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DESENVOLVIMENTO SUSTENTÁVEL DO OCEANO: UMA UTOPIA ÚTIL

SUSTAINABLE DEVELOPMENT OF THE OCEAN: A NECESSITY

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Deep Sea - From Unknown to Intended - Deep Sea Observatories, a Tool to Monitor Human Activities

Ana Colaço & Marina Carreiro-Silva[1]

Abstract:
The deep-sea environment is the largest ecosystem on earth and poorly study. The lack of affordable technology and the immense size of this ecosystem, with all its different environments and habitats, such as the pelagic realm, the benthos with abyssal planes, ridges, vents, seamounts, cold seeps, sponge aggregations, cold-water corals gardens and reefs, to name just a few, contribute to the lack of knowledge.
With the increase technological development, and with the overexploitation of land and shallow water resources, humanity is migrating deeper in the sea, by extracting oil and gas, fishing on deeper grounds, extracting minerals from the continental slopes and discussing the possibility to mine seafloor massive sulphides (SMS), nodules and cobalt crusts.
In order to understand human impacts on deep-sea ecosystems and to propose strategies to mitigate these impacts, we need to comprehend the nature of the environment. Time series are crucial, for the continuous measurement of the environmental characteristics of the deep. However, studying the deep-sea is expensive. There is the need of oceanographic vessels, underwater vehicles and sensors that cannot be continuously at sea.
To bridge this gap, the scientific community has been working together with engineers to develop continuous observation systems that will allow to have time series, and to understand the natural fluctuations of the environment. Fixed-point observatories exist in several key places around the globe. They can be cabled, tethered or autonomous, measuring continuously or at a high frequency, and sending the data to shore, to warn about potential tsunamis, seismic crises at the bottom of the ocean, or even an increase in the deep-water turbidity.

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Portugal has been involved in this effort, through the participation and usage of a fixed-point observatory installed as part of the EMSO network, Like the EMSO-Azores in the Lucky Strike hydrothermal vent(maintained by EMSO-France) , and raising funds to install other nodes at the Gulf of Cadiz and on the Condor seamount (Azores). Observatories are used to detect climate change, monitor mining and contribute to Global Ocean Observation System.

Keywords: Deep-sea; observatories; impacts

1. The deep-sea:

The deep-sea is the largest ecosystem on earth, with more than 90% of the ocean being deep-sea. More than 50 % has depths greater than 3000 meters, and only 5% is explored (Ramirez-Llodra et al 2010).

Until recently, the deep-sea has been seen as a stable cold dark environment, with low productivity, highly diverse and biomass poor. It was believed that the immense water volume that forms the deep-sea, was a huge diluted environment that no pollutants, no warming or acidification could affect (Colaço et al, 2017).

However, in the last decades, with technology improvements, new and diverse habitats were discovered (Ramirez-llodra et al, 2010), some of them with the highest productivity on earth, like the chemosynthetic environments (Levin et al, 2016).

The deep-sea environment lays below 200 meters, where the energy from the sun cannot feed photosynthesis. In general, the life beneath those depths depends on the energy produce in the surface waters and that enters the deep-ocean by sinking, biogeochemical cycles or through trophic webs (figure 1).

The immense deep-sea is mainly pelagic, with an immense water volume, however being the least known (Sutton et al, 2017). This vast pelagic habitat contains the mesopelagic (200–1000m depth) and bathypelagic (water column > 1000m depth) zones with imprecision on the transition depths zones, due to connectivity processes at large spatial and temporal scales (Sutton 2013). Taken as a whole, the bathypelagic biome is by far the planet's largest biome; 79% of the volume occupied by life on earth lies at depths >1000 m (Sutton, 2013).

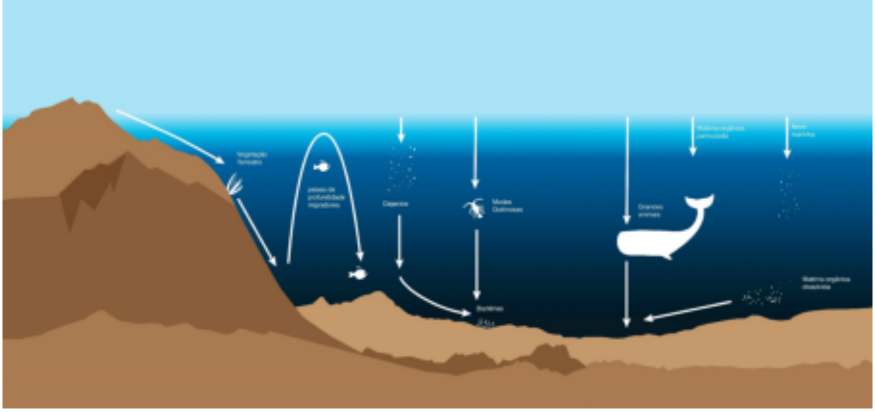

Figure 1. The deep-sea environment lays below 200 meters. The life beneath those depths depends on the energy produce in the surface waters and that enters the deep-ocean by sinking, biogeochemical cycles or through trophic webs. ©Pedro Mesquita.

This pelagic ecosystem provide supporting ecosystem services, such as carbon and nutrient cycling, and trophic exchange, which are still poorly understood (Colaço et al, 2013; St. John et al, 2016). When reaching the seafloor, the knowledge we have on several features and the associated communities increases. There are several biodiversity hotspots like the seamounts with cold-water corals reefs and gardens, sponge aggregations, canyons, and high productive environments such as the hydrothermal vents and cold seeps.

Seamounts are hotspots of species richness (Morato et al., 2010). Their high productivity can support high densities and biomass of benthic suspension and filter feeders, such as corals and sponges, together with demersal fish populations (Porteiro et al, 2013; Fock et al, 2002; Shcherbachev et al, 1985). Many seamount taxa are long-lived and slow-growing, like many cold-water coral species than can attain ages of centuries to millennia (Carreiro-Silva, et al 2013). Habitats formed by these benthic fauna are ecological complex, structured and can harbour a more diverse and abundant biological diversity than the sedimentary environment (e.g. Porteiro et al, 2013; Buhl-Mortensen et al, 2010; Gomes-Pereira et al, 2017). CWC and sponges are what we call bioengineering species, because when the environmental conditions are favourable, they form dense 3Dimensional structures. These special environments provide significant habitat for invertebrate species (Henry and Roberts, 2007), and fishes (Pham et al 2015; Gomes-Pereira et al, 2017) and may have nursery and recruitment functions (Baillon et al, 2012).

Deep-sea sediments cover around 65% of the world's surface. Sedimentary environments alike the margins and abyssal plains are low in fauna biomass, but high in biodiversity. The microbial biomass is very large, and the microbial processes that occur inside the sediments play an extremely important functional role on nutrient recycling, promoting the biogeochemical cycles that are essential to sustain primary and secondary production in the oceans (Danovaro et al 2007).

Chemosynthetic environments, like hydrothermal vents and cold seeps, were just discovered in late 70's. However, due to their uniqueness, they have been the focus of several studies, most of them multidisciplinary, since the energy source that fuels the primary productivity in loco is geothermic (a few exceptions on cold seeps). This chemosynthetic production provides nutrition to a high biomass, either as symbiotrophic species, or to benthic or planktonic heterotrophic species. Although these ecosystems were thought to be isolated oases for a long time, they are now acknowledged to interact with the water column and seafloor, exchanging elements and energy with the surrounding deep-sea environments.

Today it is commonly accepted that the deep sea plays a key role in ecological and biogeochemical processes at a global scale (Danovaro et al 2017).

However despite its remoteness and importance, several habitats are already affected by the men (Ramirez et al, 2011) (figure 2).

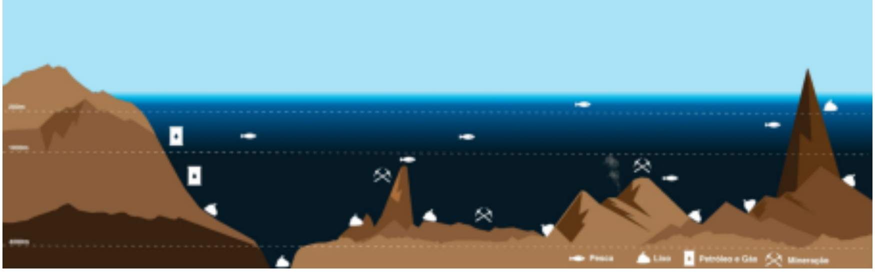

Figure 2. Humans impact on the deep-sea. ©Pedro Mesquita. Adapted from Levin & LeBris, 2105

2. The impacts and understanding the changes

In order to understand the array of processes that occur in the deep-sea, it is essential to have long-term time series studies. The processes can vary at different time scales (daily, seasonal, inter-annual, decadal or even at centennial or millennial scale). Long term time series are even more important in the deep-sea, as we know that most of the species are long-lived and slow growing. For instance, black corals can attain more than 2000 years (Carreiro-Silva et al, 2013), the orange rough maximum age has been estimated at 149 years (Fenton *et al*.1991) with a high age of first maturity (>30 years) (Bell *et al*. 1992). Several deep-sea patterns and processes are unknown. Also the responses of the biological communities to anthropogenic stressors and climatic shifts lack basic knowledge. That knowledge is essential to identify which biogeochemical or other environmental parametres can be good proxies of changes in the deep-ocean.

With the increase technological development, and with the over-exploration of land and shallow water resources, mankind has migrated their activities to deeper sea areas, by extracting oil and gas, fishing on deeper grounds, extracting minerals from the continental slopes and discussing the possibility explore the high seas to mine seafloor massive sulphides (SMS), nodules and cobalt crusts.

Fisheries

Morato et al (2006) showed that global landings of demersal marine fishes have shifted to deeper water species over the last 50 years. They suggested that depletion might be occurring in deep-water fish stocks. This is particularly serious, since their life histories render them highly vulnerable to overfishing with little resilience to over-exploitation. Deep-sea fisheries impacts are even more severe, when the fish operations contact the seabed and cause severe environmental impacts, by killing, smothering or damaging benthic animals like the CWC, sponges, which due to their life history traits are considered vulnerable marine species or ecosystems (Clark et al, 2016).

Oil and gas

Due to the decrease of oil reserves in shallow ocean margins, there is an increase in the exploration and exploitation activities for oil and gas extraction in deep waters. However, there is a huge gap on the baseline environmental data, which makes the management of such activities challenging from the environmental point of view (Cordez et al, 2016), despite the existence of several regulatory regimes under different jurisdictions (Mazor et al, 2014; Katsanevakis et al, 2015). The activity has several impacts (see revision from Cordes and co-authors 2016), from the infrastructure installation, to the daily operations water discharges and potential accidents, to the end of operations. The impacts might be persistent or not, and the severity depend on the environment and species resilience. For vulnerable species the impact might be longer or irreversible.

Mining

Until the humankind is able to recycle and have a circular economy, the need for metals for day-to-day equipment will keep rising. The seafloor hosts potential mineral resources for these needs in the form of polymetallic manganese's nodules (nodules), polymetallic sulphides (SMS) and ferro-manganese and cobalt crusts (crusts). The different resources lay on different environmental settings, each one with different characteristics (nodules on abyssal plains; SMS on active and inactive hydrothermal vent fields; cobalt crusts on the summit or slopes of seamounts at a certain depth range). All of them vulnerable to extraction activities (Van Dover et al, 2017). The vulnerability to impacts includes direct impacts on the species and on the life history of organisms, like the habitat destruction, creating barriers to connectivity and recruitment. The impacts can be more severe due to the fact that: in the case of the nodules the activity can be very extensive (in surface); the case of SMS, the environments are unique ; in the case of crusts, the habitat hosts vulnerable marine species that support other extraction activities (CWC and fisheries). The extent of impact is not known. The impact can not be extrapolated from one area to another (destruction of habitat and species). The indirect impact of the plumes, noisy and metals are yet to be determine. Thresholds can only be determined if we understand the natural variations of the environment, and be able to assess the baseline values of physical, biogeochemical and environmental parameters (Miller et al, 2018).

While densities and diversities of some taxa can recover to or even exceed pre-disturbance levels, community composition remains affected after decades. The loss of hard substrata or alteration of substrata composition may cause substantial community shifts that persist over geological timescales at mined sites (Golnner et al, 2017).

Climate change

The deep-sea plays a key role in regulating Earth's climate by absorbing excess heat and carbon dioxide from the atmosphere. Through this process the deep ocean is becoming warmer, more acidic, less oxygenated and with altered food inputs with potential impacts on deep-sea ecosystems (Levin and Le Bris 2015). Recent studies suggest the Atlantic Ocean is already facing changes in seawater chemistry and is predicted to be one of the most impacted oceans in the future (Mora et al 2013; Sweetman et al 2017). Projections for 2100 suggest temperature (T) increases between 1-4ºC, a decrease in pH of up to 0.4 pH units, declines in oxygen concentrations up to 3.7%, and 40% loss of the food supply to the ocean seafloor (Mora et al 2013; Sweetman et al 2017). Such changes can significantly affect deep-sea organism physiology, life history traits (e.g. growth and reproduction) and recruitment, with concomitant changes in biodiversity and provisioning of living resources by deep-sea ecosystems (Levin and Le Bris 2015).

Climate change will likely reduce the resilience of species and ecosystems to anthropogenic stressors, and slow rates of recovery (Sweetman et al 2017). For example, slowed CWC growth under ocean acidification will reduce recovery of habitats from fishing disturbance, and delayed larvae development under hypoxic conditions and nutritional stress with low food could impact communities recovering from mining impacts, which will further compromise ecosystem structure and function in the deep sea.

3. The observatories

To understand the human impacts and mitigate them, we need to understand the environment, how it changes naturally, to identify how human action is affecting the normal function of the system. It is crucial to be able to have time series, and ideally continuous measurement of the environmental characteristics of the deep (figure 3).

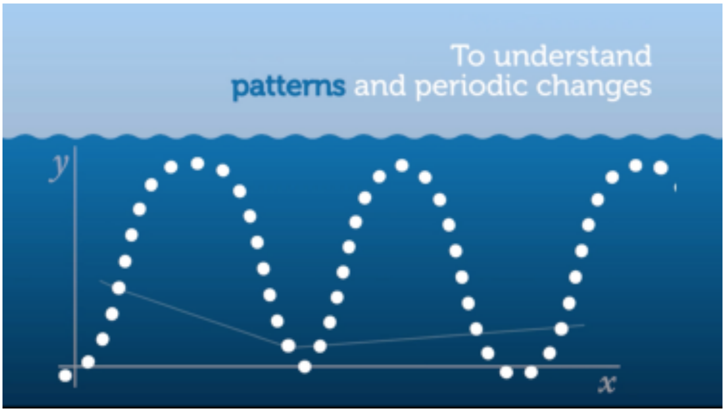

Figure 3. Time-series and continuous measurements are needed to understand the natural patterns. Snapshot can give a distorted pattern of reality. ©Aurora Ribeiro @http://www.fixo3.eu/

Studying the deep-sea requires oceanographic vessels, underwater vehicles and sensors that cannot be continuously at sea, which is not a trivial task. The instruments are expensive, ships are scarce and expensive and cannot be permanently on one spot, and vehicles just now are starting to go deep and increasing the temporal and spatial coverage.

Data collected with oceanographic vessels generally correspond to a constrained time interval, giving only a snapshot of the reality. Often the trends observed are just the effect of the lack of continuous monitoring, and not the result of natural fluctuations. Moreover, due to operational constrains, most of the data are collected during the spring and summer seasons when the weather is better, with cold seasons being undersampled.

Moorings have been used as a means to collect time series data from a specific location, and although being a delayed mode of observing the environment, they have shown the importance of temporal variations and time series (Glover et al, 2010). With technological improvements, multidisciplinary moorings and platforms were developed and left at sea for long periods of time. Nevertheless, the energetic constrains do not allow for frequent measurements and sensor synchronization (the same time stamp). Due to this fact sampling frequencies of can not be homogenized (Matabos et al, 2016).

The deep-sea is a very complex system that faces different types of disturbances, from regular cycles to chaotic behaviour that might vary from days to geological time. How those phenomena are linked is not well understood. Scientists are missing key elements of a multidisciplinary understanding of marine ecosystem functioning, including species and community level responses to environmental change (Matabos et al, 2016).

In 2000, the United States National Research Council established the definition of a seafloor observatory : "… unmanned system, at a fixed site, of instruments, sensors, and a command module connected to land either acoustically or via a seafloor junction box to a surface buoy or a fibre-optic cable …" (NRC 2000).

From more than 20 years, the scientific community has been working together with engineers to develop continuous observation systems that will allow to have time series, and to understand the natural fluctuations of the system. Fixed point observatories were created in several key places around the globe. They can be cabled, tethered or autonomous, measuring continuously or at a high frequency, and sending the data to shore, to warn about potential tsunamis, seismic crises at the bottom of the ocean, or even an increase in the deep-water turbidity.

Seafloor observatories do not replace seagoing investigations. Not all variables of interest to scientists can be measured with sensors, specially, because there are no metrics developed for most of the biological and ecological sciences (biodiversity changes; ecosystem function and services changes). Observatories give access to complementary information at temporal scales not previously available (Matabos et al, 2016) (figure 4).

With the improvement of communications, in some parts of the globe, the observatories are fed energetically and use real time data acquisition throughout fiber optical cables. This advance has given an

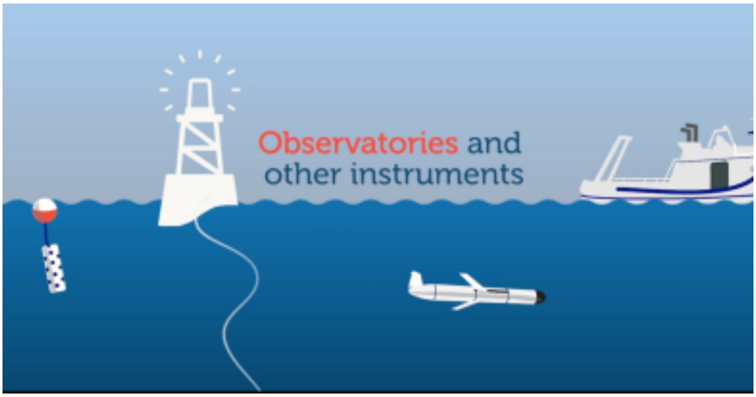

Figure 4. Seafloor observatories are complement of seagoing investigations. ©Aurora Ribeiro @http://www.fixo3.eu/

all-new way of promoting science, with millions of gigabytes of data that need to be ground-truth, quality control and analysed.

However, the story does not end here. In order to understand the changes globally, there is the need to develop best practices, homogenize the acquisition, the instrument errors, and develop the algorithms that can upgrade the new data on charts, and maps, geo-referencing on time. Also the operational costs and the price of equipment and sensors needs to be reduced so that they are accessible to all countries, including the underdeveloped ones, as well as make them operational from smaller and less "high tech" vessels.

There is the need of coexistence in land, in the sea, and on science.

There are several initiatives that develop deep-sea observatories. In Canada, the *Ocean Networks Canada Observatory* (ONC) created by the University of Victoria (Canada), oversees the management, development and operation of the VENUS and NEPTUNE Canada cabled networks. At the ONC observatory, ocean research and technology development is enhanced through a cabled infrastructure that supplies continuous power and internet connectivity to a large set of instrumentations and experiments, from geophysical to biological behaviour studies (Tunnicliffe et al. 2008; Best et al. 2012; Matabos et al 2016). In the USA, the *Ocean Observatories Initiative* is a project funded by the National Science Foundation that promotes the installation of a network of ocean observatories that will continuous measure near real-time chemical, geological, biological, and physical oceanographic data on coastal, regional, and global scales.

In Europe the EMSO network (formerly ESONET) is a co-ordinated chain of deep-sea observatories around Europe from the Arctic Ocean to the Black Sea (Best et al, 2014; Pearson, et al, 2015). ESONET was funded to integrate researchers for a marine component of GMES (Global Monitoring for Environment and Security), the GOOS (Global Ocean Observing System), comprising a network of long-term, multidisciplinary seafloor observatories at key locations around the European margin for long-term monitoring advancement in geophysics, chemistry, biology, oceanography, geochemistry and fisheries. The observatories can contribute by measuring essential ocean variables, agreed by the ocean observing community.

With the development of seafloor observatories, scientists are offered unique opportunities to study multiple, interrelated processes over different timescales (seconds to years) to conduct comparative studies of regional processes (Juniper et al., 2007).

4. Portugal and the deep-sea observatories

Portugal has been involved in the creation of deep-sea observatories, through the participation and usage of the fixed-point observatory EMSO network, and raising funds to install other nodes at the Gulf of Cadiz and on the Condor seamount (Azores).

Portugal, hosts in the Azores region two fixed-point observatories. The EMSO Azores (at the Lucky Strike hydrothermal vent field), installed and maintained since 2010 by EMSO France and the Condor Seamount observatory. Portugal's involvement in the EMSO Azores observatory includes participation on seismic surveys with standalone OBS, colonization experiments to understand connectivity patterns among different hydrothermal vent fields, and monitoring the communities physiological condition as a proxy of changes in the environment. The Condor Seamount integrated multidisciplinary scientific observatory, implemented in 2009 with funding from an EEA grant, promotes an integrated ecosystem approach for studying seamounts. It is not yet connected to shore (it will be in the near future), but it has been recording data on … in a semi- continuous long time series point. It will be expanded during the EMSO-PT infrastructure implementation phase, with, among other instruments, sediment traps, optical or acoustic plankton counter and ADCP's. The relevance of the Condor seamount infrastructure for the scientific and stakeholder community has granted a protection regime from commercial fisheries at least until 2020, but it was also designated as a Marine Protected Area as part of the Azores Marine Park.

As part of the EMSO network, the recent developed platform of multisensors (EGIM) that measures temperature, conductivity, pressure, dissolved oxygen, turbidity, ocean currents, and passive acoustics (just some frequencies) needs to be deployed in all of the nodes of this network in order to make the same measurements and at the same frequency. The EGIM prototype is now at the Lucky Strike observatory, but it is foreseen to acquire an improved EGIM with new sensors (related to climate change, nutrients, and imagery) to be deployed at Condor seamount, in a area with important biological communities between 900 and 1200 meters, to study benthopelagic coupling processes and climate change alterations.

The observatory will include several Essential Ocean Variable (EOV) measurements, including in a first phase physical variables (temperature, salinity, velocity /ocean currents), and in a later phase the carbon and biogeochemistry variables (dissolved oxygen, dissolved organic carbon, POM), which are still in the concept phase but could be tested in this observatory. In what regards biological and ecological EOVs, despite primary productivity beinga a mature EOV (as a proxy of available POM in the bottom), it is a challenge to identify other EOV's to measure change on a hard substrate environment, for deep-sea environments. Another key challenge, is the lack of mature EOV's targeting the benthic–pelagic coupling, manifested as the exchange of energy, mass, or nutrients between benthic and pelagic habitats. Benthic-pelagic coupling plays a prominent role in aquatic ecosystems, and it is crucial to functions from nutrient cycling to energy transfer in food webs. Sustained regional observations are necessary to characterize the spatial, seasonal and inter-annual variability in bathypelagic flux characteristics of a given site. Remineralization of POM as it sinks through the water column modifies both the concentration and composition of carbon in sinking particles. Oceanographic mooring with sediment traps at different water depths (from bathyal to the abyssal), with optical sensors for *chl-a* fluorescence and, assessment of flux quantities and particle character including size- and type-distributions are needed. This experiment could be coupled with sensors to measure physical and climate EOV, which are scarse on depths greater than 2000 meters, contributing to understand the variations of Meridional Overturning Circulation at global change level.

Conclusion

Monitoring of deep seafloor condition is a current global priority. The society is in need of a network of in situ multidisciplinary observation systems around the world. They will improve our understanding of the impacts of climate change, anthropogenic activities, and geo-hazards (Ruhl et al, 2011), allowing early warning in case of geohazards, which , like weather forecasting, might prevent human losses.

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O desaparecimento do Professor Mário Ruivo, após décadas de dedicação às problemáticas do oceano, representou uma perda para toda a comunidade científica. A dimensão do seu prestígio internacional e da sua capacidade de intervenção criou, com o seu desaparecimento, um vazio difícil de colmatar.

O Centro de Investigação Marinha e Ambiental (CIMA), da Universidade do Algarve, entendeu dinamizar uma reflexão abrangendo os temas do oceano e contribuindo, dessa forma, para honrar a memória de Mário Ruivo. Para tal, o CIMA desafiou os centros de investigação das universidades portuguesas que incidem as suas pesquisas nestas problemáticas, e que reconheciam a figura de Mário Ruivo como o grande impulsionador da investigação científica na área das ciências do mar, para se associarem a esta iniciativa.

O resultado deste desafio pode agora ser apresentado. Um conjunto de textos que refletem o "estado da arte" da investigação em ciências do mar realizada pelos centros de investigação das universidades portuguesas. A anteceder essas contribuições, recolhem-se as diversas intervenções destinadas a evidenciar a personalidade de Mário Ruivo, proferidas na primeira sessão da Conferência Internacional que recuperou um dos seus criativos pensamentos: "Desenvolvimento Sustentável do Oceano: uma Utopia Útil".

The disappearance of Professor Mário Ruivo, after decades of dedication to the problems of the ocean, represented a loss for the entire scientific community. The size of its international prestige and its capacity to intervene has created a vacuum that is difficult to overcome.

The Center for Marine and Environmental Research (CIMA), of the University of the Algarve, aimed to stimulate a reflection covering the ocean themes and thus contribute to honor the memory of Mário Ruivo. To this end, the CIMA challenged the marine research centers of the Portuguese universities that focus their research on these issues, and recognized the figure of Mário Ruivo as the great promoter of scientific research in the field of marine sciences, to be associated with this initiative.

The result of this challenge can now be presented in this e-book. A set of texts that reflect the "state of the art" of marine sciences research carried out by the research centers of the Portuguese universities. Prior to these scientific contributions, there were various interventions designed to highlight the personality of Mário Ruivo, during the first session of this International Conference, where and one of his creative thoughts has been taken up: "Sustainable Development of the Ocean: a Necessity."

Com o Alto Patrocínio de Sua Excelência
O Presidente da República