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GLOBAL CLIMATE CHANGE AND MARINE CONSERVATION

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1. Introduction

Global climate change is real. Compilations of instrumental global land and sea temperatures back to the mid-nineteenth century provide strong evidence of a warming world and recent unusual warmth, with 9 of the 10 warmest years since 1850 occurring between 1997 and 2006. The most recent projections of global climate change due to the enhanced greenhouse effect suggest that global average temperature could warm by 1.1°C to 6.4°C over 1980–1999 values by 2100, with best estimates ranging from 1.8°C to 4.0°C. These estimates are generally consistent (although not strictly comparable) with the earlier projections of 1.4°C to 5.8°C, and are based on more climate models of greater complexity and realism and better understanding of the climate system (Lough, 2007).

Global climate has always fluctuated, but the scale tends to be over tens of thousands of years. In the last few centuries, we have experienced an accelerated rate of climate change, largely due to the release of industrial gases, and especially of carbon dioxide (CO₂). By 2100, atmospheric CO₂ is expected to exceed 500 ppm, and global temperatures to rise at least 2°C, exceeding conditions of the past 420,000 years (Hoegh-Guldberg et al., 2007). The Earth's radiative heat balance is currently out of equilibrium, and mean global temperatures will continue to rise for several centuries even if greenhouse gas emissions are stabilized at present levels (IPCC, 2001).

In the marine environment, ongoing studies by NOAA (United States National Oceanic and Atmospheric Administration) scientists show that changes in surface temperature, rainfall, and sea level will be largely irreversible for more than 1,000 years after carbon dioxide emissions are completely stopped (Solomon et al., 2009). Global sea levels are predicted to rise for the next 1,000 years; the minimal irreversible global average sea level rise is predicted to be at least 0.4–1 m in the year 3000, and possibly double that if CO₂ peaks at 600 ppm. (Present concentrations are around 385 ppm.) The rise in sea level will be mainly due to two factors: thermal expansion of the ocean's water and input from melting ice.

Possibly as important as sea-level rise there will be changes in ocean chemistry (Diaz-Pulido et al., 2007). Continued emission of CO₂ will acidify sea waters. Oceanic pH is projected to decrease by about 0.4–0.5 units by 2100 (e.g. a change from pH 8.2 to 7.8).

The Mediterranean Sea, a somewhat special case as a smaller enclosed basin, will have additional problems of higher surface water temperatures and rising salinity. Sevault et al. (2004), using the high-resolution Ocean Regional Circulation Model OPAMED8, anticipated a surface temperature rise of 2.5°C by 2100, and a regionally variable salinity increase between 0.12 and 0.19 psu, with about 0.4 psu increase in the Aegean and Adriatic seas, in a scenario for years 2060 to 2100.

Israel fits the general pattern of rising sea levels. Monthly averaged sea-level changes at the Mediterranean coast of Israel during 1992–2008 show a rise of 8.5 cm in 16 years. (Data from the Hadera GLOSS station 80, operated by Israel Oceanographic and Limnological Research Institute.)

2. Responses to Global Climate Change

The impact of global climatic change on marine systems seems to be mainly felt in two areas. First is the impact on coastal waters, where rising sea-level shifts the distribution of species, and surface waters become warmer. Second, and more dramatic, is the impact on coral reefs.

2.1. COASTAL ZONES

Sixty percent of all human beings live on a 60-km wide strip of coastal zone in the world. Marine coastal water is the seat of 14–30% of the ocean's primary production, and 90% of the fishing catch. Sea-level rise will shift the habitats especially of coastal waters (UNEP-MAP-RAC/SPA, 2008).

Some local studies have been carried out on the effects of climate change in marine communities (Parmesan, 2006). In Monterey Bay, Sagarin et al. (1999) observed a decline in northern species and an increase in southern species. Similar patterns were seen in the English Channel (Southward et al., 1995, 2005) with a decline in cold-adapted fish and increase in warm-adapted fish. Similar patterns were observed in invertebrates (Parmesan, 2006).

Harley et al. (2006) predict changes in pH of oceans without precedent in the last 200–300 million years. Upwelling could either increase or decrease. Landward migration of intertidal habitats and biota may be impeded by anthropogenic infrastructure (sea walls, etc.). An increase in storm damage is expected. Biological interactions are likely to be affected (for example, sea star *Pisaster ochraceus* is quite likely to be more active in a warmer climate, with larger effects on mussel beds). Harley et al. (2006) expect “squeeze effects,” with potential shifts in distribution limited by a physical barrier (sea bottom, etc.) leading to local extinctions.

There is difficulty in predicting the effects of global climate change on diversity of marine plant life. However, the competitive interaction of sea grasses and macroalgae may be predicted, with CO₂ levels rising, and intertidal macroalgae already at CO₂ saturation (Beardall et al., 1998). Review of literature so far (Short and Neckles, 1999) suggests shifts in the distribution of sea grasses. Driving factors include temperature stress (and its effects on reproduction), eutrophication, and the frequency of extreme weather events. Changing water depths redistribute habitats (zonation); change in salinity affects physiology and reproduction in sea grasses. Increased disease activity is anticipated, as is shifting competition between sea grass and algae, with the advantage going to the sea grasses.

Short and Neckles (1999) also anticipate synergistic effects: the outcome of the physical changes under global change will be complicated by interactions among biological and physical factors. For example, there is a strong interaction between temperature and CO₂ effects on calcification (the impact is greater at warmer temperatures and there is a threshold). Interactions with anthropogenic factors (overfishing, pollution) will be more easily managed.

Changes in the Mediterranean Sea have been studied by United Nations teams (UNEP-MAP-RAC/SPA, 2008). Globally, the anticipated extinction rate of species in the Mediterranean is about 15–37% by 2050. There are some observed species shifts: *Sardinella*, barracudas, and coryphenes are moving north in fisheries quantities; but sprat and anchovy (small pelagics) have collapsed and tuna and amberjack have changed in their distributions. Lessepsian migrants (Galil, 2007) are on the increase in the eastern Mediterranean. Heat stress is killing sponges and gorgonians, with crashes in extremely hot spells in 1999 and 2003. Heat has also been found to trigger virulence of *Vibrio* pathogens in sponges, cnidaria, and echinoderms; apparently by inhibition of defense mechanisms of individuals subjected to heat stress.

2.2. CORAL REEFS AND MACROALGAE

Changes in pH, CO₂, and calcium carbonate saturation state will have biggest impacts on corals, and crustose and upright calcareous macroalgae. This may shift the balance in favor of turf algae over corals. Increase of CO₂ may not only reduce calcification but ultimately dissolve calcified skeletons (Diaz-Pulido et al., 2007).

The second and more obvious impact on coral reefs comes when acidification is combined with higher sea surface temperatures. Elevated sea temperatures as small as 1°C above summer average can lead to bleaching (loss of coral algal symbiotic zooxanthellae following chronic photoinhibition). After bleaching of coral occurs, acidification of water slows recovery. It is recognized that skeleton producing corals grown in acidified experimental conditions can persist and reproduce in a sea anemone-like form, and then revert to skeleton building when the conditions permit (Fine and Tchernov, 2007). However, according to some

projections, by 2050, oceans may become too acidic for corals to calcify (Caldeira and Wickett, 2003; Hoegh-Guldberg, 2005; Orr et al., 2005).

Corals are expected to become increasingly rare on reef systems, resulting in less diverse reef communities (Hoegh-Guldberg et al., 2007). Carbonate reef structures will fail to be maintained. Compounded by local stresses, functional collapse of reef systems is anticipated in some locations. This has consequences for other habitats (Hoegh-Guldberg, 1999). Coral reefs protect coastlines from storm damage, erosion, and flooding. The protection they afford enables the development of mangrove swamps and sea grass beds. As coral reefs fail, all these services will decline.

One of the anticipated effects of coral bleaching is increased substrate availability for algal turf, upright macroalgae, and crustose calcareous algae (Diaz-Pulido et al., 2007). This may be balanced by their vulnerability to terrestrial nutrient and sediment input, which may increase with erosion and desertification. Turf algae are expected to be the best competitors for the newly open spaces.

2.3. MARINE ALGAE

A summary of macroalgae response to anticipated climate change shows both positive and negative responses for nearly every climatic stress: change in ocean circulation, increased water temperature, increased CO₂, acidification, increased light and UV, sea-level rise, tropical storms, terrestrial inputs, and increased substrate availability (Diaz-Pulido et al., 2007). Algal turfs have predominantly positive response; upright macroalgae are balanced between positive and negative responses, and crustose calcareous algae, like coral, tended to have negative responses.

The direct impact of global climatic thermal rise is presumed minor due to wide temperature tolerance of macroalgae, but the high diversity of macroalgae species makes net response unpredictable. Higher temperatures may enhance turf algae as opposed to fleshy algae.

3. Recommended Conservation Measures

The general strategy for marine conservation under global climate change is best expressed by the United Nations study of the Mediterranean:

At the end of this study, it is necessary to remember that climate change and its effects are irremediable processes. In the long term, the major issue will probably be no more than successfully predicting the future of Mediterranean biodiversity, the future composition of the fisheries and the underwater landscapes, and adapting our ways of using them accordingly. (UNEP-MAP-RAC/SPA, 2008)!

The essentially irreversible nature of global climate change has been suspected for a long time; only the magnitude of change has been questioned. Hence,

conservation strategies have largely focused on amelioration of global climate changes and their effects, rather than efforts to reverse them.

So far, amelioration suggestions are sparse. In general, there are no suggestions that the direct effects of global climate change can be reversed. Instead, the suggestions are to increase system resilience by (1) reducing other stresses (such as overfishing) and (2) develop corridors and refuges for restocking.

3.1. COASTAL AREAS

Since global climate change is essentially irreversible in practice, mitigation strategies are necessary in coastal marine systems (Harley et al., 2006). Among the recommendations:

- (a) Marine protected areas and no-take reserves, based on known spatial and temporal refuges that can act as buffers against climate-related stress
- (b) Fisheries management
- (c) Prioritization of key species (by functional role in marine communities)

3.2. MEDITERRANEAN

UNEP-MAP-RAC/SPA (2008): Conservation measures in the Mediterranean mostly focus on improving adaptability (resilience) following the model of Hulme (2005). Specific recommendations include:

- (a) Widen the knowledge base about anticipated impact of global climate change on species and communities to rising temperature, rising sea level, changing rainfall regimes (river spates), increased solar radiation, modification of currents, and changes in biogeochemistry (e.g. pH).
- (b) Epidemiological studies. Changing disease patterns is an anticipated concern (see also Harvell et al., 1999).
- (c) Develop predictive modeling.
- (d) Build federal programs.
- (e) Develop economic indicators: what is the cost of global climate change and of conservation?
- (f) Assist developing countries in order to assess their vulnerability.
- (g) Good ecological engineering. Adaptations of infrastructure to global climate change tend to counter biodiversity conservation choices.
- (h) Adapt and change fisheries patterns.
- (i) Possibly implement transplantation if species decline locally.
- (j) Eliminate other sources of disturbance and stress (pollutants, invaders).
- (k) Enhance connectivity for refuges and restocking.
- (l) Work on the scale of the whole Mediterranean basin.
- (m) Protect relict, non-impacted systems by reserves.

3.3. CORAL REEFS

On its web site, the Nature Conservancy organization (TNC) has outlined its conservation strategies with respect to climate change and its impact on marine protected areas (see www.nature.org/initiatives/marine/strategies/art12286.html).

Much of the TNC focus is on coral reefs. Nature Conservancy strategies include locating areas where marine life resists bleaching and creating networks of protected areas to help nearby degraded areas to recover. Much of the strategy is to identify areas where marine life, including corals, seems relatively resistant to damage and focus on conserving these areas as refuges. In the case of coral reefs, connectivity is a consideration, with networks of protected areas allowing one area to provide colonizers to another if it should become degraded.

3.4. COASTAL MANGROVE WETLANDS

It is estimated that between human reclamation of coastal wetlands and rising sea levels due to global climatic change, by 2080 we will have lost about 80% of the world's coastal wetlands. TNC also has a focus on managing mangroves for resilience to climate change (McLeod and Salm, 2006). Most of the strategies are expected: protect coastal mangroves from other anthropogenic stressors to enhance their resilience, maintain buffer zones, restore areas with good prospects, maintain connectivity, develop adaptive management strategies, etc.

3.5. MACROALGAE

Management recommendations are mainly due to concern about expansion of algal turf, rather than loss of macroalgal cover or species. The first recommendation is to protect populations of algal herbivores, then to minimize terrestrial runoff and other sources of nutrient, sediment, and toxicant pollution. Protection of corals will also reduce expansion of macroalgae (Diaz-Pulido et al., 2007).

4. Summary

In general, the situation of marine environments under global climate change looks very bad. The factors anticipated to cause the most change in the marine environment (e.g. sea-temperature and sea-level rises) are also those least likely to be affected by amelioration, and should be seen as permanent, irreversible changes. This is grim but recognition of the situation will make practical conservation measures more effective. The standard practices for any kind of conservation (reduce environmental stress, protect key habitats, develop and protect corridors for dispersal) apply here as well. Beyond that, we simply do not have many good ideas.

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