Vulnerability of top predators to climate change and adaptations for coastal and pelagic ecosystems: sharks, a case study

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The Eastern Tropical Pacific (ETP) covers a vast area of highly productive ocean, from the Gulf of California south to Ecuador and northern Peru. Its coastal fringe includes all types of coastal habitat – mangroves, rocky shores, sandy beaches, deltas and estuaries. Its open water habitats include the continental shelf, seamounts, oceanic islands, deep sea ridges and the abyssal plain. It supports large fleets of commercial longliners and seiners, but also boasts several marine protected areas (MPA), notably the oceanic reserves of Galapagos (Ecuador), Cocos (Costa Rica), Malpelo (Colombia), the Revillagigedo Biosphere Reserve (Mexico) and several coastal areas which include some nearshore islands such as Coiba (Panama) and Gorgona (Colombia).

The ETP lies under the descending limb of the atmospheric Walker cell (Bjerkness 1969), an area where southeasterly trade winds push warm surface water to the west, allowing colder subsurface currents to rise. During El Niño events, SST rises as trade winds slacken, upwelling weakens and a deeper mixed layer replaces the shallow thermocline of the ETP (Conroy et al 2009). It is the upwelling that accounts for the high productivity of the region – the Humboldt Current to the south, the California Current to the north and the Cromwell Current, which rises to the surface along the equator at the Galapagos Islands, all drive primary production, the base of the marine food web. Recent analyses show that the Walker Circulation is weakening as a result of human-induced global warming (Vecchi et al 2006). The results of this over the next century may be further warming of the ocean, sea level rise, and increasing frequency and intensity of El Niño events.

There are at least 88 species of sharks in the ETP region (Zarate & Hearn 2008), and they inhabit every marine habitat present, from the brackish estuarine bull shark (*Carcharhinus leucas*), to the open water oceanic white tip (*C. longimanus*), and the recently discovered deep water Galapagos catshark, (*Bythaelurus sp. B*). Some species are highly migratory and have a global distribution, such as the blue shark (*Prionace glauca*), whereas others are more sedentary and may be endemic to very small areas, such as the Galapagos bullhead shark (*Heterodontus quoyi*). Several species are heavily fished (sometimes as by-catch, sometimes as target species for their fins) – the scalloped hammerhead (*Sphyrna lewini*), threshers (*Alopias sp.*) and makos (*Isurus sp.*). Little is known about the reproductive behavior and population status of many of the shark species present, so it is difficult to predict how each species will adapt to changing climatic conditions. However, a look into the past might give some insights.

The first chondrychthyans evolved over 450 million years ago. As a group, they are ancient, and highly successful. They have survived through several major extinction events. At the end of the Devonian period, 377 million years ago, 51 of the 70 families of fishes present at the time were wiped out – an extinction rate of 73%, one of the highest ever recorded. This may have been a direct result of the loss of many primary producers, or due to a rapid cooling of the oceans, which would have wiped out many tropical species. The greatest extinction occurred at the end of the Permian, 251 million years ago, when

80-96% of all marine species were lost over a period of 500,000 years. The majority of the extinctions occurred at low latitudes near the equator. Other mass extinctions occurred in the Triassic (212 million years ago) and the Cretaceous (65 million years ago). Each extinction event is thought to have brought about harsh and long-term changes in environmental conditions – biodiversity took over a million years to recover in each case.

One particular species, the giant-tooth shark, *Carcharadon megalodon*, a larger relative of the great white, may have become extinct due to climate change – although in this case global cooling rather than warming may have been the trigger. It first appeared around 65 million years ago, when all the oceans were warm, and it fed on toothed cetaceans, unlike the great white, which feeds on pinnipeds. As the waters cooled during the Pliocene, great whites were able to develop an endothermic physiology, whereas it seems that *C. megalodon* was unable to do this, and was thus cut off from its main prey, who had adapted to living at the cooling high latitudes.

However, current climate change points in the opposite direction – towards warming of the waters. It has been suggested that this may actually be good news for the Australian grey nurse shark, *Carcharias tauras*. This species is split into two isolated populations, one on the east coast of Australia, and one on the west, both of which are endangered. It is thought that the warming of the waters south of Australia may permit mixing of individuals between the populations and thus reduce the risk of extinction (http://www.abc.net.au/news/stories/2008/09/23/2371480.htm).

Until recently, it was also thought that marine extinctions were virtually impossible, and that fertile seas were the source of inexhaustible supplies of fish. This view has changed abruptly over the last few years. According to Myers & Ottensmeyer (2005), many marine species, such as sharks, may be vulnerable to extinction because of a variety of factors:

1. Long age at sexual maturity
2. Low reproductive rate
3. Adaptation to an environment with little disturbance
4. Targeting by industries encouraged to overexploitation through subsidies

Unlike most bony fish, sharks tend to be long lived, attain sexual maturity late in life, and produce few offspring. They generally display low levels of natural mortality, but this makes them especially susceptible to un-natural mortality (such as fishing). Many shark stocks have been driven to dangerously low population levels by unsustainable fishing practices - in a study of 17 shark fisheries carried out worldwide, only one was considered sustainable at the time of study (Stevens et al 2000).

The direct effects of global warming include a rise in sea temperature and therefore a lower level of oxygen in the water, and possible salinity changes in coastal areas due to runoff. While temperature may influence behavior – many sharks will feed in warmer waters and rest in cooler waters (Matern & Cech 2000), their mobile nature may lead to a change in their distribution as they seek optimal conditions elsewhere.

Indirect effects may be more damaging – loss of key nursery habitat such as coastal mangrove areas, and degradation of the food web, starting with loss of primary production resulting from decreased upwelling. Whale sharks may feel these effects directly – their movements have been correlated with the availability of plankton, and Stewart & Wilson (2005) suggested that coral bleaching events, which are related to increasing water temperatures, and rapid climate change are amongst the greatest threats to whale sharks. Chin & Kyne (2007) undertook a vulnerability assessment of sharks to climate change at the Great Barrier Reef, dividing the sharks (and rays) into six functional groups and looking at the climate change drivers which affected each group (Figure 1). They developed a vulnerability index composed of exposure, sensibility (habitat specificity, rarity) and inadaptability (chemical intolerance, trophic specificity), for specific climate change drivers.

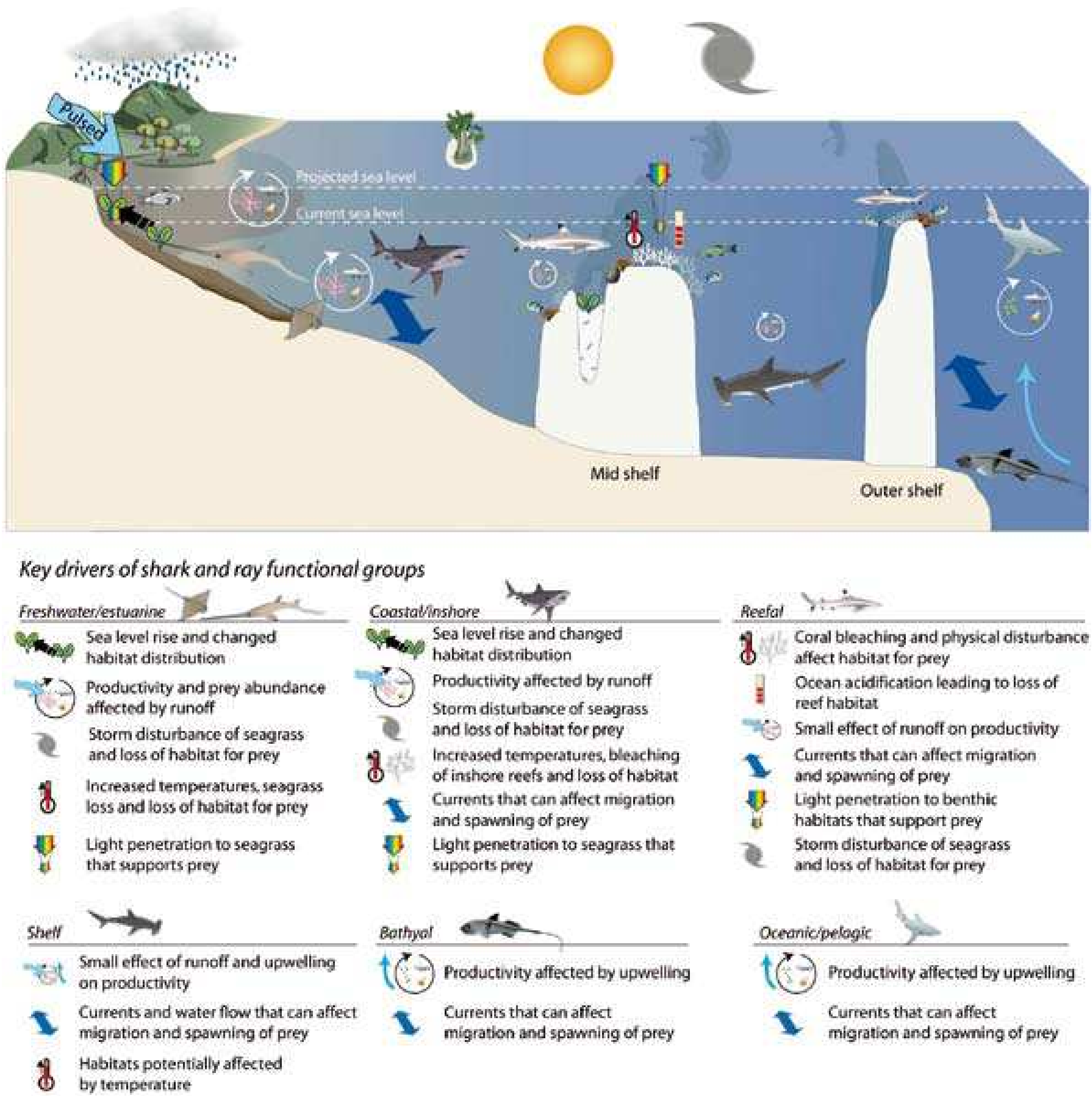

Figure 1. Six functional groups of sharks and rays and the main climate change drivers that may affect the habitats and biological processes upon which they depend (from Chin & Kyne 2007).

There is little that regional managers can do to limit climate change – that is a matter for world governments to address issues such as energy use. However, some of the other pressures on sharks can be relieved to a certain extent, such as overfishing and habitat loss. In the ETP, headway has already been made with the creation of a network of marine protected areas and new legislation regarding by-catch and shark finning. We recommend the following actions be taken:

1. Focus on species which are already of concern due to anthropogenic activities, and on endemic species.
2. Provide protection and/or restoration of key nursery habitats in coastal areas, such as mangroves
3. Reduce fishing mortality. Are shark populations sustainable? If not, their fishing mortality must be reduced regardless of what is done with the meat once the shark is dead.
4. Research to understand movement patterns, connectivity and population status throughout the ETP
5. Protect cold-water (e.g. the endemic Galapagos bullhead shark is found mainly in the cold upwelling western bioregion of the Galapagos islands) and oceanic island refugia. Oceanic islands in particular are home of the last complete assemblages of top marine predators in the whole region.

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