ECOSYSTEM EXTINCTION AND THE FUTURE OF THE OCEANS

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Ocean ecosystems are severely degraded by human impacts and entire marine ecosystems are increasingly threatened with extinction or degradation almost beyond recognition. The causes are numerous and complex, but can all be related to human resource extraction and pollution in the broadest sense. In the face of imminent and potentially irreversible loss, we need to open our eyes to how much and why the oceans have changed and to identify and act upon our realistic options for the future.

How much and why have the oceans become degraded?

The symptoms and causes of ocean degradation are so obvious that it is remarkable how reluctant we are to acknowledge them. Six major changes are of particular concern:

1. Overfishing: Most of the large animals are gone, including whales, sea turtles, sharks, and fishes of all kinds, and the reasons are obviously that we hunted them to oblivion. Fisheries biologists and managers argue whether or not the losses of big fishes like tunas or billfish are 70% or 90%, or whether we are "fishing down" or "fishing through" marine food webs, but the overwhelming evidence of loss is the serial economic collapse and closure of one fishery after another. There could be no clearer manifestation of "fishing down the food web" than the fact that the most valuable fisheries off eastern Canada, New England, and California today are invertebrates instead of fish, and similar trends are evident around the world.

2. Trawling: The three-dimensional structure of most of the sea floor of coastal seas and continental shelves, and much of the deeper ocean, has been flattened by trawling to the point that the once complex communities of sponges, corals, bryozoans and seaweeds have been transformed into vast sediment plains. The resulting loss of habitat, fin fisheries, and biodiversity requires decades to centuries to recover.

3. Introduced species: Seaweeds like the "killer algae" *Caulerpa* are smothering entire bottom communities including the hard grounds and seagrass beds of the northwest Mediterranean and coral reefs of Hawaii, introduced shellfish populations have exploded in coastal seas, and introduced jellyfish clog fishing nets in the Gulf of Mexico. Most introductions are irreversible and the economic costs are enormous.

4. Warming: The rise of carbon dioxide in the atmosphere due to the burning of fossil fuels is measurably warming the oceans, eliminating entire polar ecosystems, causing rapid poleward shifts in species' distributions, and killing corals due to the breakdown in the coral-dinoflagellate symbiosis referred to as "coral bleaching." A single bleaching event in 1998 in the Indian Ocean killed 20% of all the corals there, and episodes like this are of increasingly frequent and severe occurrence. Even more ominous are the expected effects of ocean acidification. Careful measurements have already demonstrated a drop of 0.1 pH units in the oceans, and experiments overwhelmingly demonstrate that calcareous organisms ranging from coccolithophores to reef corals cannot calcify or grow under even mildly acidic conditions. Moreover, increased stratification of the oceans due to surface warming is apparently decreasing upwelling of nutrient rich waters with obvious implications for total productivity. Climate models suggest that the oceans may move into a permanent El Niño condition.

5. Toxic Chemicals: Nearly half a century after Rachel Carson warned us of the effects of toxic chemicals in the environment, the oceans are increasingly polluted by mercury from the burning of coal, PCBs, insecticides, and the entire panoply of industrial chemicals that are allowed to run into the ocean sewer. These chemicals have built up to fatal concentrations in many marine mammals, fish, and invertebrates and are a serious health hazard to people, especially in the Arctic, where substances produced by coal-fired power plants are shunted in the upper atmosphere to enter the marine food chains.

6. Eutrophication: Nutrients and primary production are increasing throughout coastal seas due to the breakdown in the filtration capacity of organisms ranging from marsh plants to suspension feeders coupled with the massive introduction of nitrogen, phosphorous, and organic carbon due to inefficient land use and industrial agriculture and animal production. The result is runaway eutrophication I call "the rise of slime" and proliferation of coastal anoxic "dead zones" around the world. Breakdown of formerly complex food webs topped by abundant sharks, fish, sea turtles, and mammals results in greatly simplified, microbially dominated ecosystems with boom and bust cycles of toxic dinoflagellate blooms, jellyfish, and disease.

The overall sequence of events in the degradation of coastal ecosystems is strikingly similar for seagrass, oyster reef, coral reef, kelp forest, or level bottom communities. First, the large animals are eliminated by hunting and fishing. Second,

the three-dimensional structure built by large sessile organisms such as kelps and corals is lost either directly by trawling or indirectly due to disease, smothering by sediments, or climate change. Third, eutrophication is amplified by positive feedbacks such that consumption cannot keep up with production. Microbial metabolism of unconsumed phytoplankton causes anoxia, mass mortality of animals, and a drop in the useful productivity of the entire ecosystem. Transitions in ecosystem state build in intensity through the additive and synergistic effects among ecosystems. Cessation of fishing or pollution does not always result in renewal of fish stocks and water quality, raising questions about the potential for ecosystem recovery. A big unknown is the extent to which eutrophication and its consequences may extend to the pelagic realm.

What are the options for the future?

"Business as usual" will have catastrophic consequences. Wild fisheries will be eliminated and coastal seas will be too toxic for aquaculture. Dead zones will extend to ring the continents and move increasingly seaward. Toxic blooms will become chronic with increasingly severe consequences for human health and the seacoasts will become a global slum. Halting and possibly reversing this inexorable decline will require fundamental changes in fishing, agriculture, and energy production that are still widely perceived as unrealistic and naïve. But as the consequences of "business as usual" become more and more apparent, such changes are inevitable, barring some magical technological solution. Three main actions are required:

1. Stop most fishing and develop responsible aquaculture on a massive scale:

In the face of 6.5 billion people, increasing global equity, and continued human population increase, sustainable wild fisheries are an oxymoron except for weedy species like sardines and anchovies and increasingly expensive luxury fish in the developed world. Aquaculture is the only logical alternative and we should promote industries that focus on species low on the food chain and how to raise them with minimal harmful ecosystem consequences. Besides their obvious value for stabilizing the world supply of fish and shellfish, scaling back increasingly competitive and technologically intensive fishing would also contribute a modest reduction in energy consumption.

2. "Green" the "Green revolution" by eliminating subsidies for fertilizers and pesticides and taxing wastes: Dead zones like the Chesapeake Bay and the Gulf of Mexico could be dramatically improved by removal of subsidies for and taxation of the gross overuse of fertilizers and pesticides for agriculture, lawns, and golf courses and the unregulated production and dumping of animal wastes. Reduced fertilizer and pesticide production would also significantly reduce energy consumption. The rise of slime is a major threat to the development of aquaculture and human health in the coastal zone because of increasing frequency and severity of toxic blooms and disease. The challenges of such massive changes in agricultural practice are daunting, but readily and quickly achievable in developed countries that routinely destroy excess food they cannot sell or give away.

3. Cap carbon emissions in 10 years and achieve large reductions by 2025: Increased ocean warming, stratification, and acidification have been documented for more than twenty years, and the rates of change are increasingly nonlinear. The link to burning of fossil fuels is established and the adverse biological consequences are clearly demonstrated by field observations and experiments. Failure to cap and reduce emissions now will almost certainly result in the loss of coral reefs and most other calcifying organisms, including major groups of primary producers and seafood species.

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The record of actions to preserve our oceans is dismal in the extreme. The laws of open access and the "tragedy of the commons" are commonly invoked as excuses for inaction, but great progress could be made to rationalize seafood production and halt eutrophication on a case by case basis by nations and communities acting alone within their 200-mile exclusive economic zones. This is especially true for the wealthy nations of North America, Europe, Australia, and Japan, for which the only constraint to responsible behavior is greed. In contrast, the causes and consequences of global change are obviously global, although the impact of the developed nations greatly exceeds that of the rest, and unilateral actions would have immediate environmental benefits. The choice is all of ours to make.