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# The Inland Seas

## Towards an Ecohistory of the Mediterranean and the Black Sea

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# Mediterranean Scenarios

## 1. Human impact and ecosystem change

The planet's human population amounts to more than seven billion. Every species uses natural resources and the human species, due to our heterotrophic nature (we eat other living beings), relies on the availability of other species to satisfy our needs. This interaction might be reduced to a game with two players: us against the rest of nature.

The success of a species is measured by the number of its representatives. All species tend to increase in numbers. But the infinite growth of the population of any species is simply impossible, since our world is finite. It is a natural rule, furthermore, that if something increases, then something else decreases. The growth of our species (both in number of human beings and in economic capital) is balanced by the 'de-growth' of the rest of nature (the natural capital).

The growth of our species can continue until a breaking point is reached: when the rest of nature cannot sustain our number. This means that the resources to maintain our numbers will not be available any more (not to speak about the modification of the air we breathe). This will result in a reduction that may take place in three main ways: famine, disease or war. When our population pressure on the rest of nature decreases, nature has the possibility of restoring its features. The decrease in numbers of the overly successful species can continue to the point of total extinction as an outcome, or simply to a stabilizatuion at a level which is in greater harmony with the rest of nature.

The first symptom of human impact is habitat destruction. Agriculture requires habitat destruction. With agriculture, we eradicate all species and then concentrate our attention on one: the species that is useful to us. We use pesticides to prevent other species from taking the resources that we want to canalize to the target species. On land, we do not draw resources from natural populations: all the biological products we use derive from agriculture. This means that we have altered natural systems so much that they cannot of themselves provide products anymore, simply because they have been destroyed. In the sea, we still draw resources from natural populations (fisheries) but we are shifting to aquaculture because the natural populations have been overexploited.

Having destroyed terrestrial systems, we are now in the process of destroying marine ones as well. In doing so, we eradicate the diversity of life and replace it with just a few species. Natural systems cannot function just with the species that we cultivate. Our rush towards growth is natural, but it is also natural that this growth is terminated by the lack of sustainability: infinite growth is impossible in a finite world. The condition of marine systems is measured by the possibility of continuing to exploit natural marine populations.

Fisheries are the measure of the well-being of the sea. The growth of aquaculture is an alarm, a warning about the overexploitation of the marine ecosystem.[1]

## 2. The ecosystem approach

Ecology, for a very long time, tried to deal with Nature as if humans either did not exist, or were intruders into natural systems. Studies either searched for 'pristine' conditions, in undisturbed habitats, or focused on our impact on 'natural ecosystems'. In both cases, ecologists perceived humans as aliens in natural ecosystems. The ecosystem approach calls for including humans as natural components of ecosystems. This has profound ecological implications that change our perspectives on the way we interact with the rest of the environment. Everything humans do is 'natural' since we are a product of organic evolution, but this may lead to the belief that, then, there can be nothing wrong in what we do. This reinforces the conviction that the changes we are witnessing are part of natural variability and not due to our action. Speaking against a belief held in the majority of the world's institutions, ecologists have for a very long time been almost alone in underlining our responsibilities for the state of the planet.

## 3. 2015

The year 2015 signalled a historical shift. For the first time, two important institutions converged with the ecologists in delivering a clear message: we are abusing nature and must change our approach if we want to survive.

First, Pope Francis published *Laudato Sì*,[2] an Encyclical dedicated to the environment and to the care we must dedicate to it. Then the leaders of 198 countries, assmbled at the 21st Conference of the Parties (COP21) held in Paris in 2015, agreed that humans, as a collective entity, must reduce their impact on the planet, since in an increasing number of cases, the conditions for our survival are not being met – first of all in terms of availability of breathable air. We must change the way we interact with the environment, most importantly by reducing the use of fossil fuels, so as to reverse the tendency towards global warming due to an excess of carbon dioxide in the atmosphere.

Probably, however, this novel awareness of the importance of ecological issues will not be enough. The economic sector does not really care much about the environment and will probably resist a change that all other sectors are now acknowledging as no longer delayable.

## 4. The Mediterranean proxy

The ocean masses play a crucial role in determining the conditions that are conducive to our well-being, in terms of climate and of resource availability. It is, therefore, extremely important to understand our impact on marine ecosystems and to try to protect it from our misbehaviour.

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[1] The present contribution expands on Boero 2015, developing approaches that are not only ecological, and that pertain also to the social and economic sciences, proposing possible outcomes of the impact of our activities on the structure and functioning of marine ecosystems.

[2] Bergoglio 2015.

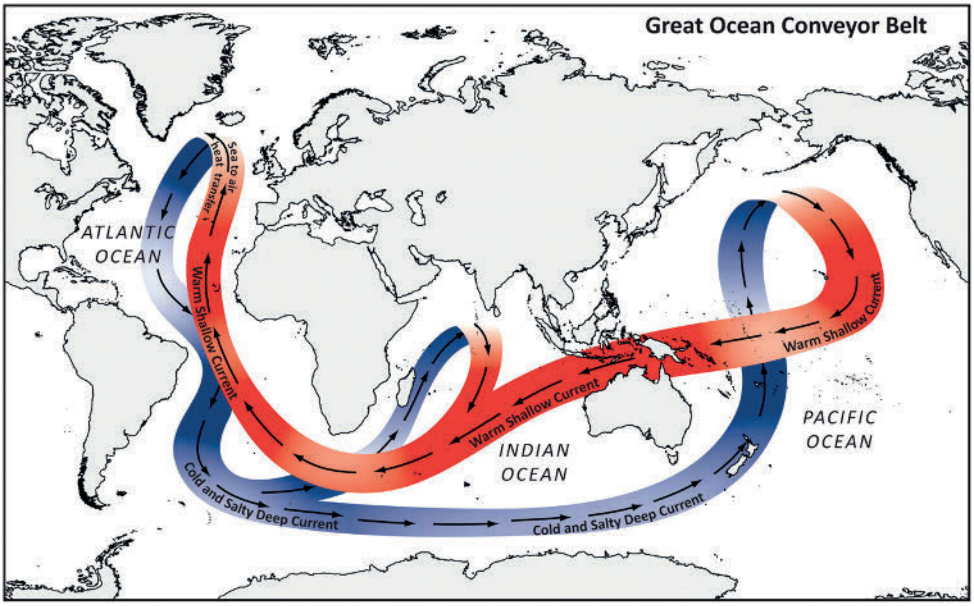


Fig. 13.1: The Oceanic Conveyor Belt. (After Tillinger 2011).

Bianchi and Morri (2000), Lejeusne et al. (2010) and Coll et al. (2010) have suggested that on the basis of its oceanographic and biogeographic features, the Mediterranean Sea can be considered as an ocean *en miniature*: what is happening in the Mediterranean Sea provides a hint about what will happen in the rest of the world oceans in the future. The Mediterranean Sea, thus, is a test case for detecting impact and attempting remedies with management options. There are no other seas that might be used for this purpose: the Mediterranean offers a unique opportunity for ecological insight!

The resemblance between the oceanic water circulation and that in the Mediterranean is impressive. The Great Ocean Conveyor Belt is driven by the 'cold engine' (i.e., site of deep water formation near the surface) in the Sea of Norway (fig. 13.1).

The warm water flowing north becomes cooler and denser when it reaches the high latitudes and, due to its greater density, sinks to the depths of the Atlantic ocean. The engine of the conveyor belt is just this cooling of the warm surface waters flowing northwards: the cold waters, having sunk to a lower level in the cold engine area, flow south, pass the equator and meet the warmer waters of the sub-Antarctic (the Anctarctic Convergence). The coupling of this North-South current with the Antarctic Circumpolar Current leads to a northwards flow of deep water in the Pacific that, in its turn, generates a current which crosses the Pacific and the Indian Ocean to enter the Atlantic, so closing the circle.[3]

The circulation of the Mediterranean Sea is a replica of the oceanic conveyor belt (fig. 13.2). Riverine inputs in the basin do not compensate for the evaporation of Mediterranean waters; this causes a salinity increase and draws Atlantic waters in through the Straits of Gibraltar. The Gibraltar Current enters the Mediterranean at the surface, reaches the east-

[3] Broecker 1991.

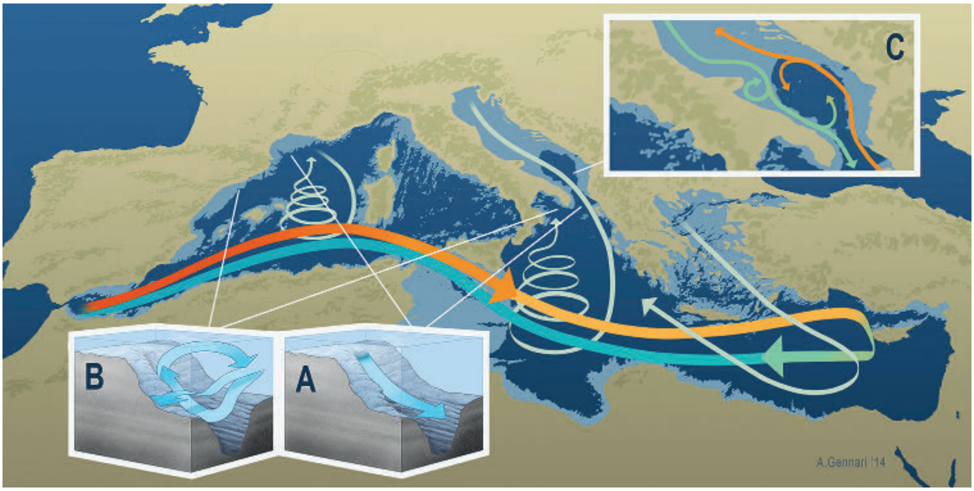


Fig. 13.2: The circulation in the Mediterranean Sea. The Gibraltar Current enters from the surface, flows to the easternmost part of the Mediterranean basin and returns as the Intermediate Levantine Current. The cold engines in the Gulf of Lions, the Northern Adriatic and the Northern Aegean cause surface waters to cascade through canyons (A) triggering offshore upwellings. In the canyons not affected by cascading phenomena, the currents parallel to the coast trigger inshore upwellings, bringing deep waters towards the coast. Gyres (C) are other important features of ocean circulation. (Artwork by Alberto Gennari after Boero 2015).

ernmost part of the Mediterranean basin and flows back at about 500 m depth to exit the Mediterranean back into the Atlantic. The average depth of the Mediterranean basin is about 1.500 m, hence the 500 m layer renewed by the Gibraltar current is insufficient to provide oxygen to the deep sea. That life persists below 500 m is due to the presence of 'cold engines' that have similar effects to those of the oceanic cold engine of the northern hemisphere. Cold-water formation occurs in the Golfe de Lion, in the northern Adriatic and in the northern Aegean due to a complex sequence of events based on the prevalence of strong cold winds that cool well-oxygenated surface waters; these sink into the deepest parts of the basin, pushing the deep, nutrient-rich but de-oxygenated waters upwards.

So, just as with the Ocean conveyor belt, in the Mediterranean there is a horizontal current that runs from west to east (similar to the Antarctic current) and a series of vertical currents that flow from north to south, triggered by the cold engines (similar to the current generated by the cold engine of the Norwegian Sea). Other circulation patterns are generated by canyons, with the formation of upwellings; and by capes and straits, with the formation of gyres (cf. fig. 13.2).

No other inland sea has such an extraordinary resemblance to the great oceanic belt, and this makes the Mediterranean Sea a perfect replica of the world's oceanic system, to be used as an experimental basin where we can foresee the future of the ocean.

The three cold engines in the northern part of the Mediterranean Sea replicate the cold engine of the Norwegian Sea. The Gibraltar Current and the Intermediate Levantine Current resemble the Antarctic current, but have a different origin and are not 'functionally' linked with the cold engines. These differences are to be considered when comparisons are made, but the resemblances between the two current patterns are still significant.

## 5. The Mediterranean: very sensitive to global warming

It could be hypothesised that global warming might impair the cold engine of the Norwegian Sea, leading to a change in deep water formation patterns, since this already happened in 1995 when the Eastern Mediterranean Transient (EMT) occurred, with profound implications on ecosystem functioning.[4] During the EMT, the cold engine of the Northern Adriatic failed to trigger deep water exchanges in the Eastern Mediterranean Basin, and the Northern Aegean engine took over this role. The Mediterranean Sea has 'spare' cold engines which can provide a supplement during periods when deep water formation by one of the three engines is impaired.[5] This seems less probable for the oceanic conveyor belt, since its functioning is based on a single cold engine.

Rising water temperatures are a phenomenon on the global scale, and they are occurring faster in the relatively small volume of the Mediterranean Sea than in the whole volume of oceanic waters. Their consequences will have great impact both on the biodiversity and the ecosystem functioning of the Mediterranean basin and are an anticipation of the response of the biota of the oceanic system of the whole planet.

In winter, the temperature of the Mediterranean Sea is homogenous from the surface to the deep sea, with an average of 12 °C or even less, especially in the cold engines, but during the summer months its surface almost tropical and can reach 28 or even 30 °C. The surface layer of water where temperature changes are great is featured by a sharp seasonality, and the species which inhabit it are divided into two main categories: cold water species, thriving in the winter, and warm water species, thriving in the summer.

Seasonal variations have been studied in detail for the Hydrozoa, a group of sessile animals that are sensitive to seasonal changes and that, in the Mediterranean Sea, show markedly seasonal activities. In a study of the Hydrozoa of Portofino (Ligurian Sea), the recent species composition and phenology were compared with those of the early 1980s.[6] The study revealed that, in recent times, species typical of cold water restricted their depth ranges of occurrence to deeper levels and throve for shorter periods than in the past; on the other hand, warm-water species are now present throughout the year and have a longer reproductive period than before, whereas previously this was restricted to the summer. The number of species is roughly the same as before, but the species are different. This fraction of biodiversity is now showing many features different from those of three decades ago, with a clear trend towards a dominance of species of warm-water affinity and a corresponding retreat of species of cold-water affinity.

The increases of sea surface temperatures that characterize the recent decades also disturbed other components of the benthic communities besides the Hydrozoa. Cold water species, in fact, repeatedly showed clear signs of distress, with mass mortalities of benthic populations over very large coastal areas. Due to higher sea surface temperatures the thickness of the warmer layer that is formed during the summer tends to increase, exposing

4 Danovaro, Dell'Anno and Fabiano 2001.

5 Boero et al. 2008.

6 Puce et al. 2009.

benthic species to temperatures which exceed their tolerance limits. The mass mortalities of cnidarians and sponges that have occurred in the northern part of the basin are all related to an expansion of the warm water layer during the summer.[7] The indigenous species that live in the Mediterranean below the layer of water that is heated during the summer months are in distress, and find a refuge at greater depths than usual. In places where they cannot find deeper refuges, they are in danger of extinction, as suggested by Boero, Carlton et al. (2013).

Non-indigenous species in the Mediterranean Sea are almost invariably of tropical origin and these are changing the functioning of the ecosystems in radical ways. Biological invasions are currently perceived as a serious threat to biodiversity, and the Mediterranean Sea is without doubt the most 'invaded' sea of the planet.[8]

The new thermal conditions of the Mediterranean Sea, while disfavouring cold water species, open new possibilities for many tropical species that are, indeed, invading the basin by the hundreds, an invasion trend that may even increase after the doubling of the Suez Canal.[9]

## 6. From a fish-dominated to a jellyfish-dominated Mediterranean

Global change is not the sole factor responsible for the impoverishment of the indigenous contingent: the Mediterranean Sea is also characterized by overfishing, with the consequent depletion of most commercial species.[10] Britten et al. (2014) have demonstrated trophic degradation of fish stocks in the Ligurian Sea, with a sharp decrease of top predator species and a new dominance of species situated at intermediate levels in the trophic networks.

Nature does not like voids, so the place of the fish is being taken by jellyfish,[11] a trend that is becoming so evident worldwide that jellyfish are increasingly seen as a possible target for a focused fisheries activity, a potential solution that must be considered with the greatest caution.[12]

The Adriatic Sea well illustrates the changes that affect the entire Mediterranean Sea. This sub-basin of the Mediterranean benefits from significant nutrient inputs from the Po river, and has for centuries been among the most productive areas of the whole Mediterranean Sea. The ecological history of the Adriatic (fig. 13.3) starts with a situation dominated by fish, but the outbreaks of the scyphozoan jellyfish *Pelagia noctiluca* that affected the Mediterranean in the early 1980s were particularly intense in the Adriatic Sea: *Pelagia* almost instantly clogged the nets of the fishermen within minutes and catches were much reduced for about three years.[13]

The first interpretation of these events was that fish were not caught because the jellyfish had clogged the fishing gear, impairing its efficiency. It is more likely, however, that the reduced catches had a different cause: the jellyfish ate the fish eggs, larvae and juveniles,

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7 Rivetti et al. 2014.
8 Galil et al. 2014.
9 Galil et al. 2014; 2015.
10 Coll et al. 2010.
11 Boero 2013.
12 Gibbons, Boero and Brotz 2015.
13 Boero and Bonsdorff 2007.

Fig. 13.3: Top: Circulation patterns in the Adriatic Sea. Below: The regime shifts that have characterized Adriatic 'ecological history' from the '70s to present (from right to left): Fish and benthic molluscs are abundant, sustained by high plankton production; the jellyfish *Pelagia noctiluca* swarms the basin and depletes food webs in the water column; unicellular dinoflagellates dominate the system and also impact on benthic populations, which are also impacted by the use of hydraulic dredges; dominance of bacteria, leading to mucilage formation; present conditions, with increased dominance of gelatinous organisms. (Artwork by Alberto Gennari).

depleting the fish stocks. *Pelagia* also fed on the crustaceans that are the main diet of fish larvae and juveniles. This is what happened in the Black Sea, when the ctenophore *Mnemiopsis leydyi*, another voracious gelatinous plankter, brought Black Sea fisheries to their knees. In this case, *Mnemiopsis* did not clog the nets and it was apparent that the fish were not caught because they had been eaten by the ctenophore.

When the *Pelagia* years came to an end, however, the situation in the Adriatic Sea did not return to normal. Dinoflagellates, unicellular organisms that are part of phytoplankton, replaced the jellyfish, giving rise to abnormally large populations (red tides) that spread over the northern and central part of the Adriatic Sea. The blame for these events was placed on nutrients, and numerous actions were taken to reduce their inputs. After a series of years characterised by red tides, in the mid-1980s, marine scums termed 'mucilages' replaced the dinoflagellate harmful algal blooms![14] The causal factor behind the mucilages was iden-

[14] Conversi et al. 2010.

Fig. 13.4: The Fish-Jellyfish transition, with a tendency towards
the prevalence of jellyfish-eating species. (Artwork by Alberto Gennari).

tified as intense bacterial metabolism due to high carbon availability. Apparently, these dystrophic events do not take place when thaliaceans (gelatinous planktonic organisms that feed on microbes) become dominant in the water column; the reason might be that they remove all the microrganisms, so preventing their proliferation. This, however, is not well documented since, due to their irregular appearance, studies on thaliaceans are sparse: their dramatic blooms are seen, but the organisms themselves remain unstudied.[15]

The Adriatic Sea of today is much different from that of thirty years ago: the difference is due to physical changes, to biotic changes and to human impacts, all acting together. The same is true for the whole Mediterranean,[16] where jellyfish are becoming increasingly abundant, both in the case of indigenous species such as *Pelagia*[17] and the increasing number of reports of tropical species entering the basin from the Suez Canal.[18] The regime shift from fish to jellyfish seems to affect all oceans and what is being recorded in the Mediterranean is probably going to happen at a world scale (fig. 13.4).[19]

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15 Boero, Belmonte et al. 2013.
16 Boero, 2015.
17 Canepa et al. 2014.
18 Boero, 2013.
19 Brotz et al. 2012.

Based on an assessment of the present state of the Mediterranean Sea,[20] in a period of rapid change it would be useful to attempt to predict future scenarios, in order to be prepared to face new conditions. The insights gained from the analysis of the Mediterranean situation will aid researchers attempting to predict for the future condition of the global oceanic system.

Acting as historians, we can compare what we now know about the distant and more recent past of the Mediterranean Sea with our knowledge of the present and recognize the patterns; thus identification of the drivers of past recent, and present change provides insights into the underlying causal processes, enabling us to draw some inferences about future trends.

## 7. What will be the future of the Mediterranean Sea?

The Mediterranean is undergoing important changes that strongly affect the biota. Based on Boero (2015) the main issues regarding the future of the Mediterranean-Black Sea Ecosystem can be summarized as follows.

*Tropicalisation*. The prevalence of species of warm-water affinity (either tropical non-indigenous species or indigenous species whoch normally thrive in the summer, or in the southern portions of the basin) is radically changing the biota. This is already very evident at species level, and the chances are high that these species will start forming new communities and will change the functioning of the ecosystems. It is difficult to predict, however, how the species will aggregate to form new communities. The ongoing changes in the distribution of species requires careful monitoring at the areas where different biogeographic regions meet. The success of warm water species is paralleled by the distress of cold water species. These will move northwards and/or to deeper levels, in search of favourable environmental conditions where the high surface temperatures do not have the devastating effects which have already caused mass mortalities in the Mediterranean Sea.

*Impairment of cold-water engines*. The Eastern Mediterranean Transient showed that the cold engines can cease to generate deep waters near the surface. In a period of global warming, a worst-case scenario envisages the onset of permanent stratification due to the impairment of the cold engines, with widespread anoxia in the deeper portions of the whole Mediterranean basin. If this should happen also for the cold engine that drives the Great Oceanic Conveyor Belt, dramatic consequences are probable for the global climate and for marine life in general.

*Changes in the phenology of species*. Changes in physical factors are modifying the phenology of species, with greater opportunities for species of warm-water affinity and fewer opportunities for species of cold-water affinity. This might also select genotypes that allow cold water species to face the new conditions; this may be happening for *Fucus virsoides*, a northern Adriatic endemic alga which, instead of disappearing as a consequence of the higher temperatures, is now particularly abundant.[21]

*Extinction of cold-water species*. The species endemic to the areas of the 'cold engines' will be forced into deeper waters or, where this is not possible (e.g., in the northern Adri-

[20] Coll et al. 2010; Boero 2015.
[21] Boero et al. 2008.

atic), they will become extinct.[22] This prediction, however, might not be fulfilled if some species evolve and adapt to the new conditions.

*Less fish, more jellyfish*. The fish-jellyfish balance is shifting on a global scale, and the change is particularly dramatic in the Mediterranean, where tourism and fisheries are highly developed. Fisheries are heavily affected by jellyfish blooms, but chances are high that overfishing is among the causes of gelatinous plankton outbreaks. Since very few species are really dangerous – and jellyfish are rather beautiful – we must learn to cope with them; in other parts of the world they are considered tourist attractions (in Palau, for example) or even culinary delicacies (in China, for example) even though Gibbons et al. (2015) have warned against industrial exploitation of the jellyfish. There is an indication that organisms which feed on jellyfish, such as sunfish (Molidae) and sea turtles, are increasing (fig. 13.4), since their food is now abundant. Perhaps they will reduce the prevalence of jellyfish, so creating space for other fish species and releasing them from jellyfish competition and predation on their larvae.

*Habitat destruction*. The growth of human populations has an increasingly high impact on both terrestrial and marine ecosystems. At current rates of resource consumption, our well-being is maintained at the expense of the rest of the natural world; the destruction of habitats is the most dramatic outcome of this trend. If the curve of economic production increases (growth), inevitably the curve of environmental integrity will decrease. It is among the duties of the scientific community to warn decision-makers about the dangers of ignoring the laws of nature while enforcing human laws (the laws of economy). The growth of economic and financial capital usually has the erosion of natural capital as its consequence.

## 8. Conclusion

The potential scenarios that lie ahead of us are not comforting; we are currently experiencing warnings that our presence on the planet is too demanding and that all that we take for ourselves is being taken from the rest of the natural world. The so-called 'laws of economy' do not take the 'laws of nature' into account; we unwisely expect the laws of economy to be stronger than the laws of nature, and we are already paying a very high price (in terms of the natural world, but also from an economic point of view) for our lack of wisdom. That price will increase with time, because the pressure we exert will inevitably force the systems that sustain our well-being to breaking point, and it is not to be taken for granted that the resulting, new situation will be as favourable to us as the present one (and especially past ones).

It is difficult to predict what will happen and when it will happen. We might become wiser and decide to live differently, with different lifestyles. If we allow nature to prevail over economy (which it will do ultimately anyway, even if we do not encourage it to, or even want it to) and change our way of life, the opportunity of a bright future for the human race will exist. But we must stop our insane rush towards growth. Otherwise the pressure we impose on nature will become too great, and we will no longer benefit from the sustaining goods and services that we have taken for granted since the beginning of human history.

The Mediterranean Sea is affected by global threats that cannot be unilaterally removed (for example global warming or ocean acidification), but there are many other pressures that can be relieved more easily. We might stop rearing carnivores to be fed on wild animals

[22] Boero and Bonsdorff 2007.

(as is taking place in aquaculture), we might stop developing coastlines with new urban and industrial installations, we might consider environmental costs when assessing the costs and benefits of any human enterprise (with both ecologists and economists doing the accounting). Finally, the populations of the so-called First World might choose to live in a simpler way; they should be the first to make sacrifices, since they have profited the most at the expense of nature.

These issues are well expressed in the recent Papal Encyclical *Laudato Sì*.

Scientists must warn decision makers about the situations facing humanity in the future. We must be honest, and admit that accurately predicting the future is not in our power; yet we have gathered sufficient knowledge and insights about the state of the environment to show that our present way of life is not compatible with the well-being of ecosystems, and that our well-being depends on their well-being. The trend towards unsustainability is clear and has to be reversed by means of proper policies, based on a more rational use of natural resources. The Mediterranean Sea is a small-scale ocean and its recent history dramatically demonstrates the consequences of our direct and indirect pressures on ecosystems; consequences which call for novel ways to tackle the complex problems regarding the interaction between the physical and the biological domains of marine environments.

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