Life on Planet Ocean: Present, Past and Future

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Oceans cover over 70% of the planet and profoundly influence many crucial physical and biological processes. Life began in the sea, and two thirds of the major forms of animal life are either primarily or exclusively marine. About half of the human population lives within 200 km of the coast[1]. Thus, the oceans are a crucial component of planetary health (including human health[2]) by any conceivable standard.

Despite the central role of oceans and ocean life on the planet, we have historically ignored the oceans in the context of biodiversity. There are many reasons for this. First, people sit next to and look at the ocean, dump their garbage in it, and remove their food from it, but most people don't experience life in the sea first-hand. There are Christmas bird counts but not Christmas fish counts; with the exception of whales and dolphins, most marine life is not cuddly or charismatic, "Finding Nemo" notwithstanding. Second, the simple vastness of the ocean has led people to assume that humans in their ships - mere specks on the ocean - could never seriously impact it. Finally, on the scientific side, most oceanographic research has been dominated by measurements of currents, temperature, salinity and other physical parameters, in part a legacy of war-related concerns in which submarines were considered the most important components of marine ecosystems. And most universities have at most one, and more typically no, specialists in marine life. Perhaps not surprisingly, then, we don't even know to the nearest order of magnitude how many species live in the sea, and ocean health has declined precipitously with hardly anyone taking note.

The Decline of Coral Reefs - an Eyewitness Account of an All Too Familiar Tale

Numbers can be numbing, so before going further I would like to tell a rather personal story of the decline of Caribbean reefs to make the problems oceans face less abstract. In 1974, as a beginning graduate student, I came to the Discovery Bay Marine Laboratory on the north coast of Jamaica to start my research. The reefs of Jamaica had lush growths of coral, typically covering more than 50% of the bottom. Although scientists at the time clearly recognized that these reefs were over-fished, none of us ever contemplated the possibility that the reefs themselves were at risk. If we studied corals at all (many of us, myself included, did not), we did so assuming that the organisms and relationships we were studying had existed unchanged for thousands of years in the past and would continue to do so for the foreseeable future.

This assumption was challenged in 1980, when Hurricane Allen shattered the shallow water reefs we had studied, as well as our assumptions about their stability. Most of us dropped our business-as-usual research and began programs to quantify the recovery of the reefs. What remained of our confidence in reef resilience eroded as corals continued to die, and soon collapsed along with the reefs themselves. By 1985, coral cover had dropped from 50% to less than 5%[3], and not just on the reefs of Jamaica. Indeed, a recent report indicates that over the last three decades, 80% of Caribbean corals have disappeared[4], a rate of loss staggering even by terrestrial standards and particularly grim in the context of how slowly corals grow - typically less than half an inch per year. And globally, even the healthiest reefs appear to be on a similar trajectory[5].

So what kills coral reefs? Coral reefs are considered the rainforests of the sea because of their staggering diversity, but unlike rainforests, their decline cannot be simply attributed to people cutting them down. Although in some parts of the world dynamite fishing is the equivalent of clear cutting, typically many factors, some poorly understood, are involved, a situation that makes solutions less obvious both in principle and in practice.

To illustrate the nature of the problem, consider the Caribbean, where the following factors are of primary importance[6]:

1) Overgrowth by seaweeds - The reason that coral reefs are not seaweed reefs is that seaweeds grow faster but taste better than corals do, so that herbivores keep them under control. In the Caribbean those herbivores have been greatly reduced by chronic overfishing, followed in 1982 by the catastrophic die-off of the most important remaining herbivore, the black-spined sea urchin *Diadema*. Within a year, more than 98% of these urchins died; afterwards, one could swim for hours without spotting a single urchin on reefs where densities once averaged 20 per m^2. At any one location the devastation took just four days - one reason why we still do not know the identity of the pathogen. By way of analogy, consider how the Center for Disease Control (CDC) would handle an organism with lethality greater than Ebola and contagion greater than the chicken pox.

2) Disease - *Diadema* is not the only reef organism to be devastated by disease. The branching staghorn and elkhorn corals that dominated most shallow water reefs of the Caribbean have been reduced to such an extent by disease that in March 2004 a suit was filed petitioning that they be listed under the Endangered Species Act. Unfortunately, whole suites of coral diseases now affect essentially all reef-building corals. We know almost nothing about these diseases, as is obvious by the names we give them - white plague, white spot, yellow band, etc. We are still largely at the stage of simply recording their increasing frequency, but this is comparable to a human health care system that limited itself to an annual survey of the num-

bers of people with chest pains, difficulty walking, and severe headaches!

3) Bleaching - Reef-building corals would grow even more slowly were it not for the single-celled algae (zooxanthellae) that live within their tissues and provide them with the products of photosynthesis in exchange for nitrogen-rich waste products. Such symbioses are delicate arrangements because each partner must be vigilant to avoid being taken advantage of by free-loaders - partners that profit by failing to reciprocate. Unfortunately, environmental stress can cause even “well-behaved” symbionts to fail to live up to their obligations, and in the case of corals, this results in the phenomenon of coral bleaching - corals that expel their zooxanthellae and then slowly starve to death. Almost any form of environmental stress can potentially cause bleaching, but warmer than usual seawater is especially problematic because just 1° C above the normal seasonal maximum causes bleaching. During the last El Nino event in 1988, 80% of the corals in the Indian Ocean bleached and 20% died. Global climate models suggest that such temperatures could be reached worldwide on an annual basis by 2020, resulting in the devastation of many if not most reefs.

Human Impacts on the Global Ocean Biosphere

The recent history of coral reefs is particularly striking, but hardly unique. Reefs may be the canary in the coalmine, but they are not alone down there. Globally, the threats falls into a few broad categories.

Excessive and Destructive Resource Extraction

The impacts of fishing on coastal oceans go back centuries in the New World, and thousands of years in the Old World[7]. To give but one example, the biomass of turtles in the Caribbean used to exceed that of the large herbivores on the Serengeti[8]. In the last decades, however the reach of human beings has become truly global. A recent report indicates that during this period we have literally eaten 90% of the big fish in the ocean[9]. That is to say, there is no more blue frontier. Closer to shore, we have pushed once abundant fish to the brink of extinction. Consider groupers, who aggregate just once a year to reproduce. In many places most of the traditional aggregation sites have been destroyed by targeted fishing, and once they are gone they do not appear to return. In some cases, the organisms we intensively harvest - the orange roughy comes to mind - actually live longer than we do, a pattern of exploitation that represents an extreme version of unsustainability. World-wide, we are systematically fishing down the food chain, and we now eat things that were considered trash fish only decades ago[10].

Unfortunately, the intended targets are not the only victims. Long lines harvest not just tuna, but also turtles and albatrosses, organisms whose long life spans leave them especially vulnerable to increased adult mortality. The above mentioned orange roughy is harvested by trawling sea mounts, undersea equivalents of the Galapagos Islands whose surfaces are stripped bare not just of the fish, but also the slow growing corals and sponges, many unique to individual sea mounts, that provide the three dimensional structure upon which the orange roughy and others depend[11]. The apparently vast continental shelves of the world's oceans are in effect strip-mined on an annual basis for their bottom-living inhabitants, only a small proportion of which are actually consumed[12].

Inappropriate Land Use

Our traditional philosophy with respect to waste disposal has been that dilution is the solution to pollution. Our capacity to outstrip the ocean's capacity in this regard is perhaps not surprising when it comes to enclosed bays, but the scale of human impacts is now much more extensive. The Mississippi River drains a watershed equal to about 40% of the continental U.S., including agricultural lands inundated with fertilizers. The consequence has been the creation of a "dead zone" - an area lacking in oxygen and large organisms - the size of New Jersey[13].

Deforestation itself, and coastal development generally, can have catastrophic effects on ocean life. Erosion resulting from the removal of trees literally smothers near shore environments in mud, and the cutting down of mangrove forests eliminates essential habitat for large numbers of marine organisms, including commercially important fishes[14].

Transport of Invasive Species

Marine organisms are being moved around the globe on a massive scale thanks to ballast water in ships being dumped far from home, and via aquaculture of non-native organisms that shelter many additional stowaways. In some places the transformation of entire ecosystems has occurred as a result[15]. In San Francisco Bay, for example, most of the dominant organisms are non-native.

Even the aquarium trade has resulted in introductions. Although lion-fishes on the southeast coast of the U.S. may seem (for now) an innocuous curiosity, the transformation of vast parts of the Mediterranean by the "killer alga" Caulerpa is not. This rapidly growing and toxic seaweed, apparently introduced by the aquarium in Monaco, forms a monoculture that has reduced diversity substantially in areas where it has become established[16].

Atmospheric Change

The reality of anthropogenically induced global warming is now widely accepted by the scientific community. Although most of the catastrophic impacts remain as future scenarios, coral reefs have already suffered substantial losses and they are not likely to be alone in this regard for long. Warmer water is typically poorer in nutrients, and has impacts not just on the surface but in the deep sea, which largely depends on what rains down from above. Here, far from direct human activities, scientists have detected nutritional shortfalls over the last several decades.

As on land, the ranges of marine organisms are predicted to shift as sea temperatures warm, and some changes have already been detected. But marine organisms that are largely landlocked or live in the coldest marine environments may be limited in their ability to migrate. The northern Gulf of California, the Gulf of Mexico and the Mediterranean are particularly at risk for extinctions, as are high arctic and Antarctic communities generally. Rapid sea-level change can also be expected to "drown" light-dependent shallow water communities such as coral reefs.

Although temperature change is the most prominently featured aspect of the consequences of atmospheric emissions, we are also changing oceanic chemistry. In particular, we are making shallow oceans more acidic. In general, this slows the growth of organisms with stony skeletons such as corals[17], and thus compromises their ability to recover from other stresses.

The Likely Consequences of Current Trajectories and Lessons from the Past

Unexplained Declines and Failures to Recover of Species and Ecosystems

Some marine organisms have attributes that make them vulnerable in unpredictable ways to human impacts[18]. One example is reproductive failure associated with low densities. Because even heavily decimated marine populations can still have huge population sizes (2% of a super-abundant organism like Diadema is still a lot of sea urchins) we tend to underestimate the potential for these species to suffer. In the case of Diadema, this urchin failed to recover for over twenty years, despite the fact that every female releases about one million eggs per month. What this figure ignores, however, is that eggs must be fertilized, and sperm can only swim so far (often only distances of a few meters to tens of meters) before they run out of steam. The failure of conch to respond to reduced fishing pressure has similarly been attributed to reproductive failure.

Humans are conducting a massive experiment on marine food chains. In essence, we are removing the predators from the top and adding nutrients to the bottom. Left unchecked there is only one end-point - dominance by seaweeds and microorganisms on a global scale. This is clearly undesirable (bacteria burgers anyone?), but we are also likely to experience some rather nasty surprises along the way because ecosystems, particularly marine ones, can respond unpredictably to changes in complexly interlinked species[18]. Exhibit

A in this regard is the collapse of the cod fishery, which has not recovered despite a total ban on fishing. It remains debated why cod have not come back, but one possible explanation is the rise of jellyfish due to the elimination of their predators, who then eat all the baby cod. Indeed, failure to recover at the expected rate has characterized a number of fisheries[19].

The straw that breaks the camel's back provides an apt analogy. Many stresses contribute to the problem, and unexpected collapse can result from a seemingly small additional stress. Failure to recover upon removal of the stress (e.g. fishing of cod) is an even more worrying aspect of the analogy. Finally, taking the camel to a vet is an expensive (and sometimes futile) proposition, as is the process of restoring damaged ecosystems (the invasion of the Mediterranean by *Caulerpa*[16] being a particularly compelling marine case).

Mass Extinctions

The fossil record sends a mixed message with respect to the prognosis for the future. On the one hand, many marine organisms survived the large changes in temperature and sea level associated with the waxing and waning of glaciers during the last two million years. On the other hand, marine life has periodically been subjected to massive upheavals. Sixty million years ago an asteroid eliminated not only the dinosaurs but also many marine organisms as well. Perhaps more ominously and for reasons that are less well understood, 250 million years ago 95% of all marine species went extinct, and recovery, though it did take place, took tens of millions of years[20].

Could human impacts rival the scale of asteroid impacts? Given that we consume over 40% of the planet's productivity, have already removed 90% of the top marine predators, and are on a trajectory for making the planet warmer than it has been for 60 million years, the answer to this question is hardly a resounding no.

Moreover, even seemingly healthy species can be doomed to extinction if too much of their habitat is destroyed. Theorists call this an extinction debt, and suggest that destruction of 50% of suitable habitat could doom many species even though at the moment they appear healthy[21].

Paths Towards a Different Future for the Ocean

Recognizing the Problem

In one sense we are already doing this, as witnessed by the recent reports by the Pew Ocean Commission[22] and the U.S. National Ocean Commission[23]. Surveys in the U.S. suggest that people are generally aware that the health of the ocean is not what it should be and are concerned about it.

On the other hand, people are largely unaware of the scale of the problem and its causes. The same surveys suggest that people consider oil spills the biggest threat to ocean health, and worry the most about issues immediately related to human health. For example, recent news about contaminants in farmed salmon generally failed to note the broader ecological impacts associated with salmon farming, namely that it depends on unsustainably massive fishing to provide the salmon with food.

There is also the problem of shifting baselines - the tendency to view what one started out with as the normal condition. Major human impacts on marine ecosystems began centuries ago, and few people living today even remember the relative abundance of marine life that existed in the mid-twentieth century. This problem is of course not unique to the oceans, but is something that needs to be overcome if current trajectories are to be halted and reversed (see http://www.shiftingbaselines.org/).

Doing Something About It

Awareness alone does not suffice - motivation to do something about problems is also essential. People know about the threats of climate change and continue to buy SUVs, and even marine biologists do not necessarily translate understanding to action when faced with a gastronomically tempting but ecologically dubious menu choice. Fortunately, comparatively few marine species have gone extinct so the situation is far from hopeless if we act now.

In 2003, Conservation International together with other major NGOs held a conference in Cabo San Lucas entitled Defying Ocean's End. The initial product (http://www.defyingoceansend.org/) was a set of actions that needed to be taken - and for the first time, a price tag.

1) Reducing perverse economic subsidies. Remarkably, the fishing industry receives subsidies greater than the value of the fishes harvested!

2) Global ocean governance. 60% of the open ocean lies outside the 200 mile Exclusive Economic Zones of the world's nations, and in these areas no regulations govern harvesting.

3) Coastal zoning. Currently only 0.7% of the world's oceans are protected - increasing this number to 5% within the next 10 years is a crucial step. Protected areas are arguably even more important in the ocean than on land, because marine organisms grow bigger with protection and produce many more offspring than do smaller ones.

4) Attitude change. It is no longer fashionable to wear leopard skin coats - ordering orange roughy at the supermarket should provoke a similar reaction.

5) Targeted research. Where solutions are lacking because of a knowledge gap, the gap needs to be filled. The World Bank, for example, is working on a multi-million dollar program to provide crucial information needed to protect coral reefs.

The cost will not be trivial - initial estimates that emerged from the meeting were about 18 billion US dollars over ten years. At first glance, this seems like a huge amount. But recent history shows that far greater sums can be mobilized when a grave threat is recognized, and the threat to the world's oceans and the people that depend on them is indeed grave.

Notes

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