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The influence of climate changes on the hydrobionts

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Abstract

Climate and its changes have a direct impact on the development of the different hydrobiont species. These effects on aquatic organisms could be either positive or negative. Every species adapts specifically to natural periodic and seasonal changes, however, the response to unexpected climate changes is inconsistent and not always adequate. Climate-related factors could influence food safety via numerous pathways, namely changes in temperature and rainfall, increased frequency and intensity of extreme meteorological phenomena, ocean warming and increased acidity of aquatic habitats, higher pollution level. Climate change could also have a socioeconomical impact on population feeding i.e. agriculture, animal production (aquaculture), global trade, demographic factors and human behaviour. The paper is aimed at describing some of current and future climatic changes and their possible impact on aquatic organisms in general. Global climate influences the ocean, but the ocean also plays an essential role in global climate patterns. Aquatic organisms are actively involved in the turnover of carbon dioxide and other compounds, hence hydrobionts should not be ignored.

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Introduction

Natural hydrobiont populations experience the most dramatic climate effects. Artificially farmed species are also influenced, if reared in open natural systems.

A number of researchers and scientific organisations perform observations on natural populations of economically important hydrobiont species, exposed to various climatic impacts.

Global climate changes are a generally acknowledged fact and most of underlying causes are a direct result of human activity (IPCC, 2007; Hansen *et al.*, 2007). In 2008, fossil fuels production, cement production and the changes in the use of land in particular, resulted in increased atmospheric carbon dioxide concentrations over the 280 ppm pre-industrial level to 385 ppm (Meure *et al.*, 2006). The higher ambient temperature consequently to the greenhouse effect of carbon dioxide, methane and other gases is without parallel for the last 22 thousand years (Joos and Spahni, 2008) and marine environment and organisms already suffer its effects. The event includes increase in global sea surface temperature by 0.13^{o}C per decade after 1979 and increase by 0.1 ^{o}C in ocean depths after 1961, higher wind speed and storm incidence, changes in ocean circulation, vertical structure and nutrients (IPCC, 2007), as well as increase in sea level by more than 15 cm over the last century (Rahmstorf, 2007) and now by 3.3 mm annually on average. Due to the equilibrium between gas concentrations in the atmosphere and the ocean, increased atmospheric CO_2 results in more dissolved CO_2 in the ocean, carbonic acid (H_2CO_3) formation and consequently increased acidity of oceans: water pH has decreased by 0.1 over the last 200 years (The Royal Society, 2005). In most instances, these physical changes and their effects on sea organisms are unprecedented, so ecosystems also tend to respond in an exceptional way. It is assumed that the critical threshold for atmospheric CO_2 is 450 ppm, and if it is exceeded, the consequences would be disastrous and irreversible. This would increase the global average temperature by 2^{o}C over the pre-industrial values. Evaluating the current conditions, the threshold would be attained in 2040. Anyhow, climate systems are notoriously non-linear (Lenton *et al.*, 2008). After 2040, some exceptionally sensitive marine ecosystems as coral reefs and ice-covered arctic seas could disappear, but other unexpected consequences are also possible (Hester *et al.*, 2008).

Every year, human activity releases in earth atmosphere millions of tons of pollutants, including CO2. It is among greenhouse gases having both direct and indirect influence on global temperature increase, which in turn results in a number of unwanted and dangerous outcomes for life on earth. Among them, we must note sudden and unusual regional weather changes, increased sea level, increased ocean acidity, impaired global ocean circulation etc. All these circumstances disturb the biological processes in aquatic ecosystems – marine and freshwater. These interrelated events pose a threat on the existence of global food chains, including human feeding. Biological changes occur consequently to the physiological response of hydrobiont species to climate changes and resulting living environment alterations. As everything in nature is interconnected, this hides risks. The indicated consequences showed the actuality of the subject connected with the influence of climate changes on the hydrobionts, their ecosystems and biodiversity. The aim of the current review was to investigate the research conducted in this area of science and to emphasize the necessity of future steps in the investigation of this global planetary problem.

Temperature, CO_2 and pH

The global climate is changing (Zachos *et al.*, 2001) and will keep on changing (Crowley and Hyde, 2008) in the future (Brierley and Kingsford, 2009). Owing to modern computers, the temperature patterns in the past could be easily reconstructed (Mann *et al.*, 2008). Temperature is closely related to living beings' physiology (Clarke, 1993). The rate of biochemical reactions could increase twice with a temperature increment of 10^{o}C, and water density is characterised with a specific non-linear pattern – the cold water sinks, but ice flows on the surface. These as well as other properties of water, which are in direct relationship with climatic factors, influence aquatic ecosystems, and hence, the life on earth as a whole.

Geological records provide evidence for multiple abrupt temperature changes. These changes mark boundaries between ages lasting tens of millions of years. For instance, during the Paleocene-Eocene, characterised with a temperature maximum for the last 56 million years, global temperature had increased by 6 ^{o}C over 20,000 years, as during that time, atmospheric carbon dioxide emissions within one thousand years were 1500-2000 gigatonnes. This amount is lower than the current emissions resulting from anthropogenic activity (The Royal Society, 2005). Perhaps, temperature lowering after the Paleocene-Eocene ages was due to prolific growth of the aquatic plant Azolla sp. (Brinkhuis *et al.*, 2006), which have reduced dramatically carbon dioxide concentrations from 3500 to 650 ppm (Pearson and Palmer, 2000), which resulted in earth climate change from greenhouse to icehouse state, i.e from a period of warming to a glacial period. This example illustrates very well the power of marine biological impact on global climate.

The changes in sea level, ocean water pH and oxygen deficiency level with formation of dead zones are extensively discussed (Rahmstorf, 2007; The Royal Society, 2005; Diaz and Rosenberg, 2008). In many instances, these as well as other factors act together (Jackson, 2008) to produce adverse effects to which organisms and ecosystems are less resistant.

There is a direct relationship between atmospheric CO_2 and ocean water pH (The Royal Society, 2005): the increase of CO_2 results in lower pH. This poses a serious threat to many marine organisms and ecosystems. During the last 300 years, oceans have absorbed almost half of anthropogenically produced CO_2 (The Royal Society, 2005) and at present, the process continues at a rate of one million tonnes of CO_2 per hour. The result is reduction of pH by 0.1 units during the last 200 years; a decrease by 0.3 to 0.5 units until 2100 is anticipated, which is more than 100 times faster compared to any period over the last hundreds of millennia (The Royal Society, 2005). One of the most important sequels of ocean acidification on marine organisms occurs as a result of the interaction between acidity and the presence of carbonates. A taxonomically diverse spectrum of marine organisms, including phytoplankton, pelagic and benthic molluscs, starfish, sea urchins, massive corals require calcium carbonate for their skeletons, while the key structures of others are rich in carbonate (for example, fish otoliths). All they would probably suffer when increased acidity causes lower availability of carbonate, with cascade effect on the species level, altering the generic communities (Hall-Spencer *et al.*, 2008).

Low oxygen concentrations make some parts of the global ocean hostile for multicellular organisms (Vaquer-Sunyer and Duarte, 2008). The solubility of oxygen in seawater is a function of temperature and oxygen availability. In the global ocean, it decreases, as since the 1950s (Garcia *et al.*, 2005), the ocean water temperature has substantially increased. Over the range from 0 to 15^{o}C, dissolved oxygen concentration in seawater has an almost linear relationship with temperature and decreases by approximately 6% for each degree increment. The active warming along with increase in atmospheric CO_2 would result in broadening of hypoxic zones, probably by more than half of their current volume until the end of the century (Diaz and Rosenberg, 2008). These spreadings would have an impact on some of biggest fish production regions in the world and would entail both economic and ecological consequences. The behaviour of fish is related to the different oxygen concentrations in the depths (Bertrand *et al.* 2008). The abundance of krill could also be limited by dissolved oxygen (Johnson *et al.*, 1984). The altered behaviour of schooling fish consequently to lower oxygen availability, could influence predators feeding on pelagic prey

(Abrahams *et al.*, 2007). Furthermore, the coastal eutrophication resulting from increased fertiliser flow from rivers and increased sea level, would lead to additional accumulation of organic matter and thus, to enhanced activity of microbial dissolved oxygen consumers (Diaz and Rosenberg, 2008). Motile organisms are able to avoid low oxygen concentrations whereas sedentary ones could only choose between surviving low dissolved oxygen levels or perish.

Global temperature fluctuations reflect on water and ice, hence on sea level (Rahmstorf, 2007). Sea level has an effect on flooding and coastal habitats and ecosystems (Peters, 2008). The rate of sea level increase during the last century is proportional to the increase in pre-industrial temperatures (Rahmstorf, 2007), presuming further elevation by 0.5 to 1.4 m over the 1990 level by year 2100. The sea level alters the habitats, the speciation, biological diversity (Peters, 2008) and the nutrient flow.

The assessment of susceptibility of marine organisms and ecosystems to climate changes should also consider the possibility for influence on all biological levels of organisation. It includes the gene expression, cell structure and systemic physiology, skeletal structure, the behaviour of individuals, population dynamics, community dynamics, structures of the ecosystem and trophic interactions. In compliance with the ecological niche theory, the tolerance ranges of species influence at the same time their physiology, environmental factors, interspecies competition and distribution. The sensitivity to climate change could differ between the different levels of organisation, similarly to the response of organisms to changes in basic values of global stressors, which could be either independent or critically related among the levels. The varying sensitivity to the changed factors in competing species could disturb the interactions and entail complex indirect responses on the community level (Poloczanska *et al.*, 2008).

The changes in surface ocean water temperature have led to multiple biogeographical changes in the species' distribution. The plankton communities in the North Atlantic exhibited a location shift by more than 10 degrees latitude since 1960 (Beaugrand *et al.*, 2002). The warming of the Arctic includes transpolar invasion of Pacific plankton species to the Atlantic (Reid *et al.*, 2007). Whales, which are among the largest, the most dynamic and the oldest marine creatures, are expected to resist to climate changes, although some of them are influenced via their food – zooplankton from the low trophic levels, which reacts fastly to climate changes (Greene and Pershing, 2004; Leaper *et al.*, 2006). Sea ice covers up to 7% of the earth surface and is one of largest and most dynamic biomes on the planet (Clarke *et al.*, 2008). The geographical range, temporal pattern and average thickness of Arctic sea ice decreased significantly after 1960 by 7.4% per decade (IPCC, 2007). The lowest shrinkage extent was recorded in the summer of 2007. In general, Antarctic sea ice seems stable at present (IPCC, 2007), despite the regional variations with years, but the probability of a great decline similar to that in the mid 1960s, still remains (de la Mare, 1997). In both hemispheres, sea ice is expected to shrink during the 21st century and it is even believed that in the summer of 2030 the Arctic Ocean could remain without ice cover. Sea ice is the habitat of rich and diverse microbial communities within the main aquatic ecosystems, it is a site for breeding and hunting of vertebrates (i.e. penguins, seals, white bears). Therefore, the loss of ice is equal to loss of habitats.

The decrease in pH could influence the ion exchange and suppress the metabolism, hence leading to a more narrow thermal tolerance window (Portner *et al.*, 2005).

Coral reefs are among the most diverse and economically important ecosystems on earth. They are endangered by numerous changes, including sea level and water temperature increase, and higher water acidity. Corals require calcium carbonate (under the form of aragonite) to build their skeletons, but acidification reduces its availability. Since 1990, the calcification of the Great Barrier Reef has decreased by 14.2% (Death *et al.*, 2009). Provided that the increase in atmospheric CO_2 is maintained at the current rates, the accretion of carbonates is expected to be lower and as a result, corals would become less frequent by 2050 (Hoegh-Guldberg *et al.*, 2007).

Corals, and their symbiotic algae in particular, are highly sensitive to temperature increase. Symbiotic relationships are disturbed at temperatures over 31°C, and consequently, the expulsion of algae causes bleaching of corals (Hoegh-Guldberg *et al.*, 2007). The intensity and scale of coral bleaching has increased after 1960, and the most massive bleaching incidents have occurred in 1998 and 2002, when entire reef systems were affected (Berkelmans *et al.*, 2004). The waters of the Great Barrier Reef are expected to become warmer by 1 to 3°C during the next 100 years, which increases the threat of events triggered by high temperature, fatal for corals.

As a result of human activity, global atmospheric carbon dioxide, methane and nitrous oxides concentrations have substantially increased, and from 1750 to present they are far above the pre-industrial levels, determined by investigation of ice cores over hundreds of thousands of years. Carbon dioxide levels increased from approximately 280 ppm in pre-industrial times to about 380 ppm nowadays, mostly due to the use of fossil fuels and deforestation (IPCC, 2007). Direct and indirect effects of increased greenhouse gas concentrations on oceans consist of increased temperatures, acid rain, altered density gradient of surface ocean waters, which could change the vertical mixing of waters, intensification or reduction of winds, change in weather and freshwater flow in coastal sea water etc. In fact, there is much evidence that some of these changes are already occurring (Bindoff *et al.*, 2007).

The predicted changes in oceans could be probably influenced by the interactions between men and oceans. The Black Sea has undergone changes following the extensive fishing, invasion by jellyfish and eutrophication (Daskalov *et al.*, 2007); many coral reefs suffer from increased temperatures, acidification, diseases, fishing and tourism impacts, sediments and excessive nutrients from river flows (Carpenter *et al.*, 2008). The analysis of North Atlantic fish populations suggests that lower catch is caused by climate changes (Brunel and Boucher, 2007) and by its own, fishing could not explain the observed descendent trends. The assumption that the climate changes have permitted fishermen to catch more fish is not correct (Schiermeier, 2004), because overfishing would not certainly aid ecosystems. There is an increasing awareness of the requirement for ecosystem-friendly approach to sea fishing and environmental management: this is an approach which could account for the entire spectrum of anthropogenic impacts and natural threats for ecosystems, including climate change (DeYoung *et al.*, 2008). The most recent research demonstrates the general response of oceans to future climate changes, and the impact of changes for human societies is acknowledged (Laws, 2007; Patz *et al.*, 2006; McMichael *et al.*, 2006). In a similar way, during the last decade, several studies have presumed the existence of possible relationships between the climate and the frequency and duration of harmful algal bloom (Erickson and Nishitani, 1985; HEED, 1998; Trainer *et al.*, 2003; Hayes *et al.*, 2001; Dale *et al.*, 2006; Edwards *et al.*, 2006). The adjective "harmful" is used to describe algal blood which could cause a number of adverse physiological environmental effects (Smayda, 1997). Some harmful algae produce potent natural toxins, which go through clam and fish filters and enter the food chain, causing disease or death if consumed by men or other organisms. Other algae are non-toxic, but accumulate an extensive biomass within the phytoplankton structure consequently to substantial reduction of phytoplankton biodiversity and the amount of light reaching the benthos (Erdner *et al.*, 2008). The decomposition of dead algae could result in a serious decrease in dissolved oxygen concentration. Due to ecological and physiological differences between algal species, their response to the same climate changes would differ.

The effect of climate on algal bloom could potentially affect the human health (Moore *et al.*, 2008). This could happen in large-scale or low frequency climate change, for example El Niño, as well as from anthropogenic change. These are time-opposing events, occurring within very short terms – weeks or days. Climate confines the range, timing and intensity of infectious outbreaks (Epstein, 2001), which is also applicable to algal blood. Anthropogenic climate changes are responsible for the global occurrence of algal bloom (Hallegraeff, 1993). There are only few examples in the literature demonstrating quantitatively this potential relationship, as it is extremely hard to distinguish the influence of natural and anthropogenic climate changes from other anthropogenic impacts, known to contribute to algal bloom (Moore *et al.*, 2008).

The studies on the ecology and trophic interactions of Pacific salmonids conducted after the 1950s (e.g. Allen and Aron, 1958; Ito, 1964; LeBrasseur, 1966, 1972; Manzer, 1968; Shimazaki and Mishima, 1969; Nishiyama, 1970, 1974, 1977; Kanno and Hamai, 1971; Takeuchi, 1972; Kaeriyama, 1986; Pearcy *et al.*, 1988; Kaeriyama *et al.*, 2000) have shown that they are well adapted to ocean environment changes and the foodniche. In general, chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) feed on larger micronektonic prey such as fishes and squids, while sockeye (*O. nerka*), chum (*O. keta*), and pink salmon (*O. gorbuscha*) are more opportunistic feeders, feeding on smaller prey such as zooplankton. However, sockeye and pink salmon in the Gulf of Alaska can feed at many different trophic levels by switching their diets from zooplankton to micronekton, such as squids and fishes (Kaeriyama *et al.*, 2000). The study conducted by Kaeriyama M. *et al.*, 2004, presents information on the changes in the feeding ecology and trophic dynamics of Pacific salmon, related to climate phenomen such as El Niño and La Niña, in the central Gulf of Alaska during 1994–2000 The recent increase in foodniche overlap of Pacific salmon also suggests that intra- and inter-specific feeding competition will increase in the Gulf of Alaska due to a change in the available food resources. The monitoring of the ocean feeding ecology of Pacific salmon in the future could help us to predict the influence of climate change on the inter- and intra-specific interactions that occur in this region.

Future monitoring of the ocean feeding ecology of Pacific salmon could help us better understand inter- and intra-specific interactions that occur in this region, and how climate change affects these interactions.

The reproduction of fishes could also be affected by increased water temperature as a result of climate change. Normal changes in environmental temperatures are able to influence the endocrine function, gametogenesis and maturation. In Atlantic salmons (*Salmo salar L.*), exposure to high temperatures at the time of gametogenesis damages the sexual glands and steroid synthesis, as well as liver function, which finally results in lower viability of gametes. Exposure to high temperatures during the maturation impairs the sexual glands and inhibits ovulation. High temperature has an adverse effect on the reproductive development of female rainbow trouts (*Oncorhynchus mykiss* (Walbaum) and Arctic chars (*Salvelinus alpinus* L.). Among the wild populations, a behavioural thermoregulation is triggered in response to increased temperature with consequent change in the geographical range or extinction. In response to altered thermal regime, the normal reproduction of salmonids and other fish species would be altered, in a way differing according to the temperature variations following climate abnormal extremes (Nakano *et al.*, 2004) or increased atmospheric CO_2 levels (IPCC, 2007). At some extent, the increased temperature would have a negative effect on the reproductive function of fish (Van Der Kraak & Pankhurst, 1997), but these effects could be manifested in a variety of ways in natural or cultivated stocks of salmon.

At a global scale, an immediate reduction of carbon dioxide emissions is deemed necessary as an essential measure to counteract the future anthropogenic climate changes. So far, a planetary warming by 2.4°C over the pre-industrial levels is registered, which is beyond the 2°C threshold for "dangerous anthropogenic interference" (Ramanathan and Feng, 2008). If the current rate of emissions is maintained, atmospheric carbon dioxide is anticipated to attain 1000 ppm that is associated to corresponding warming of 5.5°C until the end of the century and extinction of numerous species (Romm, 2008). Facing such a terrible scenario, even large-scale interventions as the creation of enormous networks of protected areas (Pala, 2009), where unsafe activities such as fishing are prohibited, would be inefficient. The direct way for warming limitation is to reduce CO_2 emissions. The primary ocean production as well as other biomanipulations could contribute substantially to this end. The fertilisation of the oceans with trace elements, including iron, stimulates the growth of phytoplankton. At a large scale, it could uptake considerable amounts of carbon dioxide from the air towards ocean depths (Denman, 2008) and using the biological pump theory, this carbon could be isolated there. This approach is however largely uncertain (Cullen and Boyd, 2008) and furthermore, there are international restrictions with respect to experimental fertilisation of the ocean (Kintisch, 2008) as the direct injection of CO_2 into ocean depths could result in storage of large amounts of acids and other contaminants, posing a threat to marine ecosystems. Low-scale disposal experiments were revoked in 2002 due to environmental concerns (Huesermann, 2008).

Wind farms and tidal energy generation are two of the several options for electric power production without emitting CO_2 (Schiermeier *et al.*, 2008), but ironically, both have a potentially adverse impact on marine ecosystems and could additionally cause degradations indirectly associated to climate (Kirby, 1997; Koschinski *et al.*, 2003). The “flow” of species and biomass from protected marine areas could be beneficial for adjacent unprotected zones (Gell and Roberts, 2003).

The ozone shield and UV radiation

Another side effect from the anthropogenic global pollution is the thinning of the ozone layer and the appearance of the so-called ozone hole. The most recent results support the general belief that the reduction of ozone and the related increase in UV radiation level could influence negatively many aquatic species and aquatic ecosystems in general (lakes, rivers, marshes, oceans). Solar UV radiation penetrates into water pools at a significant depth and could affect both marine and freshwater ecosystems. It could exert its effects at different trophic levels – from the largest producers of biomass (phytoplankton) to its consumers at higher levels of the food chain (zooplankton, fish etc.). Many factors could influence the depth of radiation penetration in natural waters, including the dissolved organic compounds, whose concentration and chemical composition could be possibly influenced by the future changes in UV radiation. There is also a large body of evidence showing that aquatic species possess numerous mechanisms for photoprotection against excessive levels of radiation. Often, these defense mechanisms raise interspecies conflicts thus making UV radiation a source of additional stress for organisms. Several studies show that the effect of UV radiation on the ecosystem level could be more pronounced on the community and food chain structure and hence, on subsequent biochemical cycles, rather than on the biomass growth (Hader *et al.*, 2007).

Aquatic ecosystems are the main components of the biosphere on earth, by producing more than 50% of the global biomass and having carbon dioxide content at least equal to that of the atmosphere (Zepp *et al.*, 2007). The primary producers in freshwater and marine ecosystems are the base of complex food chains providing energy to primary and secondary consumers and therefore, significant factors for production of key human food – crustaceans, fish and marine mammals. Solar UV rays could have a negative influence on aquatic organisms (Hader, 2003; Sinha and Hader, 2002). The massive Antarctic stratospheric ozone loss during the last two decades, as well as the depletion of ozone over the Arctic, high and moderate latitudes, raises concerns about the impact of more intensive solar UV radiation on marine and freshwater ecosystems (Helbling and Zagarese, 2003). Pure lakes and oceans in alpic and polar regions, where UV rays penetrate deep into the water, could be especially vulnerable. Organisms in polar waters are exposed at a greater risk due to the limited regenerative potential under the inhibitory effect of low temperature (Vincent *et al.*, 2006). The exposure to UV radiation could reduce the production; affect the reproduction and development, as well as to enhance the mutations rate in phytoplankton, macroalgae, the eggs and larval stages of fish and other aquatic animals. The consequences of reduced productivity are the lower capacity for atmospheric carbon dioxide disposal, and the negative effects on species diversity, ecosystems stability, trophic interactions and finally, on global biochemical cycles (Zepp *et al.*, 2007).

The recognition of UV radiation significance for aquatic ecosystems led to numerous research reports showing that solar UV radiation could have a negative effect on aquatic organisms. The studies document a significant effect on different species. Yet, the evaluation of impact on ecosystems remains uncertain. Several studies demonstrated that the effect of increased UV radiation would be relatively low when seen as a general response of the biomass, unlike the specific response of species, which is manifested with a plenty of responses to distribution and other effects. The ecosystem response to the change could vary from synergic to antagonistic reactions to UV radiation effects and these influences make the comprehension and forecasting at the ecosystem level rather complex. The assessment of UV radiation effects associated to climate deviations, indirect effects such as sea ice reduction, altered bio-optical features of water and changes in oceanographic biochemical areas are often more important than direct effects. The decreased primary productivity would limit the possibility for atmospheric carbon dioxide disposal with respect to its effect on climate change. Global trends for reduction in amphibian populations are likely associated to several complex interacting causes. While one review clearly rejects any relationship between solar UV radiation and amphibian populations decline (Licht, 2003), there is still evidence from all around the world about tens of amphibian species, affected by UV radiation (Blaustein and Kats, 2003). A lot of recent reports supported and enhanced the proofs about the substantial effect of UV radiation on the community structure of aquatic ecosystems. In lakes, the abundance of phytoplankton could vary according to the future change in UV level (Leavitt *et al.*, 2003). Also, lakes often exhibit a thermal stratification and consequently, vertical distribution of plankton communities, whose species composition could be strongly influenced and controlled by UV radiation regimes (Cozza *et al.*, 2004). There are facts in support of the hypothesis that UV radiation has an influence on zooplankton and lake community structures (Williamson *et al.*, 2001), the studies on meso environment, including phytoplankton and species feeding on it showing that the species composition and structure as well as the entire algal biomass could be influenced by UV radiation (Roy *et al.*, 2006). The results suggest that UV radiation could be a more important factor for aquatic ecosystems' structure than is currently recognised (Ferreyra *et al.*, 2006).

Conclusion

Most marine species and ecosystems are suffering multiple threats at a time. The resistance of species to single threats could be reduced by various factors and disturbances in ecosystems experiencing loss of biodiversity, which could compromise the function of the ecosystem and its resistance to further challenges. A difficult choice should soon be made to avoid the trespassing of the critical atmospheric carbon dioxide threshold of 450 ppm, even though the ocean has so far buffered the climate change by absorbing about half of anthropogenically generated CO_2, but if the change of climate goes on, the CO_2 in the ocean which is not accounted for, could be a source of additional problems. Methane hydrates in the ocean could become unstable with warming until a large-scale release of gaseous methane with dangerous sequels for ecosystems occurs. The improvement of models increases also our ability to predict physical changes in the ocean with effects on marine and land biology, but we should develop beyond the forecasting and monitoring and act to stop the degradation. Despite the interference options, it could be too late to avoid big irreversible changes in many marine ecosystems. As history has shown, these changes in the ocean could have a major effect on the planet.

Abbreviation

CO_2-carbon dioxide;

pH-logarithmic measure of hydrogen ion concentration;

UV radiation – ultraviolet radiation

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