

Another aspect that can demonstrate this type of series obtained from the collaboration between science and school is the need to regulate the shellfish collection to ensure that individuals of greater size are captured, avoiding the shellfish of adult individuals of a smaller size than recommended for a resource that is being diminished by global change.

Conclusions and Pedagogical Implications

This experience showed that school communities can be strategic to generate scientific data series, which are urgently needed to know the impacts of global change. This is why this experience suggests that this type of scholar scientific research can establish synergies between science and school, in such a way that they strengthen each other, and at the same time they give joint, synergistic and coordinated responses to global change.

Educational responses to global change require students to study the impacts on aspects that are very relevant to these educational communities. In the case of this curricular experience the students reflected and debated the possible impacts of global change, proposing possible measures to defend the main resource of Noia, which contributes to this town, each year, millions of euros.

The training that the students followed in this proposal requires a scientific formation, based on experiences that allow the reflection on the scientific concepts and procedures that are demanded. Its application, by means of an investigation in the shellfish bank, offers a scholar research of scientific value and significantly increases the educational quality of these students.

The media impact of this experience, which involved the professional association that manages the course, gave an opportunity to disseminate to society the relevance of the study, which is very useful to sensitize citizens to the urgency of the challenge. In addition, this diffusion brought to the initiative an evidence of educational innovation.

Disclosure statement

No potential conflict of interest was reported by the authors.

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