Changes in flora and fauna on terrestrial and aquatic environments as the climate warms

Bacelar-Nicolau, P., Azeiteiro, U.M.
pnicolau@uab.pt, ulisses.azeiteiro@uab.pt

Department of Science and Technology, Universidade Aberta, Portugal

Centre for Functional Ecology, Universidade de Coimbra, Portugal

Abstract

The aim of this paper is to describe the main impact of climate change on terrestrial and on coastal and estuarine systems.
There is now ample evidence of the effect of climate change on terrestrial and marine environments. Hence, understanding and predicting the effect of climate change on plants is of major importance, because their responses can affect entire food webs, disturbance regimes and crucial ecosystem, services, including pollination, carbon and nutrient cycling, and water supply. We will herein review responses of flora to climate change in what concerns phenology and physiology of organisms, the range and distribution of species, the composition and interaction within communities, and the structure and dynamics of ecosystems.

Estuarine and coastal ecosystems are strongly affected by variations in climate through alterations in freshwater input, which result in changes in water temperature and salinity. Predicting the response of estuarine systems to future scenarios of climate change requires knowledge of the present relationships between estuarine and coastal communities and variations in local weather patterns. The impact of biological, hydrodynamic and large scale climatic variables on the zooplankton, ichthyoplankton, fish and jellyfish communities of Mondego estuary (evaluated from 2003 to present) are presented and discussed. Ongoing Research programmes in zooplankton, ichthyoplankton, fish and jellyfish communities on the Mondego estuarine system (Portugal) are also described.

General Concepts

Earth and Climate

Our Earth is the only astronomical object known so far to accommodate life. The primordial Earth was formed 4.54 billion years ago (Dalrymple, 2001) and life appeared at least 3.5 billion years ago (Schopf, 2006). The diversity of life forms on Earth has since expanded continually, except when interrupted by mass extinction events (Figure 1). It is estimated that over 99 % of all species that ever lived on the planet are extinct (Stearns and Stearns, 2000). A predicted number of 10 to 14 million species (Miller and Spoolman, 2000) currently habits Earth, of which about 1.2 million have been documented, but over 86 % remain to be described (Mora el al., 2011).

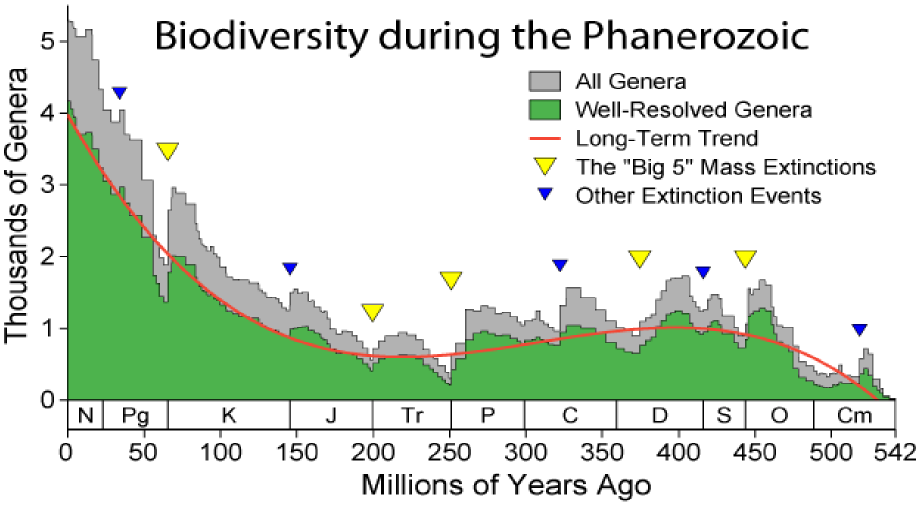


Figure 1. Trends of biological diversity during the Phanerozoic
(Licensed under CC BY-SA 3.0 via Commons
https://commons.wikimedia.org/wiki/File:Phanerozoic_Biodiversity.png#/media/File:Phanerozoic_Biodiversity.png)

The future of the planet is closely linked to that of the Sun. It is estimated that Earth may be able to continue to support life for a period of time ranging from 500 million years up to 2.3 billion years. Under natural conditions, the Sun's total luminosity is expected to slowly increase, thus increasing the radiation that reaches the Earth, which in turn will have various direct consequences. As the Earth's surface temperature increases, the inorganic CO_2 cycle is expected to accelerate, reducing its atmospheric concentration to levels which will be lethal for plants, from 500 to 900 million years from now. The consequent decrease of vegetation will result in the loss of O_2 from the atmosphere, which will lead to the extinction of animal life within several million more years.

Due to anthropogenic action, Earth is now facing different stressing conditions from those in the past. Since the period of the industrial revolution, the human population has grown, recently reaching 7.2 billion people on Earth in 2015. During this time period, recently referred to as Anthropocene (Waters *et al*., 2016), environmental conditions have changed due to our activities, namely there has been an increase of atmospheric CO_2 concentrations, as well as other "greenhouse" gases (F-gases, CH_4, CO_2, N_2O), an increase of atmospheric temperature, and also an increase of extremes of climate events. All current projections of climate models for the future predict that there will be an increase of (i) precipitation intensity, (ii) frequency of heat waves and (iii) number of dry days, and a decrease of number of frost days (IPCC, 2014).

Climate is now-a-days recognized as a complex, interactive system, with five major components: atmosphere, hydrosphere, cryosphere (frozen regions), land surfaces and the biosphere (particularly the regions of vegetation). These components are acted upon by a number of external factors, including the

Sun (changes in solar radiation), the volcanic activity, changes in plate tectonics, changes in the Earth's orbit, and human activities (Figure 2) (Wilson *et al*., 2012).

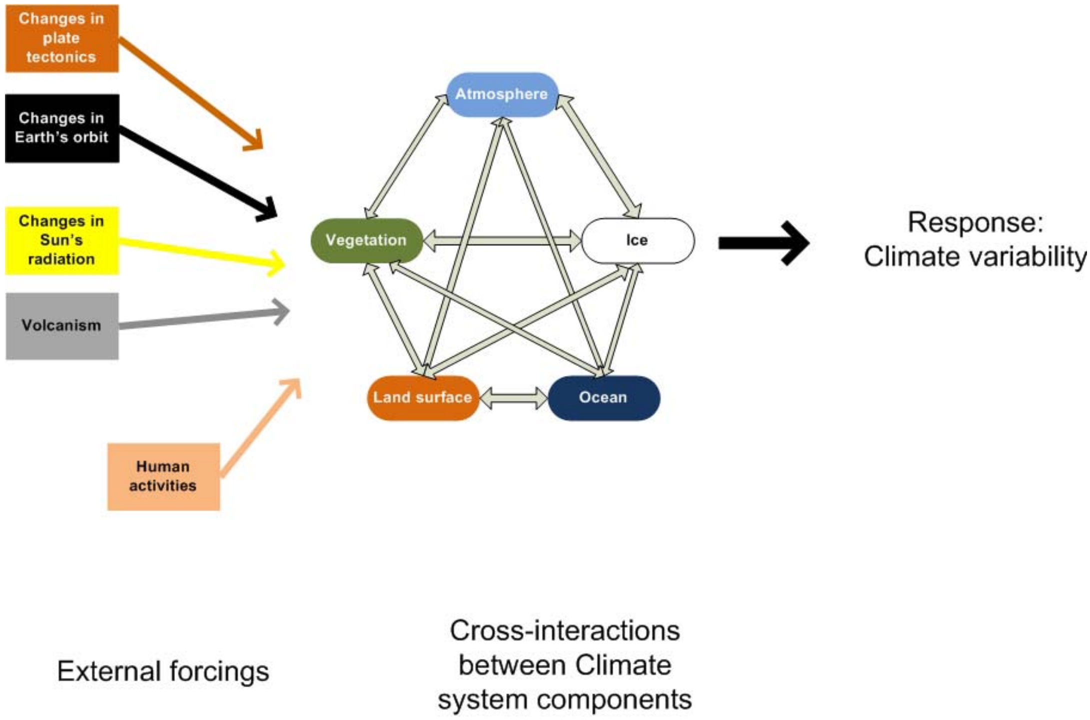


Figure 2. Climate as a complex, interactive system, with five major components: atmosphere, hydrosphere, cryosphere, land surfaces and the biosphere (from Wilson *et al*., 2012).

Biodiversity and the network of life

Biodiversity refers to all the diversity of life forms on Earth, including its genetic variation, species variation, and variation within ecosystems, within an area, biome or planet. Biodiversity is an essential component of ecosystems and underpins the provision of ecological, environmental, social and economic goods and services that we define as "*Ecosystem Services*", on which human survival and well-being depend upon (Corvalan *et al*., 2005). Biodiversity ensures for (i) *provisioning* services, such as food, fuel, shelter, medicines and other renewable resources, (ii) *supporting* services, such as nutrient cycles and crop pollination, (iii) *regulating* services, such as climate regulation, purification of water and air, and pest control (Cardinale *et al*., 2012), and for (iv) *cultural* services, such as spiritual and recreational benefits (Daniel *et al*., 2012). The conservation of biodiversity at all levels – genetic, species, ecosystem – is mandated by the International Convention on Biological Diversity (www.cbd.int/).

All life forms are open systems. Life forms exchange matter and energy with the external environment. Species interact with other species of plants, microorganisms and animals, through symbiotic interactions (such as mutualism, predation, competition, amensalism), as well as with the abiotic environment in which they live (using resources from the environment and releasing metabolic waste compounds, and thus altering their environmental conditions). Also, each species has its set of optimum environmental conditions (temperature, humidity, CO_2 concentration, O_2 concentration, pH, etc.) that define the circumstances in which they thrive, in which they survive, or in which they die.

The community of all living organisms together with the nonliving components in their environment, interacting as a system through nutrient cycles and energy flows, defines an *ecosystem*. Ecosystems can be of any size but usually encompass specific, limited spaces.

Some regions of the Earth have more or less the same abiotic and biotic features/ characteristics spread over a large area, creating a typical ecosystem over that area. Such major ecosystems are termed *biomes*. Biomes are defined by factors such as plant structures (such as trees, shrubs, and grasses), leaf types (such as broadleaf and needle leaf), plant spacing (forest, woodland, savanna), and climate. Biomes are climatically and biogeographically defined as contiguous areas with similar climatic conditions, and with similar communities of plants, animals, soil microorganisms, and viruses. The concept of biome illustrates well the dependence of ecosystems on climate factors (Figure 3). Six major types of terrestrial biomes and their characteristic vegetation are shown on Table 1.

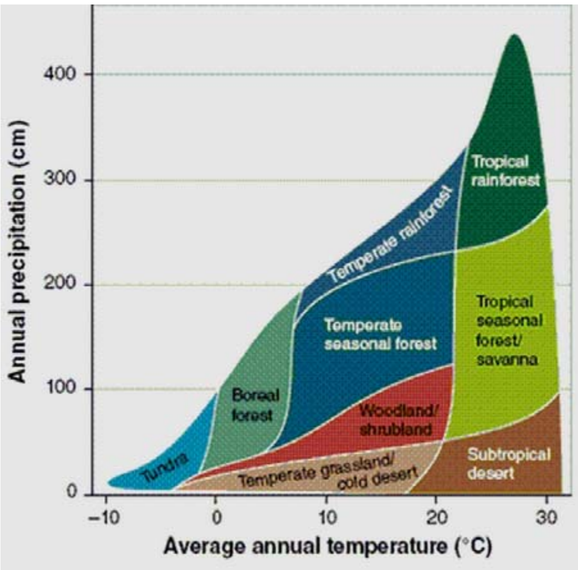
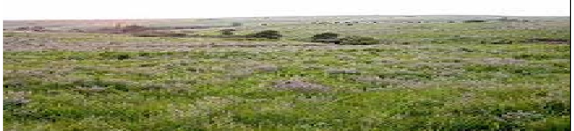


Figure 3. Classification scheme of the distribution of vegetation types (biomes) as a function of mean annual temperature and precipitation (from Whittaker, 1962).

Biodiversity and climate change

Each biological species has a set of optimum physiological conditions that define the environment in which they thrive, survive or die. When environmental conditions change and fall out of the optimum physiological ranges, for a given biological species, their populations may (i) migrate, (ii) evolve and adapt, (iii) survive in "refuges" or (iv) go extinct. Climate changes, through its components, will therefore naturally affect all life forms to some extent.

Table 1. Major terrestrial Biomes/Ecosystems and their Vegetation

Major Terrestrial Biomes/Ecosystems		*Characteristic vegetation*
	Tundra	grasses ,shrubs & lichens, no trees
	Taiga (or Boreal Forest)	coniferous evergreens
	Temperate forests	include evergreens (spruce), deciduous forests (oaks), mixed forests, and temperate rain forests (sequoias)
	Tropical rain forests	greatest amount of diversity in vegetation (vines, orchids, palms)
	Grasslands	grasses, prairie clover
	Deserts	cacti, small bushes

Climate changes are known to have affected biological evolution throughout its history, with major episodes in evolutionary radiations or mass extinctions (Figure 1; also see Harrison and Sanchez Goñi, 2010; Alroy, 2008). In the same manner, future climate changes will likely generate novel communities, due to the gain or loss of species in the existing communities. These new biological assemblages will also likely have different community dynamics, which may affect large-scale patterns and processes such as biome boundary shifts and ecosystem functions. The resulting interactions between species are difficult to predict and require extensive information and knowledge still very incomplete (Gilman *et al*., 2010).

So, if this is a normal process on Earth, why should we care about biodiversity, now? The present concern with biodiversity, under climate change scenarios, is due to it being a major component of ecosystems, on which human life and well-being depend upon.

- Ecosystems provide ecosystem services that sustain and fulfil human life (Alcamo *et al*., 2005), including food provision, fibre production, carbon sequestration, nutrient cycling, pollination, and climate regulation, among others.
- Biodiversity is substantially responsible for the resilience of these services under climate change and other environmental stresses.
- Biodiversity conservation is mandated by the International Convention on Biological Diversity.

As with other areas of global change science, current models / predictions are limited by incomplete theoretical knowledge, imperfect modelling tools and insufficient data to develop and improve the model projections. Some of the critical challenges for credible predictions of the climate change effects on biodiversity were identified, and recommendations were made for research priorities to reduce those uncertainties by IPCC Working Group 2 (see Settele *et al*., 2014; see McMahon *et al*., 2011).

Climate change in terrestrial ecosystems

Ecosystems are dynamic and respond to changes in climate and other environmental (biotic and abiotic) factors.

The climate changes that occurred in the late 20th century are now known to have affected a broad range of organisms (plants, animals, fungi, etc.) with diverse geographical distributions. These effects include (i) phenology and physiology, (ii) range of distribution of species, (iii) composition and interaction within communities and (iv) structure and dynamics of ecosystems.
Plants are a focus of study on climate change because their responses can affect entire food webs, disturbance regimes and crucial ecosystem services, including pollination, carbon and nutrient cycling, and water supply. Plants are components of vegetation and the main primary producers in terrestrial ecosystems, and the basis of food chains. Their energy source is the sunlight that they use to fix atmospheric CO_2 (through photosynthesis; that provides the carbon building blocks of life) and they absorb water and the dissolved nutrients that they need from the soil. Hence, general direct constraints for plant growth include:

(i) *incoming solar radiation*, regulates several processes e.g. photosynthesis,
(ii) *water availability and dissolved nutrients,* affect the duration of growth (e.g. leaf area and photosynthetic efficiency),
(iii) *air temperature*, which controls the duration of the growing period and other processes linked with the accumulation of dry matter (e.g. leaf area expansion, photosynthesis, respiration). As an example, above optimal temperatures, photosynthesis is first reversibly inhibited, and subsequently suffers increasing damage from which recuperation is slow or impossible. For most C_3 plant tissues, heat damage begins between 40 and 50 ºC, but some desert succulent plants (e.g. C_4 and CAM) can tolerate temperatures above 60 ºC (see Corlett, 2011).

Plants are also affected by local/regional climate constraints, such as heat stresses, hails and storms and floods. Additionally, the response of plants of climate change is influenced by their complex community interactions, including their microbial root community, where much research is needed (e.g. Pickles *et al*., 2012).

In animals, and particularly in mobile animals, acclimation to increasing temperatures can be behavioural (e.g. migration or other) rather than physiological. However, selecting cooler geographical areas may reduce species fitness in other ways, such as those related to specific interspecies and community interactions (Gilman *et al*., 2010).

The biogeochemical cycles are also impacted by climate change via a variety of mechanisms that involve interactions between plant and below-ground communities, namely at individual and community level. Interactions between plant and soil communities play a major role in determining the impact of climate change on ecosystem functioning and the carbon cycle, and the mechanisms involved operate over a wide range of spatial and temporal scales (Bardgett *et al*., 2013; Pickles *et al*., 2012).

Evolve, acclimate, move or die

Species' populations have a potential for *evolutionary response* under environmental stress conditions and over long periods. However, the role of biological evolution to rapid changing climate is a controversial issue. As a rule, species with short generation time (e.g. microorganisms, arthropods and annual plants) are expected to evolve faster, while species with long generation time will, generally, have lower evolution potential to rapid climate change.

There is a fast growing evidence that climate change influences phenology and physiology, and life cycles of many plants and animals (Figure 4; reviews in Walther *et al*., 2002; Wolkovich *et al*., 2012). For example, temperature changes are known to affect phenological processes of plants, such as flowering time, growth, or pollination time. As such, some Mediterranean deciduous plants now leaf 16 days earlier and fall 13 days later than 50 years ago. Also, plants in temperate zones have their flowering time occurring earlier in the season, and the growing season of some plants increased in both Eurasia in North America over past two decades (18 days and 12 days, respectively).

Climate changes are also reported to affect aspects of plant physiology, such as plant production (Friend, 2010).

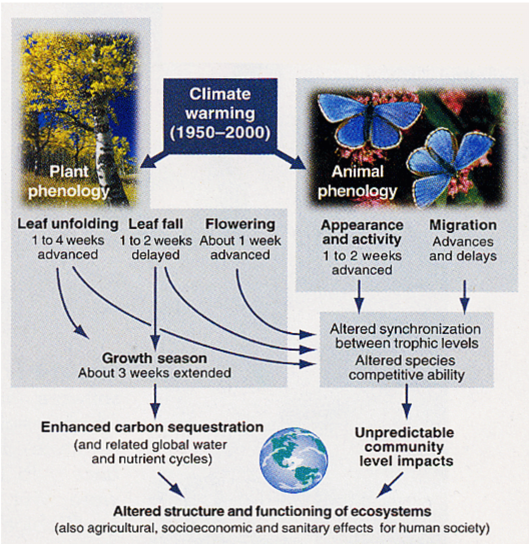


Figure 4. Ecological consequences of climate warming on plant and animal phenology (source: Penuelas and Filella (2001)

Species migration is a response to a changing environment.
Sessile organisms, such as plants, are physically incapable of moving, so plant migration, is mainly limited to their seeds dispersion and therefore potentially more impacted by a changing climate than mobile organisms. The effective colonization of a new geographical area depend on various factors, including environmental requirements of the species, species functional ecological traits and landscapes characteristics. Even though there are evidences of past forest migration (at rates above 50 km/ century) during episodes of climate change, at present, the problem is aggravated by the high level of fragmentation of natural landscapes, for agriculture or urban development purposes (e.g. Renton *et al*., 2013).

Increases in plant mortality in the tropical and old grown boreal forest and shifts in the range boundaries of species and plant functional types have been observed worldwide, and in some regions this has been attributed to climate change (Figure 5) (Settele *et al*., 2014). As an example, areas of northern Canada and Alaska are already experiencing rapid warming and reduction of ice cover. As a consequence, the vegetation existing in these areas will be replaced with temperate forest species. Also, tundra, taiga and temperate forests will migrate pole ward. Arid deserts are predictable to shrink, as precipitation increases. It is predicted that at the end of the 21st century there will be large scale shifts in the global distribution of vegetation.

The climate is changing more rapidly than plant migration can keep up. In this situation, some plants will face extinction because their habitat will become too small (e.g. mountain tops of European Alps).

Also, associated with increasing droughts, there is an increase in fire episodes. This was reported to have happened in the recent past and during the last glacial period (Moreno *et al*., 2014; Harrison and Goñi, 2010). The fire regime is predicted to change, increasing in the future, thus triggering a more rapid change from e.g. broadleaf forests to other biomes (such as savannas).

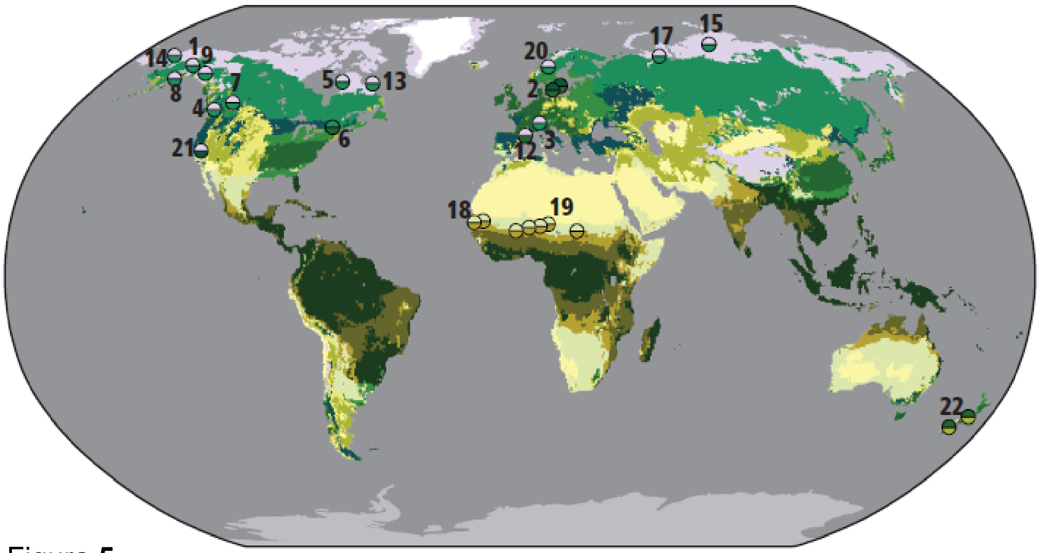
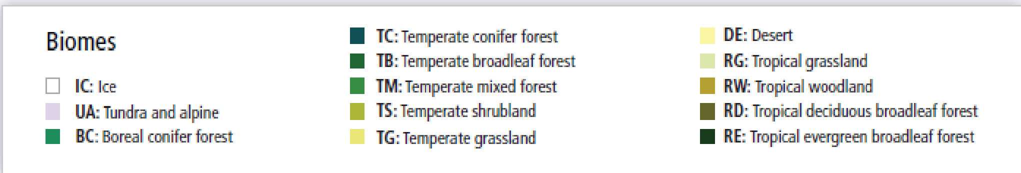


Figura **5**.



Locations of observed biome shifts during the 20th century, listed in Table 4-1, derived from Gonzalez et al. (2010). The color of each semicircle indicates the retracting biome (top for North America, Europe, Asia; bottom for Africa and New Zealand) and the expanding biome (bottom for North America, Europe, Asia; top for Africa and New Zealand), according to published field observations. Biomes, from poles to equator: ice (IC), tundra and alpine (UA), boreal conifer forest (BC), temperate conifer forest (TC), temperate broadleaf forest (TB), temperate mixed forest (TM), temperate shrubland (TS), temperate grassland (TG), desert (DE), tropical grassland (RG), tropical woodland (RW), tropical deciduous broadleaf forest (RD), tropical evergreen broadleaf forest (RE). The background is the potential biome according to the MC1 dynamic global vegetation model under the 1961–1990 climate. No shift was observed on locations 10, 11, 16, and 23

(source: Settele *et al*., 2014)

Climate change in marine ecosystems

Marine ecosystem are important to human societies as they provide services such as the supply of food (fisheries and aquaculture) and other natural resources; nutrient recycling; regulation of global climate, including production of oxygen (O_2) and removal of atmospheric carbon dioxide (CO_2); protection from extreme weather and climate events; and aesthetic, cultural, and supporting services. Estuaries and coastal ecosystems share the provision of these services and constitute important habitats, including nursery and refuge areas, for a multitude of commercially important species.

Climate variability influences the abundance, structure and biodiversity of both marine ecosystems and estuaries and coastal ecosystems, by affecting their main drivers (salinity, circulation, temperature, nutrients, CO_2, O_2 and light). Therefore, a better knowledge of their sensitivity to both human intervention and climate variability is essential.

Estuaries and coastal ecosystems are particularly, and strongly, affected by variations in climate, mainly through alterations in freshwater input (which result in changes in water temperature and salinity), increasing air and water temperature, shifts in connectivity to the sea and increased intrusion of marine waters.

The Intergovernmental Panel on Climate Change has published severe climate scenarios, namely seawater temperature rising and the increase in occurrence and magnitude of extreme events such as floods and droughts (IPCC, 2007). In its 5th Report, the IPCC predicts that coastal systems will increasingly experience the rise of sea level with its adverse impacts. It is also predicted that acidification and warming of coastal waters will continue with significant negative consequences for coastal ecosystems (Wong *et al*., 2014).
However, evaluation of the responses of marine ecosystems and assessment of negative impacts of climate changes are still scarce in literature, imposing a need for more and continued global studies. Predicting the response of estuarine systems to future scenarios of climate change requires knowledge of the present relationships between estuarine and coastal communities and variations in local weather patterns.

Ecological responses to recent climate change in estuarine ecosystems

The Mondego river estuary is a mesotidal system, located in the western Atlantic coast of Portugal (40º08’N, 8º50’W). Its hydrological basin has an area of 6670 km^2 and provides an average freshwater flow rate of 79 $m^3 s^{-1}$. Mondego is a well-mixed estuary with two channels, separated by a small island. Most of the freshwater discharge is throughout the northern channel which is directly connected with the Mondego River.

The response of the Mondego estuary (Portugal) biological communities to environmental fluctuation has been studied over the last decades. In particular, the impact of biological, hydrodynamic and large scale climatic variables on the zooplankton, ichthyoplankton, fish and jellyfish communities of Mondego estuary were evaluated from 2003 to 2013 (e.g. Marques *et al*., 2014; Primo *et al*., 2012; Primo *et al*., 2015; Rodrigues and Pardal, 2015).

In the Mondego estuary, primary productivity is mostly carried out by phytoplankton (and less by seagrass or macroalgae). In this estuary, the intra-annual and inter-annual variations in the primary productivity were found to fluctuate temporally due to climate-driven events (Rodrigues and Pardal, 2015). Structural changes in the zooplankton communities of the estuary were also observed and related to climate driven factors, such as wind, air temperature, water temperature and salinity (Figure 6; Primo *et al.*, 2012; 2015).

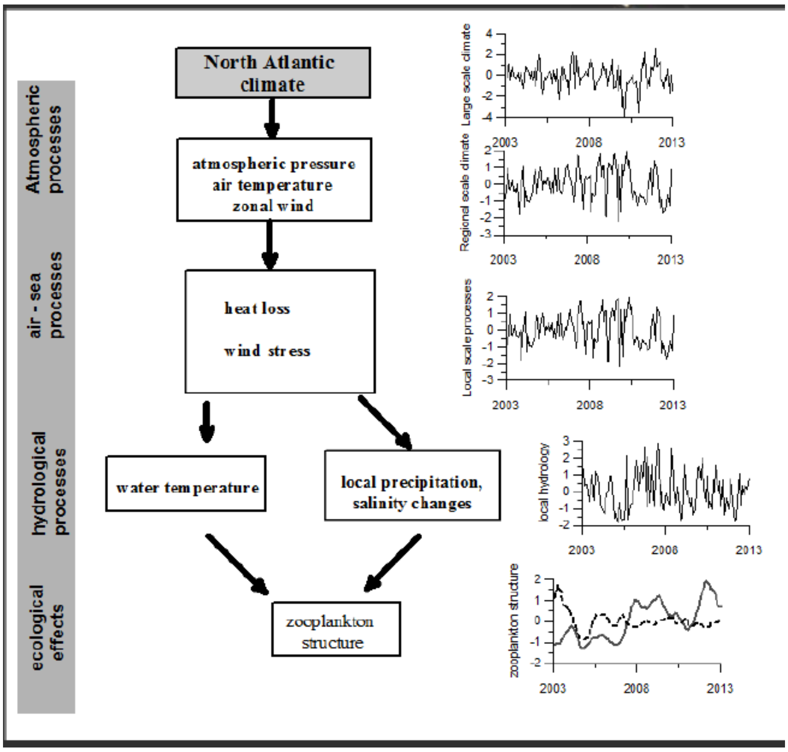


Figure 6. Conceptual diagram of cascading processes shaping the interannual changes of zooplankton in the Mondego Estuary (source: Marques *et al.*, submitted).

Climate variations (drought events versus non-drought) were also found to cause changes in the structure and composition of the fish community in the Mondego estuary; in non-drought years, the more important species of the fish community were present, and in greater densities than in drought years (Baptista *et al.*, 2010).

Large climate events and their influence in winds and ocean currents also seemed to influence directly and indirectly the community and the phenology of jellyfish blooms in the Mondego estuary, between 2003 and 2013; temperature was found to be a major factor influencing jellyfish communities (Primo *et al*, 2012). A causal factor of jellyfish increase in these ecosystems has been suggested to be the removal of competitors and predators, in concurrence with warming conditions (Thrush and Dayton, 2010). The loss of top predators (e.g. fish) and habitat destruction remove the environmental heterogeneity created by large and old organisms and decreases the depth and extent of sediment bioturbation and bioirrigation, resulting in the collapse of the ecosystem. Thus the findings with the jellyfish community in the

Mondego estuary, under warming conditions, may also hint to an ecosystem collapse under those climate change events.

Hence, these long time series studies have allowed to gain a better understanding of the relationships between estuarine and coastal communities and variations in local weather patterns in the Mondego estuary, issues that are of great importance in understanding and managing these ecosystems (Figure 7).

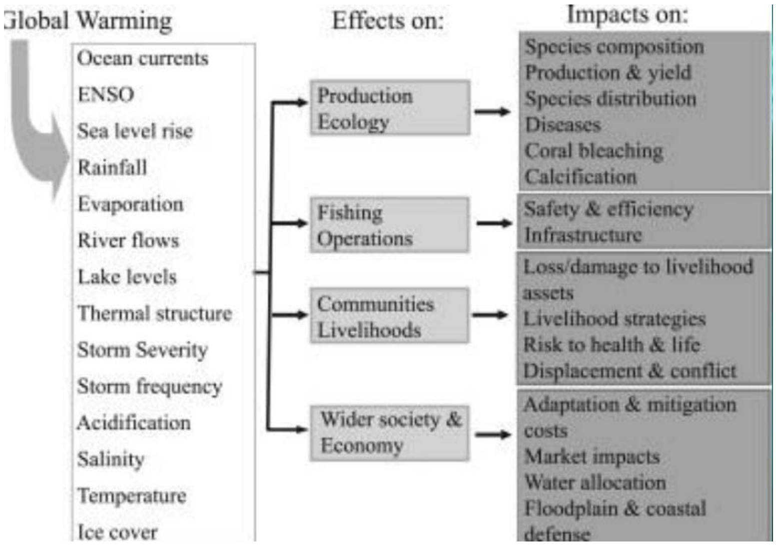


Figure 7. Global Warming and Fisheries (source: Badjeck *et al*., 2010)

Concluding remarks

Climate change is a global science subject, which needs to be studied and understood in that complex context. The dimensions of climate change issues and climate change analysis comprise (at least) the following dimensions:

- Biodiversity,
- Agriculture and Forestry,
- Ecological and Economic,
- Health and Environmental Health (the health system response to climate change, and to ensure that health is appropriately considered in decisions made by other sectors, such as energy and transport),
- Human (solutions to the many problems of climate change mitigation and adaptation will require an understanding of the human aspects of the problem),
- Cultural (cultural dimensions of lives and livelihoods that include the material and lived aspects of culture, identity, community cohesion and sense of place),
- and Social dimensions (Equity and Vulnerability).

This chapter aimed to contribute towards a better understanding of the core ideas in “Biodiversity and climate change” and to the development of a climate-literate public.

References

Alroy, J (2008). "Dynamics of origination and extinction in the marine fossil record". Proceedings of the National Academy of Sciences of the United States of America, 105, 11536–11542. doi:10.1073/pnas.0802597105.

Baptista, J; Martinho, F; Dolbeth, M; Viegas, I; Cabral, H and Pardal, M (2010) “Effects of freshwater flow on the fish assemblage of the Mondego estuary (Portugal): comparison between drought and non-drought years”. Marine and Freshwater Research, 61,490-501.

Badjeck M-C; Allison, EH; Halls, AS and Dulvy, NK (2010) “Impacts of climate variability and change on fishery-based livelihoods”. Marine Policy, 34, 375–383.

Bardgett; RD; Manning, P; Morrien, E and De Vries, FT (2013) “Hierarchical responses of plant–soil interactions to climate change: consequences for the global carbon cycle”. Journal of Ecology, 101, 334–343.

Corlett, RT (2011) “Impact of warming on tropical lowland rainforests”. Cell Press. 26(11), 606-612. doi:10.1016/j.tree.2100.11.015.

Corvalan, C *et al*., 2005 “Ecosystems and Human Well-being: Health Synthesis”. A report of the Millennium Ecosystem Assessment.

Cardinale, B *et al*. (2012). "Biodiversity loss and its impact on humanity". Nature, 486 (7401), 59–67. doi:10.1038/nature11148.

Daniel, TC *et al*. (2012). "Contributions of cultural services to the ecosystem services agenda". Proceedings of the National Academy of Sciences 109(23), 8812–8819. doi:10.1073/pnas.1114773109.

Dalrymple, GB (2001). "The age of the Earth in the twentieth century: a problem (mostly) solved". Special Publications, Geological Society of London 190(1), 205–221. doi:10.1144/GSL.SP.2001.190.01.14.

Friend, AD (2010) “Terrestrial production and climate change”. Journal of Experimental Botany, 61, 1293-1309.

Gilman, SE; Urban, MC; Tewksbury, J; Gilchrist GW and Holt RD (2019) “A framework for community interactions under climate change”. Trends in Ecology and Evolution, 25, 325-331.

Harrison, S and Sanchez-Goñi, MF (2010) “Global patterns of vegetation response to millennial-scale variability and rapid climate change during the last glacial period”. Quaternary Science Reviews, 29, 2957-2980.

IPCC (2007) Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, RK and Reisinger, A (Eds.)]. IPCC, Geneva, Switzerland. pp 104.

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, RK Pachauri and LA Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Penuelas, J and Filella, I (2001) “Response to a warming world”. Science, 294, 793 – 795.

Pickles, BJ; Egger KN; Massicotte, HB and Green, DS (2012)”Ectomycorrhizas and climate change”. Fungal Ecology, 5, 73-84.

Primo, AL; Kimmel, DG; Marques, SC; Martinho, F; Azeiteiro, UM and Pardal, MA (2015) “Zooplankton community responses to regional scale weather variability using a synoptic climatology approach. Climate Research”, 62, 189–198. doi: 10.3354/cr01275.

Primo, AL; Marques, SC; Crespo, D; Falcão, J; Pardal, MA and Azeiteiro, UM (2012). “Environmental forcing on jellyfish communities in a small temperate estuary”. Marine Environmental Research, 79, 152–159. doi: 10.1016/j.marenvres.2012.06.009.

Marques, SC; Primo, AL; Martinho, F; Azeiteiro, UM and Pardal, MA (2014) “Shifts in estuarine zooplankton variability following extreme climate events: a comparison between drought and regular years”. Marine Ecology Progress Series, 499, 65–76. doi: 10.3354/meps10635.

Marques, SC; Pardal, MA; Primo, AL; Martinho, F; Falcão, J; Azeiteiro, UM and Molineiro, JC, (*Submitted*). “Discontinuous climate forcing foster structural changes in estuarine zooplankton”. PLOS ONE.

Miller, G. and Spoolman, S. (2012). Environmental Science - Biodiversity Is a Crucial Part of the Earth's Natural Capital. Cengage Learning. p.62. ISBN 1-133-70787-4. (Retrieved 2014-12-27).

Mora, C; Tittensor, DP; Adl, S; Simpson AG and Worm, B (2011). "How many species are there on Earth and in the ocean?". PLOS Biology. doi:10.1371/journal.pbio.1001127. (Retrieved 26 May 2015).

Moreno, MV; Conedera, M; Chuvieco, E and Pezzatti, GB (2014) “Fire regime changes and major driving forces in Spain from 1968 to 2010”. Environmental Science & Policy, 37, 11–22. doi:10.1016/j.envsci.2013.08.005

Renton, M; Childs, S; Standish, R and Shackelford, N (2013) “Plant migration and persistence under climate change in fragmented landscapes: Does it depend on the key point of vulnerability within the lifecycle?”. Ecological Modelling, 249, 50– 58.

Rodrigues, ET and Pardal, MA (2015) Primary productivity temporal fluctuations in a nutrient-rich estuary due to climate-driven events. Estuaries and Coasts, 38,1-12.

Settele, J; Scholes, R; Betts, R; Bunn, S ; Leadley, P; Nepstad, D; Overpeck, JT and Taboada, MA (2014) "Terrestrial and inland water systems". *In* Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, CB, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea, and LL White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 271-359.

Schopf, JW (2006). "Fossil evidence of Archaean life", Philosophical Transactions of the Royal Society of London B Biological Sciences, 361(1470), 869-85. doi: 10.1098/rstb.2006.1834.

Stearns, BP and Stearns, SC (2000). "Watching, from the Edge of Extinction". Yale University Press. p.1921. ISBN 978-0-300-08469-6.

Thrush S and Dayton P (2010) "What can ecology contribute to Ecosystem-Based Management?". Annual Review Marine Science, 2, 419-441.

Walter, GR *et al*. (2002) "Ecological responses to climate change". Nature, 416, 389-395.

Waters, CN *et al*. (2016) "The Anthropocene is functionally and stratigraphically distinct from the Holocene" Science, 351 (6269) doi: 10.1126/science.aad2622.

Wilson, G; Otto, D and Abbott, D (2012) T869 "Climate change: from science to lived experiences". Module 1: Introduction to climate change in the context of sustainable development. Workbook. United Kingdom: Open University. 37 p. (http://hdl.handle.net/10400.2/2126).

Whittaker, RH (1962)"Classification of Natural Communities". Botanical Review, 28(1), 1–239.

Wolkovich, EM, *et al*. (2012) "Warming experiments underpredict plant phonological responses to climate change". Nature, 485, 494-497.

Wong, PP; Losada, IJ; Gattuso, J-P; Hinkel, J; Khattabi, A; McInnes, KL; Saito, Y; and Sallenger, A (2014) "Coastal systems and low-lying areas". In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC [Field, CB, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea, and LL White (eds.)]. Cambridge University Press, Cambridge, UK and NY,USA, pp. 361-409.