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Global change and loss of biodiversity in the world's oceans

Anna OCCHIPINTI-AMBROGI[1] & Romano AMBROGI[2]

[1] Dipartimento di Ecologia del Territorio, Università degli Studi di Pavia, Via S. Epifanio 14, 27100 Pavia, Italy
[2] CESI RICERCA SpA, Via Rubattino 54, 20134 Milano, Italy
[*] Corresponding author e-mail: *occhipin@unipv.it*

SUMMARY - *Global change and loss of biodiversity in the world's oceans* - The global climate change and the loss of biodiversity at a planetary scale have been recognised since the 1980s as important issues, stemming from human activities that cause environmental modifications and in turn may have highly detrimental effects on mankind. The paper reviews some aspects of marine biodiversity loss caused by the introduction of alien species, which is considered one of the major changes in oceans worldwide. The changing distribution of species and the consequent biodiversity decline interact with the global climatic changes, as they affect the physical properties of water basins and enhance the opportunities for alien species to successfully compete with native species. The Mediterranean Sea, having a high biodiversity, is subject to the highest known rate of introductions historically, since the opening of the Suez Canal. In the last decades the rate of new species additions and the velocity of spread across the Mediterranean have been increasing dramatically. The approach of ecology is crucial in understanding these complex phenomena, through observation and hypotheses on mutual relationships between biological populations and physical factors. Some consequences of change on key functions of the environment at the ecosystem scale are also described. The insight gained by ecological study methods can be a precious contribution to make predictions about future developments and inform decisions by policy makers.

RIASSUNTO - *Cambiamenti climatici e perdita di diversità negli oceani* - Il cambiamento climatico e la perdita di biodiversità in conseguenza delle attività umane sono tra i principali problemi ambientali globali. Questo lavoro tratta della perdita di biodiversità in ambiente marino, in conseguenza dell'introduzione di specie aliene e della possibile interazione con i cambiamenti climatici, i quali, modificando le proprietà fisico-chimiche dei bacini, aumentano le probabilità delle specie aliene di competere con successo con le specie native. Il mare Mediterraneo, caratterizzato da un'alta biodiversità, è anche soggetto a tassi di introduzione fra i più elevati sin dall'apertura del Canale di Suez. Nelle ultime decadi l'introduzione di nuove specie e la loro velocità di diffusione nel Mediterraneo ha avuto un continuo incremento, in relazione al progressivo sviluppo dei traffici marittimi e delle pratiche di acquacoltura. L'approccio scientifico dell'ecologia può essere utile nell'affrontare tali fenomeni in quanto l'ecologia osserva il mondo naturale e formula ipotesi sul suo funzionamento e sulle reciproche influenze fra gli organismi e l'ambiente fisico. Dopo aver descritto alcune possibili conseguenze dei cambiamenti globali sulle funzioni dell'ecosistema marino, vengono brevemente discusse recenti tecniche di previsione delle invasioni biologiche, quale ulteriore contributo dell'ecologia per l'adozione di scelte rispettose dell'ambiente da parte dei decisori.

Key words: alien species, Mediterranean sea, climatic change, ecosystem functions
Parole chiave: specie aliene, Mare Mediterraneo, cambiamenti climatici, funzioni dell'ecosistema

1. INTRODUCTION

Global change is a term used to encompass multiple environmental and ecological changes. Global change implies the study of climate change, species extinction, land use change, as well as many other scientific areas. It concerns transformations that occur on a worldwide scale (e.g. the increase in carbon dioxide in the atmosphere) or exhibit sufficient cumulative effects to have worldwide impact (e.g. local species extinction resulting in global loss of biodiversity). Such environmental changes occur around the earth in response to a combination of factors, that we are going to briefly summarise here.

These global issues have been initially raised by scientists and academy in the 1970s but have more and more gained the scene in the social and political arena, especially after the Rio (1992) and Kyoto (1997) conferences. The Convention on Biological Diversity (CBD) concerns the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. It is the combination of life forms and their interactions with each other and with the rest of the environment that has made Earth a uniquely habitable place for humans. Biodiversity provides a large number of goods and services that sustain our lives.

At the 1992 Earth Summit in Rio de Janeiro, world leaders agreed on a comprehensive strategy for "sustainable development", a widely used term that means "meeting our needs while ensuring that we leave a healthy and viable world for future generations". One of the key agreements adopted at Rio was the Convention on Biological Diversity. This pact among the vast majority of the world's governments sets out commitments for maintaining the world's ecological underpinnings as we go about the business of economic development. The Convention establishes three main goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources.

The global climate change is being observed both at a global scale (increase of main temperatures over large areas) and at a local scale (increase of extreme climatic events, change in precipitation regime) and has been related to the rise of concentration of greenhouse gases in the atmosphere. The increased emissions and the change in land use have been recognised as the main human factors that are responsible of global change (IPCC 2007, http://www.ipcc.ch). The most important greenhouse gas is carbon dioxide, which is produced by combustion (mainly of fossil fuels), whose concentration is raising steadily, having reached levels unprecedented in geological times. Many remote observing stations worldwide are monitoring greenhouse gas concentrations, such as the one on the Italian Alps operated by CESI RICERCA (http://greeninfo.ricercadisistema.it/).

On the other hand, the living organisms at a planetary level are confronted with the increased pressure of man's activities. These manifold operations are using natural resources and changing the face of the earth, so animal and plant communities have to adapt to the new environment.

This paper mainly concerns a particular aspect of global changes induced by man: the transport of species outside their known range of distribution in the world's oceans, the consequences of this extensive reshuffling of the biota, and some interconnections with other aspects of global climatic change.

The approach of ecology in addressing this issue must imply:

- observing the structure of the natural world,
- formulating hypotheses on its functioning and on mutual relationships between populations and physical factors,
- making predictions about their evolution and the consequences of planned actions.

This approach places the role of human activities in an evolutionary perspective, so that evaluating all the consequences of economic and social development in a comprehensive way is made easier.

2. BIOLOGICAL INVASIONS AS A COMPONENT OF GLOBAL CHANGE AT SEA

Introduction of non-indigenous species is one of the most pervasive and irreversible impacts of human activities on natural ecosystems. Marine and aquatic ecosystems are particularly vulnerable to alien species invasions. Organisms can spread rapidly and are hard to detect, and control and eradication options cannot be used in the same way as in terrestrial habitats. Biological boundaries and ecosystems do not recognize political borders: at sea borders are even more difficult to define and control. Governing species introductions should be addressed at the international and regional level as well as at the local one.

Data from different biogeographic regions reveal that world maritime trade has dramatically increased the rate of introduction of species in areas where they were not previously present. The consequences have been in some cases abnormal proliferations (known as biological invasions), native species extinctions and a general homogenisation of biological communities worldwide.

The vectors for such introductions are navigation through man-made canals, such as the Suez Canal, and vessels (adult organisms are transported as fouling on ship hulls, and larvae and spores in ballast waters). Intentional introductions also take place in connection with aquaculture and mariculture operations. Of course many un-invited and un-welcome species, including parasites, can accompany target aquaculture species.

The world-wide changing distribution of species, and the consequent biodiversity decline, interacts with global climate changes (Occhipinti-Ambrogi 2007). The global temperature rise affects the physical properties of water basins and thus enhances the opportunities for alien species to successfully compete with native species (Harris & Tyrrell 2001; Parmesan 2006). Traditional conservation strategies are also challenged by the combined threat of climate change and invasive species (Rahel *et al*. 2008). The consequences of global climatic changes in the oceans are the increased sea level, the change in temperature and salinity, which in turn can cause very large changes in the global and local circulation, the change in the frequency and severity of storms and the change of the equilibria in the carbonate cycle, involving alkalinity (IPCC 2007).

The change in biodiversity is apparent in all the oceans of the globe. Of course pollution and eutrophication are imposing stress onto the marine communities in many areas, especially along the coast, and the impact on the physical environment (e.g from dredging and sediment load) result on changes in the biota (Occhipinti-Ambrogi & Savini 2003); thus local factors together with global ones can have a profound effect on alien species distribution and on their invasion success.

3. THE CASE OF THE MEDITERRANEAN SEA

Historic trends of temperature from the observing sea-surface temperature registrations demonstrate the actual change of climate in the Mediterranean. In recent times the observations are derived from satellite measurements that are of course incomparably more detailed both in time and space. Temperature and salinity anomalies show that climatic change is not only a matter of average heating of the waters but also a change in the usual cycle of the conditions experienced by marine life. The influence of climatic changes are not restricted to surface and coastal environments but are evident also in deep waters (Danovaro *et al*. 2001; Rixen *et al*. 2005).

The "tropicalisation" of Mediterranean waters has been mentioned as one of the causes for the rapid dispersal of species of Indo Pacific origin that entered in the Mediterranean after the opening of the Suez canal and colonised the Levantine Basin. In recent years they are spreading through the Mediterranean and are increasingly found also in the Western Mediterranean, having passed the crossroads of the straits of Sicily (Bianchi & Morri 2003; Bianchi 2007;

Galil 2008; Gambi *et al*. 2008).

The Mediterranean Sea is known for being a basin of high biodiversity that has evolved in the geological time as a different province of the Atlantic Ocean. Some 2000 metazoom species have been recorded here, representing > 7 % of Earth biodiversity, although the Mediterranean is 0.8 % ocean surface and 0.3 % ocean volume (Bianchi & Morri 2000; Zenetos *et al*. 2002).

A very high number of introduced species (573, according to Galil 2009) has been observed in the Mediterranean. These figures are much higher than those of other European seas (Streftaris *et al*. 2005; Gollasch 2006).

At a local scale, evidences from hotspots of introduced species show that the pristine diversity patterns in some localities have been deeply affected in relatively a short time by the success of a few introduced species, concomitantly with a trend of change in general marine climate conditions.

In the lagoon of Venice, even if changes in current regimes and overall sediment transport cannot be linked to seasonal cycles or to climatic forcing, a great number of alien species have been establishing with success (Occhipinti-Ambrogi 2000a) and a general decrease of the biodiversity (Pranovi *et al*. 2008) is observed, mainly at the expense of those species that were a peculiar feature of this biotope and especially in recessed areas such as those at the interface with inland runoff. The Bryozoan fauna has been studied through time, and the native species have suffered a severe decline concomitant to the establishment of the Indo Pacific species *Tricellaria inopinata*, that was discovered in the late 1980s and has since progressed in all areas of the Lagoon (Occhipinti-Ambrogi 2000b).

The main hotspot in the Mediterranean is located by the Levantine coasts, impacted by the so called lessepsian immigrants since the opening of the Suez canal that have been the object of several studies by the Israeli scientists (Galil 2007a and references herein). The coasts of Greece and the Sicily straits are now being the places where most of recent new observations of alien species are being made (Relini *et al*. 2000; Azzurro *et al*. 2004; Zenetos *et al*. 2005; Ragonese & Giusto 2007).

The increased interest of the scientists for introduced species can only partially account for this extraordinary performance: the occurrence of new species is increasing year after year even in areas that have been well-known to marine biologists for a long time. The taxonomic expertise is generally lacking, nevertheless Mediterranean countries are still a stronghold of the botanical and zoological disciplines.

In some cases, the massive development of alien species has caused biological invasions, with important consequences on the whole ecosystem. Some case histories are mentioned in the following sections to illustrate the magnitude of changes already going on in the Mediterranean Sea.

4. CLIMATIC CHANGE AND ALIEN SPECIES, HOW CAN THEY INTERACT?

Alien species interact with climatic change at two different levels (Harley *et al*. 2006).

The individual level implies responses to variations in temperature, salinity, pH, both at the adult stage and at the larva or spore stage. Moreover, climatic change is causing large hydrodynamic modifications, which in turn influence the distribution of organisms (see for instance Koppelmann & Weikert 2007). As far as introduced species are concerned, individuals and propagules are also affected by current modifications, that may influence their secondary spread. Alien species may react better than native species to the abiotic changes, and this translates into population changes. The final effect can be that sometimes native species are driven toward (local) extinction.

The ecosystem level implies that, following the general paradigm of ecology, what happens at the individual species level also reflects into more general properties and equilibria at the community and ecosystem level. Responses at a higher level comprise distributional shifts, changes in diversity, changes in productivity, microevolutionary changes.

The effects of sea warming, in the case of the Mediterranean may favour the range extension of many warm water species of Erythrean origin that have until now restricted their distribution into the Levantine basin. They are better competitors in comparison with their native counterparts because of their better tolerance of high temperatures and preference for higher average temperatures (Galil 2007b). Another cause of disturbance for native organisms is the modification or disruption of seasonal cycles, that are often linked with the reproductive cycle. In the case of sessile benthos, for instance, the periods of recruitment (and hence competition for space) are strictly linked with the thermal regime and alien species may take advantage of the mismatch between new climatic conditions and gonadal and developmental timetables of native species. Stachowicz & Byrnes (2006) have given experimental evidences for these mechanisms.

Climate changes and man activities, such as the opening of new waterways across previously separated biogeographic regions, have interacted in shaping totally different biological communities in freshwater, estuarine, and marine ecosystems (Galil *et al*. 2007).

But climate modifications bring also changes in the circulation patterns and in water stratification of the sea: again for the Mediterranean this means changes in the formation of deep waters and the renewal rate of waters in some parts such as the Adriatic (Galil, 2008a), favouring yet other occasions for native species replacement with alien ones. As far as carbonate chemistry, which is known to change in response to elevated CO_2 partial pressure in the atmosphere (Caldeira &Wickett 2003) it may influence the competition among species with calcified body structures, both in the plankton and in the benthos (Feely *et al*. 2004; Peng 2005).

Coming to ecosystem responses, the so called emergent properties, the concomitance of climatic changes and of the development of large populations of alien species can have severe consequences on biodiversity and energy flow.

The Mediterranean Sea, as shown above, is one of the world areas with the largest number of known introductions of alien species. Such massive addition of species to the fauna and flora of the basin raises nevertheless major concerns about biodiversity, that is not viewed as simply the number of species in an area but a conglomeration including genetic variability and species interactions. The interrelationships of native and alien biota has been advocated to explain many sudden concurrent changes in abundance, but, as Galil (2008) points out, this might be part of profound anthropogenic alteration of the marine ecosystem, including climatic change.

However, even if it is difficult and time consuming to disentangle the factors and consequences of multiple drivers of the loss of diversity (Didham *et al.* 2005), one has to consider:

- that the poleward shift of species (Hickling *et al.* 2006; Pearson 2006) in response to warming is not possibile in the Mediterranean, due to its morphology, so many of the endemic temperate species are specially at risk;
- that changes that have taken place are probably irreversible, as it has been the case with the native fishes that were replaced by goatfish, lizardfish and other Erythrean species in the Southern Levant Sea during the abnormally 1954/5 warm temperatures (Galil 2007b).

5. ECOSYSTEM – WIDE EFFECTS

Alien species may cause shifts in trophic nets and organic material flow. Such events have been reported from estuarine and marine coastal areas for different taxa; and have provoked multiple effects involving the overall ecosystem functioning. The relatively low numbers of introduced species in comparison with the full contingent of species in a given region might hinder the fact that the contribution to total community abundance or biomass can be overwhelming. For instance in the Eastern Gulf of Finland, the cumulated number of plankton and benthos alien species accounts only for 5% of all recorded species, yet this alien component makes up approximately 96% of the total biomass within the community (Orlova *et al.* 2006).

The so called ecosystem engineers (i.e. species having influence on the habitat itself either directly or indirectly) have inherently the potential for causing great shifts in the equilibria of large sea areas. Ecosystem engineers are keystone species for the ecosystems (Jones *et al.* 1997; Wright & Jones 2006) and have been studied mainly in cases when they have decreased dramatically (e.g. following over-fishing: Coleman & Williams 2002). Wallentinus & Nyberg (2007) pointed out that non indigenous species, acting as ecosystem engineers, have had profound impacts (positive and negative) from an ecosystem perspective. Their review describes direct physical changes on the condition of substrate (e.g. by species digging burrows) and habitat architecture (e.g. by seaweeds, acting sometimes as a barrier for foraging species); indirect changes on the physical conditions of the substrate are also common (e.g. by trapping sediment particles or by modifying the light climate on the bottom). Chemical changes include nutrient cycling between the water column and the bottom, biodeposition, surface clues to epibionts changed by the presence of allelopathic or toxic substances.

Examples of ecosystem engineers in the Mediterranean include the well known green algae, *Caulerpa taxifolia* and *C. racemosa* var. *cylindracea*, that change the habitat by competing with other canopy species (Piazzi *et al.* 2001, 2003) and affect the whole submarine landscape (Meisnez *et al.* 2001; Verlaque *et al.* 2003, Ruitton *et al.* 2005; Klein & Verlaque 2008), diminishing the structural complexity, richness of species and diversity (Longpierre *et al.* 2005) over large parts of the infralittoral.

The presence of other alien algae, such as the filamentous turf-forming rhodophytes *Acrothamnion preissii* and *Womersleiella setacea* reduces species numbers and diversity by trapping sediments which prevent the development of other species (Piazzi & Cinelli 2001). The latter species may establish an almost monospecific stratum suffocating the underlying coralligenous communities (Boudouresque 1994). In the Tuscan Archipelago *A. preissii* often overgrows rocks, other macrophytes and seagrasses, including Posidonia rhizomes. The toxic secondary metabolites produced by another alien macrophyte, *Asparagopsis armata*, repel grazers such as the sea urchin, *Paracentrotus lividus* and the fish *Sarpa salpa*, and free it to form dense stands in the Northwestern Mediterranean (Ribera & Boudouresque 1995).

Many introduced filter feeders, such as the bivalves *Tapes philippinarum* in the Northern Adriatic, have changed not only the macrobenthic community but also the nutrient flux in lagoon ecosystems (Bartoli *et al.* 2001). Estimating the clearance rate of the most abundant bivalve species in the lagoon of Venice before and after *T. philippinarum* introduction, Pranovi *et al.* (2006) have calculated that the filtration capacity, expressed as $l\ h^{-1}\ m^{-2}$, has more than doubled. This has altered the functioning of the ecosystem, resulting in a stronger benthic–pelagic coupling; in addition to that, the harvesting by boats resuspending the bottom sediments have had severe consequences over the entire Lagoon of Venice (Sfriso *et al.* 2005).

The calcareous tube worm *Ficopomatus enigmaticus* builds reefs in western Mediterranean lagoons, altering the habitat by forming hard substrata. In the Albufera de Menorca, Balearic Islands, for instance a continuous layer up to 3 m thick is formed, including encrusting molluscs and small rocks (Fornos & Ahr 1997).

Changes of functional groups at different trophic levels lead to reorganisation of food webs, because new members in a group establish different connections with other groups. Cascading effects caused by biological invasions have been described for instance by Crooks (2002).

Perhaps the most striking example world wide of the disruption of the entire food chain involving the invasion by an introduced metazoan is the case of the ctenophore *Mnemiopsis leidy* in the Black Sea and the Caspian Sea (Kideys *et al.* 2005). The Black Sea ecosystem, exhibiting a high susceptibility to climate change (Öszoy 1999), is also particularly vulnerable to mass development of invasive organisms, causing great changes in the biological communities and of energy flow through the different trophic levels as discussed by Gomoiu *et al.* (2002).

6. CONCLUSIONS

Enclosed seas as the Mediterranean are probably more at risk of developing such revolutionary changes in ecosystem properties and services, where the influence of climatic forcing is not so easily demonstrable, even if it is well clear that they are the consequence of global changes both in the climatic conditions and in the increased pressure of propagules being transported across biogeographic ranges by human-mediated transfer.

Predictions on future introductions are difficult and many approaches have been applied, starting from the biological characters of the most "invasive" species, the probability of transport if vectors are known (Herborg *et al.* 2007), and the susceptibility of habitats to invasions (Wiley *et al.* 2003). Many modelling exercises can be quoted, even if a common drawback is the lack of detailed information on the actual occurrence of species over large areas. For instance, Reusser & Lee (2008) used a new modelling technique (Non-Parametric Multiplicative Regression – NPMR) to predict species distribution over different spatial scales for estuaries and their habitats over the entire west coast of the United States, where they could make use of a large data set of species with associated landscape and watershed characteristics. Lee *et al.* (2008) suggest that combining the outputs from biological information systems with environmental data would allow the development of ecological niche models that predict the potential distribution or abundance of native and non-native species. Environmental projections from climate models can be used in these niche models to project changes in species distributions or abundances under altered climatic conditions and to identify potential high-risk invaders. Integration of biological and environmental information systems, niche models, and climate projections would improve management of aquatic ecosystems under the dual threats of biotic invasions and climate change. In the Mediterranean Sea, some attempts for species, such as *M. leidyi*, have been used to predict a possible expansion outside the Black Sea towards the Aegean Sea (Siapatis *et al.* 2008).

As far the entire Mediterranean Sea, further introductions are expected from the increasing propagule pressure coming from a very active maritime traffic and increased trade of aquaculture products. Moreover, the climatic change is already evident in both temperature rise, seasonal distribution of precipitation and consequent change in hydrodynamic features. This will have a decisive influence on the rate of spreading of introduced species especially those Erythrean species that have been dwelling in the Levantine basin for several decades and are now ready for the leap towards western parts of the Mediterranean.

The scientific approach of ecology permits to observe the present situation of biota in the world's oceans and in the Mediterranean in particular, and to formulate hypotheses of a further loss of biodiversity and value of ecosystems based on the mutual relationships between populations and physical factors. Man's responsibility and role in this projected trend is advocated, both for the emission of greenhouse gases that interfere with global climate and for the vectors of aquatic species transport across the world's oceans.

The consequences of these facts on economic and social development are outside the scope of ecology but are obviously worrying the public opinion and the governments. The scale of these problems is inherently global, but action must be taken locally by each single human community within its own place. International collaboration, and even more important, a common understanding that human wellbeing is at stake, are essential for dealing with the conservation of natural goods.

Ecological facts and conceptual frameworks must be provided to decision makers clearly and authoritatively, in order to know what is essential about the equilibria of the living world (Pyke *et al.* 2008).

Failing to set in a correct and wise manner, the problem of man's relation to nature leads inevitably to instrumental and ideology driven positions, on the one hand raising a generic alarm of imminent catastrophes in order to radically boycott the existing economic system, on the other hand refusing to take into account the facts in order to promote an equally generic confidence in the capacity of market economy to solve every need for human kind.

A new interpretation and a new practical implementation of the concepts of development and technology need to be sought; in fact any human intervention leads to inevitable modification of the environment, but this must not have devastating and irreversible consequences on the environment itself, in order to preserve the future of mankind.

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