Chapter 6.1 How Sustainable are open Ocean Fisheries?

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Fisheries

6.1 How sustainable are open ocean fisheries?

6.1.1 Summary and Key Messages

Following a brief definition of the open ocean (in terms of geomorphology, physical oceanography and marine biology), a description is provided of the system of 200 mile Exclusive Economic Zones (EEZs) produced by the UN Law of the Sea Convention (UNCLOS), which defines the open ocean legally as the ocean beyond national jurisdiction. The functioning of open ocean ecosystems, which represent 60 per cent of the world's ocean, is then discussed with emphasis on the role of tuna and other large pelagic fishes, whose catches have now probably peaked. The main factor currently affecting the sustainability of these fisheries is their governance, which is largely entrusted to Regional Fisheries Management Organizations (RFMOs). The difficult task of these organizations, however, is hampered by their lacking the authority necessary to restrict the efforts of countries exploiting offshore pelagic fish. In the medium to long-term, the multiple effect of CO_2 emissions will increasingly impact the pelagic ecosystem of the open ocean, and undermine the sustainability of the fisheries based thereon.

Key messages

- The open ocean is home to large but thinly spread populations of large pelagic fishes which gather and concentrate even more thinly spread, and otherwise inaccessible, prey resources;
- These prey gathering and concentration processes rely on fine-tuned evolutionary adaptations which can – and *likely* will – be easily disrupted as primary production and other key ecosystem processes are rapidly modified by ocean warming, increased stratification and lowered pH; and
- To mitigate ecological disruptions, catch quotas should be as low as possible, and fished areas interspersed by as many unfished marine reserves as possible.

6.1.2 Main Findings, Discussion and Conclusions

Since the establishment of the UN Law of the Sea Convention (UNCLOS) in the early 1980s, the open ocean has a *legal* definition (Crother and Nelson 2006), which now largely overrides earlier, oceanographic or biological definitions. UNCLOS defines the open ocean as all the waters beyond national jurisdiction, beyond the 200 mile limit of the Exclusive Economic Zones (EEZs) along the coast of maritime countries (Figure 6.1) (See Glossary Box 1) Thus defined, the open ocean comprises about 60 per cent of the world's ocean. It can be subdivided by the large 'statistical areas' used by the Food and Agriculture Organization of the United Nations (FAO) to report fisheries catch data (Table 6.1).

Before the discussion on the sustainability of the open ocean fisheries, it is appropriate to briefly review, in part based on Pauly (1995a), the ecological basis of fish production in the open ocean and the functioning of open ocean ecosystems. It is the continued functioning of the latter which ultimately determines the sustainability of ocean fisheries (Longhurst 2007).

The ecological zones of the oceans can be defined according to different sets of criteria. One of the most widely cited zonation scheme was proposed by Longhurst (1998, 2007), which is mainly based on the mixing regime dominant in various 'provinces', of which the WARM province is one. Unfortunately, these provinces do not overlap with the 19

Figure 6.1. The extent and delimitation of countries' Exclusive Economic Zones (EEZs), as claimed by individual countries, or as defined by the Sea Around Us based on the fundamental principles outlined in UNCLOS (200 nautical miles or mid-line rules), and the FAO statistical areas by which global catch statistics are reported. This map also identifies high sea areas as defined here (see also Table 1).

Table 6.1 Open Ocean areas by FAO statistical areas

Area defined here	FAO Statistical Areas	Surface area (10^6 km^2)
1) Arctic	18	9
2) North Atlantic	21 & 27	21
3) Central Atlantic	31 & 34	29
4) South Atlantic	41& 47	36
5) Indian Ocean	51 & 57	61
6) North Pacific	61 & 67	29
7) Central Pacific	71 & 77	82
8) South Pacific	81 & 87	59
9) Antarctic	48, 58 & 88	36
10) Mediterranean	37	3
Total	--	364

FAO Areas in Table 6.1 and Figure 6.1. Another more basic classification scheme would consist of differentiating the entire ocean into an enormous body of cold water (-2° to 20°C), on top of which floats a thin but wide lens of warmer water which is deepest in the tropics.

Cold, deeper water is generally rich in nutrients – mainly nitrates, silicates and phosphates (Dugdale and Wilkinson 1998; Fauzi et al. 1993; Montagna et al. 2006) – but does not receive enough sunlight to support all the primary production they otherwise could: the nutrients are too deep for light to reach them, or in high latitudes they receive light only during a short summer season (Levinsen and Nielsen 2002). Conversely, warm waters receive sufficient light, but often lack nutrients – hence the desert-like nature of the central gyres of the ocean (Jena et al. 2013).

Massive primary production occurs wherever nutrients and light are brought together by mixing processes. Typically this is in the uppermost 10 to 100 m of the ocean. In high-latitude, colder-water areas, much of the primary productivity occurs during the well-lit summer period, when storms de-stratify the upper layers of the sea, thus regenerating the nutrients built up during the winter storms, but depleted by the first massive populations of phytoplankton, the spring bloom (Siegel et al. 2002)

The basis of open ocean production

Stratification and superficial nutrient depletion are far more of a problem in low-latitude areas, where the warm surface waters are much lighter than the waters in deeper layers and are thus harder to de-stratify. There, massive production occurs only when a mechanism stronger than the occasional storm breaks the thermocline and pumps nutrient-rich, deep water to the surface (Stigebrandt and Djurfeldt 1996). Major upwellings occur where regular, equatorward winds exert stress on the coastal waters, which are deflected offshore by the Coriolis force and replaced by upwelled water (Bakun 1990). In the open ocean, upwellings are generally confined to the edges of large eddies, for example: in the North Atlantic along the Gulf Stream, and along the Equator where the winds and the Coriolis force create divergence zones where water bodies are pushed from the equatorial zone, and replaced by upwelled water (Dugdale and Wilkinson 1998). Note that the slackening of the global winds transporting heat from the tropics to the poles predicted under most climate change scenarios implies a stronger stratification of the open ocean (Capatondi et al. 2012), and hence a decline of its biological production (for example: Polovina et al. 2011).

The central area of the warm-water lens alluded to earlier harbours another type of system in which light and nutrients are combined to yield extremely high rates of organic production: coral reefs, which are specialized in trapping nutrients from the surrounding waters (Crossland et al. 1991). Successful trapping of nutrients leads to more coral growth, and the deposition of calcareous skeletons that builds structures capable of trapping even more nutrients (Muscatine et al. 1977). This feedback loop enables some coral reefs to standout, cathedral-like, in otherwise barren expanses of highly stratified tropical seas.

The high seas in the Atlantic, Indian and Pacific Oceans also harbour thousands of seamounts (Kitchingman et al. 2007). A number of these seamounts have been visited by large industrial bottom trawlers targeting accumulated biomass of pelagic armourhead (*Pseudopentaceros wheeleri*), alfonsin (*Beryx splendens*), orange roughy (*Hoplostethus atlanticus*) and other similarly long-lived, but relatively small fishes feeding on zooplankton and micronekton concentrated around seamounts (Pitcher et al. 2010; Drazen et al. 2011). These limited fisheries, usually conducted as pulse-fishing operations, are never sustainable, and not further dealt with here.

Where warm, nutrient-poor waters seal off a deep basin, as in the central gyres of the oceans, primary and secondary production remain low, in spite of intricate adaptations by numerous species of phyto- and zooplankton to these impoverished habitats (Gonzalez et al. 2002; Montoya et al. 2004). Foremost among these adaptations are those that enable nutrients to be recycled quickly and economically within the euphotic layer (Eppley et al. 1973; Liu et al. 1997). This reduces the leakage of detritus from the surface to the deeper layers, and ultimately to the sea floor, resulting in lower biomasses of benthic, or bottom-living, organisms below the central gyres (Ekman 1967).

Migration as the key to living in the open ocean

The key adaptation of central gyre organisms, but one suitable only to fast-swimming animals, is to range over a large area and to feed opportunistically wherever food patches occur (Bushnell and Holland 1997; Bertrand et al. 2002). This defines the niche of tropical tuna, of dolphinfish (*Coryphaena*) and other large fast-growing pelagic fish such as yellowfin (*Thunnus albacares*) and skipjack tuna (*Katsuwonus pelamis*), whose density, when averaged over their entire area of distribution, is always small, but which can have a large absolute biomass because of their capacity to tap into the production of entire ocean basins (Sibert et al. 2006).

In the open ocean, it is the zooplankton that serves as key link to the fish (See Chapter 5.3) (Figure 6.2). This is because most fish feed on zooplankton, either when their larvae graduate from the less challenging capture of single-cell organisms (Nakagawa et al. 2007) or as adults specialized in filtering or particulate feeding on zooplankton

(Bertand et al. 2002). Here, however, the sardines and their relatives, the common zooplanktivores in coastal areas are replaced by lanternfish (Family Myctophidae) and their relatives (Tsarin 1997).

Another link to larger, higher trophic level fish is the micronekton, composed on very small fishes, crustaceans, cephalopods and jellyfish (Brodeur and Yamamura 2005; Polovina et al. 2014.) whose ability to perform vertical migrations (Maynard et al. 1975) distinguishes them from zooplankton, for example: a community of drifting organisms.

Zooplankton and micronekton organisms have not evolved individual defence mechanisms against larger fish. Rather, populations of weak and small organisms can maintain themselves through the very patterns of occurrence/non-occurrence of their consumers, and because large consumers and predators, when feeding on patches, cannot afford the energetic costs of "finishing them off" down to the last individuals, or to return to freshly grazed areas (Bakun 2011). Indeed, life can be precarious for large predators and consumers, which generally will not find enough food in any small area to maintain a viable population. All large predatory fish must consequently undertake feeding migrations of various lengths (Harden Jones 1968).

The best migrators of all are the warm-blooded tropical tunas, for example: yellowfin and skipjack, whose entire lives, once they have left the food patch in which they hatched, consist of nothing but high-speed searches from one food patch to the next, starving if they fail to reach, in time, a new patch of life-sustaining, high-density food (Smith 1985). In such cases, and this will have involved many older adults in earlier times, when fishing was less important, large pelagic fishes became part of the plankton fall that feed deep seafloor communities. This leakage from pelagic food webs is utilized by such organisms as large amphipods and macrourid fishes (grenadiers/rattails) specialized on nekton falls (Sainte-Marie 1992; Pearcy and Ambler 1974; Smith 1985).

Comparative studies across a wide range of taxonomic groups and ecosystems have confirmed that the ratio of food consumed to flesh produced is only about ten per cent for *all* consumers, at all trophic levels (for example: Christensen and Pauly 1995). This implies another form of leakage: the energetic loss of 90 per cent of the biomass consumed at each trophic level within oceanic food webs.

Thus, one obvious temptation is to suggest that the fisheries can increase their yield from the open ocean – about two per cent of primary production (Pauly and Christensen 1995) – by humans substituting themselves for the upper elements of the trophic pyramids leading to the presently observed yields. However, the major prey of tuna and other large pelagic fishes – notably mesopelagic fishes – is too dilute to be harvested economically, even if their abundance turns out to be higher than previously assessed (Irigoien et al. 2014).

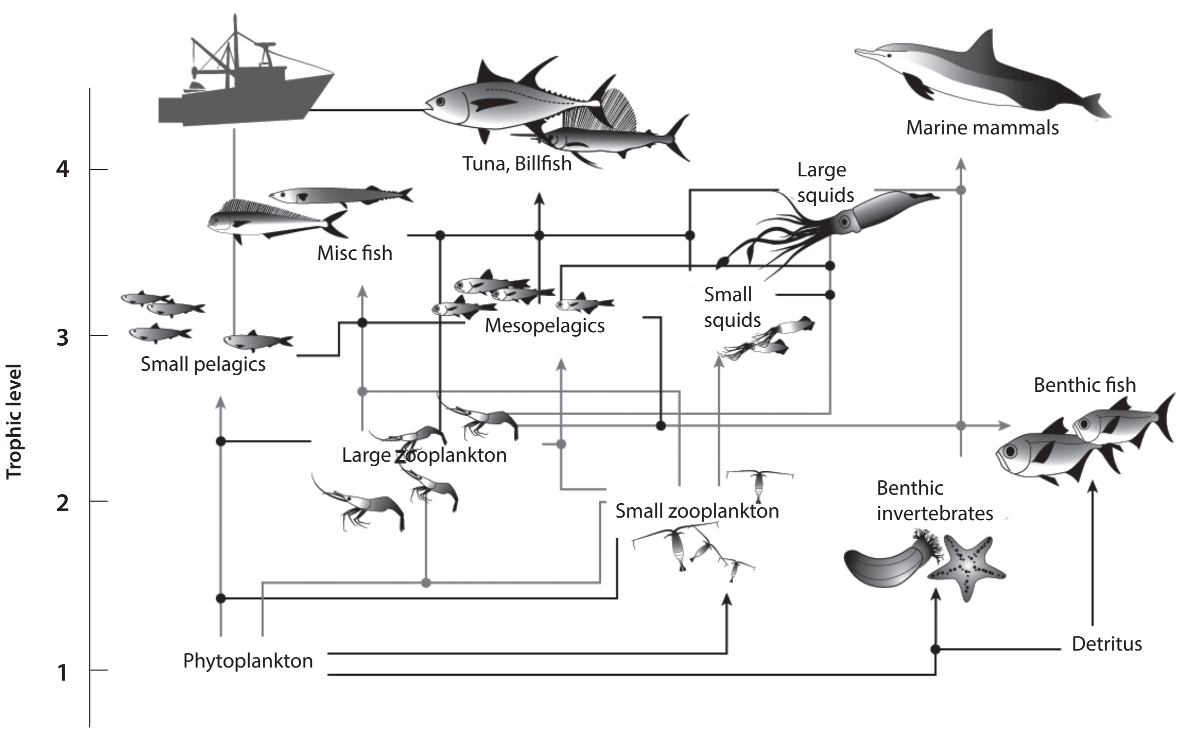
On the other hand, 'fishing down the marine food web' is occurring within the upper trophic level groups in Figure 6.2, for example: catches of large tunas, billfishes and sharks have decreased while the catches of lower trophic-level fishes including mahi mahi, pomfrets and other smaller pelagics have increased (for example: Polovina and Woodworth-Jefcoats 2013).

Within-year variability in open ocean ecosystems

The smallest physical features inducing ocean variability are minute turbulent vortices, lasting perhaps a few seconds, used by single-celled algae to break the 'skin' of nutrient-free water surrounding them and by zooplankton organisms to transport food particles within reach of their grasping appendages (Rothschild et al. 1989). These vortices, occurring at different scales, play a crucial role at very small scales connecting food aggregates and fish larvae. They also illustrate the fractal nature of the marine realm, as do eddies and fronts (Belkin et al. 2009) at larger scales.

The next most important high-frequency scale is the 24-hour rhythm of day and night, where the daytime accumulation of photosynthesis products, and the net production of oxygen (O_2) alternate with the night time net respiration and excretion of carbon dioxide (CO_2), with the balance over a 24-hour cycle being usually positive, so that overall about half a trillion tonnes (wet weight) of phytoplankton biomass are synthesized every year (Longhurst 2007).

Figure 6.2. Schematic representation of a generic pelagic food web (adapted from Figure 12 in Pauly and Christensen 1993). The 'Large zooplankton', 'Mesopelagics' and 'Small squids' groups jointly define a broad 'Micronekton' group, which also includes jellyfish, while the large fish groups ('Tuna, Billfish' and 'Miscellaneous fish') should be seen as including various pelagic sharks. Note also that the 'Small pelagics' disappear as one moves offshore until they are functionally replaced by 'Mesopelagics' in the open ocean, and that benthic fish and invertebrates are extremely sparse under the oceans' central gyres.



In most fish, feeding usually occurs during daytime, whereas the night provides protection from predators (Helfman 1986), and even time for sleep (for example: in herrings). However, some open ocean taxa groups depart from this intuitive scheme and have turned the succession of days and night into a resource that they actively use (Watanabe et al. 1999). Thus, tropical and subtropical lantern fish and their mesopelagic relatives spend most of the day in cold, deep water, typically 5° to 10°C at 300 to 1000 metres, migrating at dusk to feed in the mixed layer surface (30-100 metres), where the water is warmer (25-30°C) and rich in zooplankton and micronekton organisms that they can see despite limited moon- or starlight. At dawn, they migrate back to their mesopelagic night-time habitat, where the low temperature reduces their metabolic requirements– an adaptation that, along with their exploitation of the surface layers, has made these fishes the most abundant in the world in terms of total biomass (Gjøsaeter and Kawaguchi. 1980; Lam and Pauly 2005; Irigoien et al. 2014). However, because of their low density (few milligrams per m^3), myctophids and other mesopelagics have not yet become the targets of a major fishery.

Between-year variability of open ocean ecosystems

Among the major interannual events affecting marine ecosystems, the El Niño Southern Oscillation (ENSO) events affecting the Pacific Ocean are the most prominent (Gergis and Fowler 2009). ENSO events cause massive intrusion of warm ocean water into coast upwelling systems and, by interrupting that supply of cold, deep, nutrient-rich water, starves these systems of the high throughput of nutrients that they usually experience (Pennington et al. 2006).

El Niño events are part of even larger oceanic and atmospheric processes interlinking entire ocean basins, and causing similar or complementary effects on far-away continents (Diaz et al. 2001).

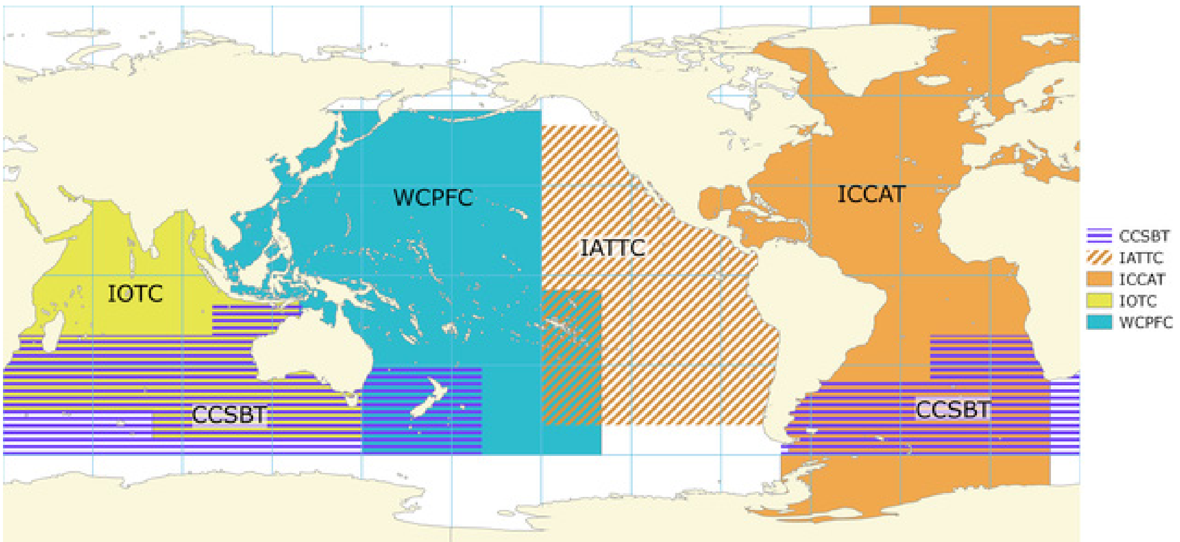
Longer-term cycles spanning decades (from commercial fisheries) or even hundred and even thousands of years have been documented and used for hind- and forecasting climatic changes (see for example: Verdon and Frank 2006), but this issue is not pursued here. Rather, the previous consideration of trophic mechanisms are combined with issues of variability and the biology and dynamics of pelagic fish populations to provide the basis for assessing the sustainability of open ocean fisheries.

Prerequisites for sustainable open ocean fisheries

Emerging in the early 1980s following decades of international negotiations, UNCLOS established that the continental shelves, from which most of the ocean's catch originates, now belong to coastal countries and form the core of their EEZs. Even so, access continues to be largely open, especially along the coastlines of developing countries that are eager to earn whatever little cash fishing access agreements can provide and/or that are unable to patrol their water and to apprehend illegally operating vessels (Belhabib et al. 2014). While some of these issues appear difficult, the legal framework (UNCLOS) exists for their resolution (Juda 1987).

The situation is different for the open ocean, as defined in Figure 6.1, where, anyone can fish. This is because the current system of RFMOs covering the open ocean (see Figure 6.3), cannot legally prevent any country from exploiting the fish resources of the high seas (Cullis-Suzuli and Pauly 2010). One of the rare exceptions is fishing with driftnet, which was banned by the General Assembly of the UN, and thus can be pursued only illegally (Freestone 1995).

Figure 6.3. RFMOs for highly migratory fish stocks (tuna and associated species) in the open ocean



Source: Boundaries provided by the FAO, Fisheries and Aquaculture Department.

The RFMOs attempt to make the best of the resources they are tasked to manage, but they are only capable of doing what their member countries allow them to do, and the results, thus are underwhelming. This particularly applies to the actual state of the stocks that they are responsible for, most of which are currently in worse shape than at the time the RFMO in question was created (Cullis-Suzuki and Pauly 2010).

The 'shifting baseline' phenomenon (Pauly 1995b) easily explains the strange rhetoric surrounding the activities of RFMOs. Thus, in recent years, it has been possible, mainly through the constant pushback from environmental Non-Government Organisations (NGOs), to stabilize the much-reduced biomass of Atlantic bluefin tuna (*Thunnus thynnus*) and even to allow it to rebuild. This was immediately celebrated as a major achievement, and seen as a reason to immediately increase the Total Allowable Catch (TAC) of this fish, even though its biomass continues to be extremely low (Mackenzie et al. 2009; Taylor et al. 2011).

Similarly, in the North Pacific, basin-wide quotas or fishing mortality level caps for bigeye tuna, yellowfin tuna, and striped marlin have been implemented. Meanwhile, in the Hawaiian-based (US) longline fishery, shark finning is prohibited and protected species bycatch is monitored by an observer with caps on the bycatch of turtles. If these caps are reached, the fishery is closed (Polovina et al. 2014). However, many of these measures pertain to a single country, with other actors showing far less concern about the long-term fate of the fisheries' resource base (mainly tuna), not to mention bycatch species, such as leatherback turtle (*Dermochelys coriacea*) (critically endangered through much of its range (http://www.iucnredlist.org/details/6494/0)).

Indeed, the debate about the sustainability of open ocean tuna fisheries is extremely acrimonious, with the tuna industry and scientists working for RFMOs generally stating that the major stocks of tuna (notably yellowfin and skipjack) are in relatively good shape while conceding that some tuna species (for example: bigeye; *Thunnus obesus*) may be overfished (Hampton et al. 2005; Sibert et al. 2006). In contrast much of the NGO community is of the opinion that tuna fisheries are overexploiting their resource base, though their evidence is not usually peer-reviewed and need not be cited here.

It is probably correct that the major stocks of yellowfin and skipjack are doing relatively well (Juan-Jordo et al. 2011). However, to hope that tuna catches, which have been increasing almost linearly from 1950 to the turn of the 21st century, will continue to do so in the next decades is probably unwarranted. Moreover, the loss of species (for example: leatherback turtles, see above, or seabirds), other than those targeted (tuna, billfishes) along with the strong reduction of their biomass (opinion vary as the exact level of this reduction) is changing the fabric of open ocean ecosystems, and hence the long-term sustainability of open ocean fisheries, our last topic.

Long-term sustainability of open ocean pelagic fisheries

It should be unnecessary to couple 'long-term' with 'sustainability', since sustainable operations can be maintained in the long term, by definition (Frazier 1997). Considering such definition, current open ocean fisheries cannot be sustainable. This is because growth, in a finite ocean, is inherently limited. Indeed, the current overall growth of global tuna catches is due exclusively to the Pacific tuna fisheries, as tuna fisheries elsewhere reached a peak in the Atlantic in the early 1990s, while the Indian Ocean tuna fisheries peaked in the early 2000s. Further detail is provided in Chapter 6.3.

This also applies to the increasing effort devoted to extracting these catches (Davidson et al. 2014), whose sophistication also keeps increasing, and now involves fish aggregating devices (FADs) that communicate with satellites (Dagorn et al. 2013).

Moreover, these fisheries will increasingly be impacted by increasing CO_2 emissions, inducing both ocean warming and acidification. The former effect has already begun to shift poleward the distribution of exploited marine fishes (Cheung et al. 2013), a trend predicted to accelerate in the next decades (Cheung et al. 2009, 2010), even if in the Pacific at least, an eastward shift of large pelagics is predicted for the near future (see Chapter 6.4). These distribution shifts can be predicted to have a massive effect on the finely-tuned processes alluded to above by which primary production in channelled up the food web of the open ocean ecosystem (Doney et al. 2009). Jointly with increased stratification (Polovina et al. 2011), these effects can be expected to have deleterious, though hard to quantify, impact on pelagic food webs.

This is the reason why ecosystem-based fisheries management, in the open ocean should consist of establishing large marine reserves where these natural processes can work, and where higher fish biomass could be expected to maintain themselves. Indeed, this approach can be viewed as one of the few avenues left, in addition to conservative catch quotas – for mitigating some of the expected ecological disruptions to open ocean food webs (Polovina et al. 2014).

Some authors (White and Costello 2014; Sumaila et al. 2015) have suggested, moreover, that a complete closure of the open ocean would not only lead, overall, to higher global fisheries catches, but would also lead to improved sustainability of the exploitation of tuna and other large open ocean fish (which would be exploited only when their migrations take them into the EEZs of maritime countries). Also, such closure would lead to a more equitable distribution of open ocean resources between countries, which currently are exploited mostly by a dozen countries with distant-water fleets (Sumaila et al. 2015). This, however, would require a major reform of UNCLOS.

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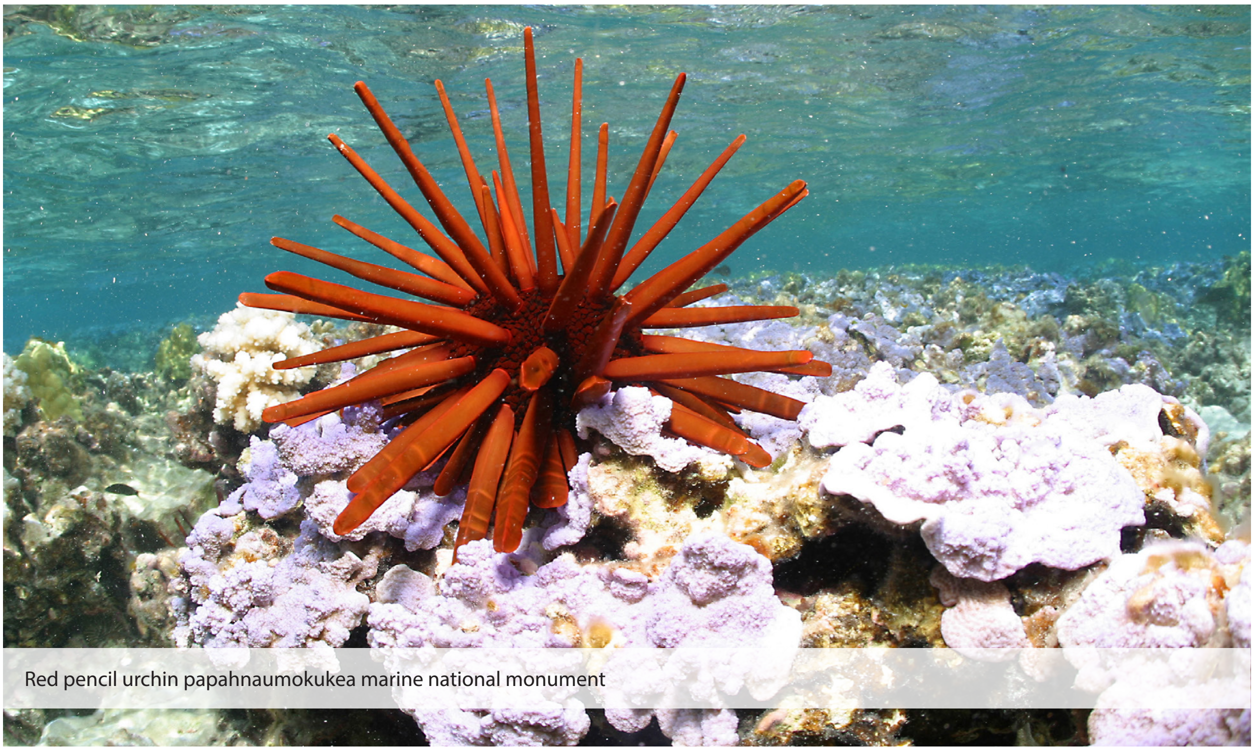

Red pencil urchin papahnaumokukea marine national monument

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