

# AVOIDING JELLYFISH SEAS, OR, WHAT DO WE MEAN BY “SUSTAINABLE OCEANS,” ANYWAY?

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## *Abstract*

*Human use of the oceans is not sustainable, as collapsing fish stocks, bioaccumulation of toxics in marine mammals, multiplying “dead zones,” and ocean “garbage patches” all attest. Moreover, climate change is exacerbating many existing problems while simultaneously subjecting marine ecosystems to new stressors, such as increasing ocean temperatures, changing currents, and ocean acidification.*

*More than many other areas of environmental and natural resources law, ocean law and policy is in need of an abrupt paradigm shift from a use-based model to a climate change adaptation model based on principled flexibility, ecosystem-based and adaptive management, reduction of stressors, and a goal of increasing resilience. This Article outlines the existing abuses of the ocean and the current and expected climate change impacts on marine ecosystems before offering a series of suggestions on how to improve ocean sustainability in our climate change era.*

## INTRODUCTION

In June 2010, I had the extreme good fortune to be able to spend a week on Midway Atoll in the Papahānaumokuākea Marine National Monument, as part of a ten-day program, Papahānaumokuākea 'Ahahui Alaka'i, run by Monument personnel.<sup>1</sup> Given its World War II history and other significant human interventions, neither Midway nor the Northwestern Hawai'ian Islands as a whole can be considered a pristine ecosystem.<sup>2</sup> Indeed, one of my favorite photographs from the trip is of a Hawai'ian monk seal—a species of marine mammal

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<sup>1</sup> For information about the program, see PAPAHAUNAUMOKUĀKEA 'AHAHUI ALAKA'I (PAA), <http://www.paaprogram.blogspot.com> (last visited Dec. 2, 2010).

<sup>2</sup> See generally MARK J. RAUSON, ISLES OF REFUGE: WILDLIFE AND HISTORY OF THE NORTHWESTERN HAWAIIAN ISLANDS (2001) (describing the many species introductions, species extinctions, shipwrecks, and human impacts on the Northwestern Hawaiian Islands, including the full history of Midway's transformation).

considered to be critically endangered by the International Union for the Conservation of Nature (IUCN)<sup>3</sup>—sleeping in a sunny spot of beach, surrounded by rusting hunks of metal dumped by the military at the northwestern end of Sand Island, the largest of the three islands that make up Midway Atoll.<sup>4</sup> The spot is nicknamed “Rusty Bucket,”<sup>5</sup> and for good reason. Among other things, it explains why participants in the program were advised to get a tetanus booster before we left home.

Nevertheless, Midway Atoll and the Papahānaumokuākea Marine National Monument more generally support a rich diversity of marine life and seabirds,<sup>6</sup> well justifying the Monument’s recent elevation to the status of a World Heritage Site.<sup>7</sup> The coral reefs in the Monument are free from fishing pressures (fishing is now prohibited in the Monument) and—Rusty Bucket notwithstanding—relatively free from significant marine pollution.<sup>8</sup> Not coincidentally, apex marine predators (sharks of various species, ulua, and others) account for over half of the biomass on the Northwestern Hawai’ian Islands’ coral reefs compared to 3 percent most other places in the world, including the main Hawai’ian Islands.<sup>9</sup> The presence of such a significant percentage of apex predators testifies to the health of the coral reefs that dominate the marine environment within the Monument.

The Black Sea in Europe, south of Russia, also once supported a healthy and complex marine ecosystem, made up of pike, sturgeon, sea grass nurseries, kelp forests, and Mediterranean monk seals (an even more endangered cousin of the Hawai’ian species).<sup>10</sup> However, development in other parts of Europe and the exploitation of the Black Sea itself subjected this ecosystem to a variety of

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<sup>3</sup> *Monachus schauinslandi* (Hawaiian Monk Seal), INTERNATIONAL UNION FOR THE CONSERVATION OF NATURE, <http://www.iucnredlist.org/apps/redlist/details/13654/0> (last visited Sept. 30, 2010).

<sup>4</sup> For a map of Midway Atoll provided by the Monument, see [http://www.lib.utexas.edu/maps/united\\_states/midway\\_atoll\\_2006.gif](http://www.lib.utexas.edu/maps/united_states/midway_atoll_2006.gif) (last viewed Dec. 2, 2010).

<sup>5</sup> The three co-managers of the Monument have provided a map of Sand Island showing the location of Rusty Bucket. See *Midway Atoll Visitor Services Plan*, U.S. FISH & WILDLIFE SERVICE 14 (Dec. 2008), available at <http://www.fws.gov/midway/volume%20iii%20app%20b.pdf>.

<sup>6</sup> *Northwestern Hawaiian Islands Marine National Monument: A Citizen’s Guide*, NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION, U.S. FISH & WILDLIFE SERVICE, & STATE OF HAWAII 3, 6–8, 14–17 (2006) [hereinafter National Oceanic & Atmospheric Administration], available at [http://papahanaumokuakea.gov/pdf/Citizens\\_Guide\\_Web.pdf](http://papahanaumokuakea.gov/pdf/Citizens_Guide_Web.pdf).

<sup>7</sup> *Papahānaumokuākea Marine National Monument becomes first mixed UNESCO World Heritage site in the U.S.*, PAPAĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT, <http://papahanaumokuakea.gov/heritage/welcome.html> (last visited Oct. 4, 2010).

<sup>8</sup> National Oceanic & Atmospheric Administration, *supra* note 6, at 16–17.

<sup>9</sup> *Id.* at 7.

<sup>10</sup> *Black Sea Large Marine Ecosystem*, CUTLER J. CLEVELAND, ED., ENCYCLOPEDIA OF EARTH (Mark McGinley ed., Nov. 21, 2008 9:10 PM), [http://www.eoearth.org/article/Black\\_Sea\\_large\\_marine\\_ecosystem](http://www.eoearth.org/article/Black_Sea_large_marine_ecosystem) (based on information from the National Oceanic & Atmospheric Administration (NOAA)).

stressors—overfishing, oil spills, industrial discharges, nutrient pollution from the many rivers (including the Danube) that feed into the sea, wetlands destruction, and introduction of non-native species.<sup>11</sup> According to the International Commission for the Protection of the Danube River, these stressors “have radically changed Black Sea ecosystems beginning around 1960 [sic], and seriously threatening [sic] biodiversity and our use of the sea for fishing and recreation.”<sup>12</sup>

Indeed, the Black Sea rapidly became a “jellyfish sea.” Vessel ballast water discharges introduced an invasive jellyfish, *Mnemiopsis leidyi*, to the Black Sea in the 1980s. That jellyfish took over the already-stressed ecosystem, displacing the native ecosystem and commercially important species of fish.<sup>13</sup> According to marine biologists at the Woods Hole Oceanographic Institute, “[t]he anchovy catch plummeted from 500,000 tons in the early 1980s to 100,000 tons in 1989. Although the anchovy harvest has since rebounded to about 300,000 tons, catches of a second food fish, the Azov Sea kilka, have fallen to zero.”<sup>14</sup> Hypoxia (a low-oxygen condition) has also taken hold, making the Black Sea’s recovery increasingly unlikely as its anoxic layer grows larger and moves toward the surface.<sup>15</sup>

Unfortunately, it’s unlikely that the Black Sea will be the last example of a jellyfish sea. Jellyfish blooms are on the rise all around the world, signaling how unsustainable our use of the oceans has become.<sup>16</sup> The specific examples are both frightening and discouraging. As the *Washington Post* reported in 2002:

Off the coast of France, aggregations of jellyfish have sunk 500-pound fishing nets. In Japan, jellyfish have clogged the water intakes of nuclear power plants. In the Gulf of Mexico, jellyfish are competing with humans for the larvae of commercially important species such as shrimp. One gulf shrimp boat captain said that in some places, the jellies are so thick “you can almost walk across the water on them.”<sup>17</sup>

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<sup>11</sup> MILLENNIUM ECOSYSTEM ASSESSMENT, ECOSYSTEMS AND HUMAN WELL-BEING: CURRENT STATE AND TRENDS 525 (Rashid Hassan, et al. eds., 2005) [hereinafter MEA 2005: CURRENT STATE AND TRENDS].

<sup>12</sup> *Danube Basin: Black Sea*, INTERNATIONAL COMMISSION FOR THE PROTECTION OF THE DANUBE RIVER, [http://www.icpdr.org/icpdr-pages/black\\_sea.htm](http://www.icpdr.org/icpdr-pages/black_sea.htm) (last updated June 26, 2008).

<sup>13</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 525 (citation omitted).

<sup>14</sup> *Amazing! Alien Jellyfish Blasts Black Sea Fish*, THE WHY FILES, <http://whyfiles.org/055oddball/fish.html> (last visited July 27, 2010).

<sup>15</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 525.

<sup>16</sup> *See generally* Cheryl Lyn Dybas, *Jellyfish ‘Blooms’ Could Be Sign of Ailing Seas*, WASHINGTON POST, May 6, 2002 at A09, *available at* <http://www.eurocbc.org/page727.html> (“Scientists warn explosive growth of jellyfish populations in oceans and seas around the world are a sign of marine ecosystems being devastated by overfishing, nutrient pollution, global warming, and the introduction of non-native species.”).

<sup>17</sup> *Id.*

More importantly, the increasing numbers and sizes of jellyfish blooms give strong evidence that the world's oceans are not being used sustainably, because jellyfish are what replace healthy and thriving marine ecosystems.

It doesn't take much thought to conclude that marine ecosystems like that in the Papahānaumokuākea Marine National Monument are preferable to the proliferation of jellyfish seas. If healthy marine ecosystems are our goal, however, we—the human community of the world at large—are far from implementing a sustainable governance regime for the Earth's oceans, especially in light of the existing and worsening impacts on the oceans from climate change. This Article begins by reviewing the existing threats to the oceans, then details the effects that climate change is already having on marine environments. Concluding that all signs show that oceans continue to decline despite several national and international regimes to protect them, this Article ends with several suggestions regarding how to start making true progress toward sustainable seas.

### I. EXISTING THREATS TO THE OCEANS

Oceans cover about 71 percent of the world's surface<sup>18</sup> and provide 99 percent of the space available for life.<sup>19</sup> One challenge for sustainability, however, is that we know very little about the oceans and their ecosystems.<sup>20</sup> Until recently, for example, it was a mystery where bluefin tuna went when they leave coastal areas.<sup>21</sup>

Nevertheless, we *do* know enough to know that oceans are valuable, in terms of both commerce and ecosystem services. In 1997, in the prestigious journal *Nature*, Robert Costanza and his colleagues estimated that the value of the world's ecosystem services is about \$33 trillion.<sup>22</sup> More importantly for this analysis, marine ecosystems contributed 63 percent of that value—almost two-thirds of the value of all ecosystem services.<sup>23</sup> Moreover, about 60 percent of the value of marine ecosystem services derives from coastal ecosystems, meaning that about 6.3 percent of the Earth's surface supplies about 43 percent of the value of the world's ecosystem services.<sup>24</sup> In direct economic terms, the Millennium Ecosystem Assessment (MEA) summarized that “capture fisheries alone [were] worth approximately \$81 billion in 2000; aquaculture worth \$57 billion in 2000; offshore gas and oil, \$132 billion in 1995; marine tourism, much of it in the coast, \$161

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<sup>18</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 479.

<sup>19</sup> NASA *Oceanography*, NASA, <http://science.nasa.gov/earth-science/oceanography/> (last visited Dec. 2, 2010).

<sup>20</sup> See MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 480, 488.

<sup>21</sup> Helen Scales, *Tagged Tuna Reveal Migration Secrets*, NATIONAL GEOGRAPHIC, (Aug. 13, 2007), <http://news.nationalgeographic.com/news/2007/08/070813-tuna-tags.html>.

<sup>22</sup> Robert Costanza et al., *The Value of the World's Ecosystem Services and Natural Capital*, 387 NATURE 253, 253, 259 (1997).

<sup>23</sup> *Id.* at 256; Robert Costanza, *The Ecological, Economic, and Social Importances of the Oceans*, 31 ECOLOGICAL ECONOMICS 199, 199 (1999).

<sup>24</sup> Costanza, *supra* note 23, at 201.

billion in 1995; and trade and shipping, \$155 billion in 1995.”<sup>25</sup> One specific example of the dangers of unsustainable use of the oceans is “[t]he early 1990s collapse of the Newfoundland cod fishery due to overfishing [that] resulted in the loss of tens of thousands of jobs and cost at least \$2 billion in income support and retraining.”<sup>26</sup>

The oceans are also deep reservoirs of biodiversity. Indeed, 43 of the approximately 70 recognized phyla of life—the second most general classification of life after “kingdom,” and hence representing broad diversity—are found in the oceans.<sup>27</sup> In contrast, only 28 phyla are represented on land.<sup>28</sup> Moreover, 45 percent of the known phyla exist *only* in the oceans, and 90 percent of known classes (the next level of classification) are marine.<sup>29</sup>

As a result, maintaining healthy marine ecosystems should be an obvious goal for all coastal nations and the international community as a whole. Unfortunately, however, a number of stressors have undermined this goal, threatening not just the sustainability but also the long-term viability of marine ecosystems. As the United Nations Environment Programme (UNEP) has summarized, marine environments face

a range of threats including [pollution] from land-based sources, oil spills, untreated sewage, heavy siltation, eutrophication (nutrient enrichment), invasive species, persistent organic pollutants (POP’s), heavy metals from mine tailings and other sources, acidification, radioactive substances, marine litter, overfishing and destruction of coastal and marine habitats . . . .<sup>30</sup>

Coastal development and the attendant destruction of coastal habitat are important general stressors for marine ecosystems.<sup>31</sup> In 2005, the MEA described the cumulative existing degradation of coastal ecosystems as follows:

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<sup>25</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 480 (citations omitted).

<sup>26</sup> WALTER V. REID ET AL., MILLENNIUM ECOSYSTEM ASSESSMENT PANEL, ECOSYSTEMS AND HUMAN WELL-BEING: SYNTHESIS 6 (2005), *available at* <http://www.maweb.org/documents/document.356.aspx.pdf> [hereinafter MEA 2005: SYNTHESIS REPORT].

<sup>27</sup> *Marine Biodiversity*, 21 CONNECT: UNESCO-UNEP ENVTL. EDUC. NEWSLETTER (UNESCO, Paris, France), Mar. 1996, at 1.

<sup>28</sup> *Id.*

<sup>29</sup> G. Carleton Ray & J. Frederick Grassle, *Marine Biological Diversity: A Scientific Program to Help Conserve Marine Biological Diversity Is Urgently Required*, 41 BIOSCI. 453, 453 (July-Aug. 1991).

<sup>30</sup> United Nations Environment Programme, *What Is Marine Pollution and How Does It Affect Marine Life*, UNEP/GRID-ARENDAL, <http://www.grida.no/publications/rr/our-precious-coasts/page/1292.aspx> (last visited Oct. 1, 2010) (citations omitted).

<sup>31</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 515.

The heterogeneous ecosystems embodied in these coastal systems are dynamic, and in many cases are now undergoing more rapid change than at any time in their history, despite the fact that nearshore marine areas have been transformed throughout the last few centuries. These transformations have been physical, as in the dredging of waterways, infilling of wetlands, and construction of ports, resorts, and housing developments, and they have been biological, as has occurred with declines in abundances of marine organisms such as sea turtles, marine mammals, seabirds, fish, and marine invertebrates. The dynamics of sediment transport and erosion deposition have been altered by land and freshwater use in watersheds; the resulting changes in hydrology have greatly altered coastal dynamics. These impacts, together with chronic degradation resulting from land-based and marine pollution, have caused significant ecological changes and an overall decline in many ecosystem services.<sup>32</sup>

Nor is such degradation likely to cease any time in the near future. Coastal populations worldwide are expected to increase from a density of approximately 77 people per square kilometer to 115 people per square kilometer by 2025, and already “the coastal areas with the greatest population densities are also those with the most shoreline degradation or alteration.”<sup>33</sup>

Coastal development also directly spurs pollution problems, such as the “discharge of untreated sewage into the nearshore waters, resulting in enormous amounts of nutrients spreading into the sea and coastal zones . . . .”<sup>34</sup> According to UNEP, coastal discharge of untreated sewage has seen the least progress of any coastal pollution problem and would cost at least US\$56 billion per year to adequately address.<sup>35</sup> In the meantime, “[a]round 60% of the wastewater discharged into the Caspian Sea is untreated, in Latin America and the Caribbean the figure is close to 80%, and in large parts of Africa and the Indo-Pacific the proportion is as high as 80-90%,” putting not just the marine environment but also human health at risk.<sup>36</sup>

However, marine pollution is a broader stressor of marine ecosystems than just coastal sewage. Importantly, about 80 percent of ocean pollution, perhaps more, comes from land.<sup>37</sup> Mercury, for example, frequently reaches the oceans through atmospheric deposition: land-based sources emit the mercury into the air,

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<sup>32</sup> *Id.* at 516.

<sup>33</sup> United Nations Environment Programme, *supra* note 30, at fig.8.

<sup>34</sup> *Id.* (citations omitted).

<sup>35</sup> *Id.*

<sup>36</sup> *Id.*

<sup>37</sup> Li Daoji & Dag Daler, *Ocean Pollution from Land-based Sources: East China Sea, China*, 33 *AMBIO* 107, 108 (2004); *Problems: Ocean Pollution*, WORLD WILDLIFE FUND, [http://wwf.panda.org/about\\_our\\_earth/blue\\_planet/problems/pollution/](http://wwf.panda.org/about_our_earth/blue_planet/problems/pollution/) (last visited Dec. 2, 2010).

which falls back into waters or onto land, where runoff carries it to sea.<sup>38</sup> Methyl mercury, the organic form of mercury, bioaccumulates in marine organisms, becoming more concentrated the further up the food web a species resides.<sup>39</sup> High-level predators such as tuna, swordfish, shark, and mackerel can end up with mercury concentrations in their bodies that are 10,000 times the ambient concentration of mercury in the water.<sup>40</sup> Mercury contamination is already prevalent in food fish, and in 2003, 70 percent of the coastal waters in the contiguous forty-eight states—including 92 percent of the Atlantic coast and 100 percent of the Gulf coast—were under fish consumption advisories for mercury; the state of Hawai'i also issued such advisories.<sup>41</sup> In March 2004, the U.S. Food and Drug Administration (FDA) and the U.S. EPA jointly advised pregnant women and children not to eat shark, swordfish, tilefish, or king mackerel because of the likely mercury content in those fish.<sup>42</sup> Other studies suggest that the population in general is at risk from mercury-contaminated fish. For example, the EPA's safety guidelines suggest that a 120-pound person ingest 38.5 micrograms per week or less of mercury.<sup>43</sup> A random test conducted by the *San Francisco Chronicle* of fish in Bay Area markets in 2003 found 23.2 micrograms of mercury in one six-ounce serving of Alaska halibut, 55.8 micrograms in six ounces of fresh tuna, 68.1 micrograms in six ounces of Chilean seabass (Patagonian toothfish), and 222.3 micrograms of mercury in six ounces of swordfish.<sup>44</sup>

Of course, humans are not the only apex predators of seafood. Marine mammals in particular also suffer as a result of bioaccumulating both mercury and other toxic pollutants, such as polychlorinated biphenyls (PCBs).<sup>45</sup> Beluga whales

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<sup>38</sup> *Mercury Contamination in Fish: Know Where It's Coming From*, NAT. RESOURCES DEFENSE COUNCIL, <http://www.nrdc.org/health/effects/mercury/sources.asp> (last visited Dec. 2, 2010).

<sup>39</sup> *Mercury Contamination in Fish: Learn About Mercury and Its Effects*, NAT. RESOURCES DEFENSE COUNCIL, <http://www.nrdc.org/health/effects/mercury/effects.asp> (last visited Dec. 2, 2010).

<sup>40</sup> *Id.*

<sup>41</sup> ZACHARY CORRIGAN, ENVIRONMENT COLORADO RESEARCH & POLICY CENTER, FISHING FOR TROUBLE: HOW TOXIC MERCURY CONTAMINATES FISH IN U.S. WATERWAYS 5 (Oct. 2004), available at [http://cdn.publicinterestnetwork.org/assets/70I4xouqei5JOkGAMODHLA/Fishing\\_for\\_Trouble\\_2004.pdf](http://cdn.publicinterestnetwork.org/assets/70I4xouqei5JOkGAMODHLA/Fishing_for_Trouble_2004.pdf).

<sup>42</sup> FDA & EPA, WHAT YOU NEED TO KNOW ABOUT MERCURY IN FISH AND SHELLFISH 2 (Mar. 2004), available at <http://www.fda.gov/downloads/Food/ResourcesForYou/Consumers/UCM182158.pdf>.

<sup>43</sup> Jane Kay, *Toxic Fish Alert: Survey Finds Mercury in 4 Species at Markets in Bay Area*, S.F. CHRONICLE, Nov. 23, 2003, at A1, available at [http://articles.sfgate.com/2003-11-23/news/17519632\\_1\\_chilean-sea-bass-mercury-contaminated-fish](http://articles.sfgate.com/2003-11-23/news/17519632_1_chilean-sea-bass-mercury-contaminated-fish).

<sup>44</sup> *Id.*

<sup>45</sup> *Mercury in Aquatic Habitats*, NAT'L OCEAN AND ATMOSPHERIC ADMIN. OFF. RESPONSE AND RESTORATION [http://response.restoration.noaa.gov/type\\_audience\\_entry.php?RECORD\\_KEY\(entry\\_audience\\_type\)=entry\\_id,audience\\_id,type\\_id&entry\\_id\(entry\\_audience\\_type\)=86&audience\\_id\(entry\\_audience\\_type\)=6&type\\_id\(entry\\_audience\\_type\)=2](http://response.restoration.noaa.gov/type_audience_entry.php?RECORD_KEY(entry_audience_type)=entry_id,audience_id,type_id&entry_id(entry_audience_type)=86&audience_id(entry_audience_type)=6&type_id(entry_audience_type)=2) (last updated Apr. 27, 2005) ("Marine mammal tissues have some of the highest

in the St. Lawrence River between Canada and the United States and orcas off the Washington coast in Puget Sound accumulate such a high concentration of toxins in their fatty tissues and blubber that they may qualify as toxic waste.<sup>46</sup> This contamination is thought to increase the cetaceans' mortality: the St. Lawrence belugas, for example, account for 40 percent of all cancers found in cetaceans,<sup>47</sup> while mortality rates in the orcas are increasing, with 42 percent of the calves dying in their first few months.<sup>48</sup>

Pollution of the sea from land-based sources causes other problems, as well. Water flowing over and from farms, in the form of both irrigation return flows and runoff from rain or snowmelt, carries excess fertilizer (mostly nitrogen compounds) to the ocean.<sup>49</sup> Nutrients also reach the waters through atmospheric deposition, such as from the burning of fossil fuels.<sup>50</sup> Once there, the fertilizer induces large blooms of marine plants—phytoplankton and algae. As the blooms then die off, their decomposition consumes all of the oxygen in the water column, leading to hypoxic conditions that make large areas of the ocean uninhabitable by marine animals.<sup>51</sup> In the United States, the largest of these so-called “dead zones” occurs seasonally in the northern Gulf of Mexico at the mouth of the Mississippi River and can reach the size of New Jersey—over 7000 square miles.<sup>52</sup> The

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concentrations of mercury found in all marine organisms, with the liver generally having the highest total mercury concentration.”); Eric W. Montie et al., *Organohalogen Contaminants and Metabolites in Cerebrospinal Fluid and Cerebellum Gray Matter in Short-beaked Common Dolphins and Atlantic White-sided Dolphins from the Western North Atlantic*, 157 ENVTL. POLLUTION 2345, 2345, 2351–55 (2009) (finding significant concentrations of PCBs in dolphins).

<sup>46</sup> See Xenia Shih, *Jean-Michel Cousteau's Ocean Adventures: Beluga Whales Under Threat*, PBS (Mar. 23, 2009) <http://www.pbs.org/kqed/oceanadventures/episodes/seaghosts/indepth-belugas.html> (finding St. Lawrence beluga blubber contains PCB levels ranging from 240 to 800 parts per million (ppm); under Canadian Law a PCB level of 500 ppm is considered toxic waste); see also Marla Cone, *A Disturbing Whale Watch in the Northwest*, L.A. TIMES, Feb. 16, 2001, available at <http://www.orcanetwork.org/habitat/la-timespcbs.html> (finding Puget Sound orca blubber contains PCB levels as high as 250 ppm).

<sup>47</sup> Shih, *supra* note 46. Cetaceans include “[a]pproximately 78 species of whales, dolphins, and porpoises are included in the Order Cetacea.” *Cetaceans: Whales, Dolphins, and Porpoises*, NOAA FISHERIES, OFFICE OF PROTECTED RESOURCES, <http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/> (last visited Dec. 2, 2010).

<sup>48</sup> See Cone, *supra* note 46.

<sup>49</sup> Robert J. Diaz & Rutger Rosenberg, *Spreading Dead Zones and Consequences for Marine Ecosystems*, 321 SCI. 926, 927 (2008).

<sup>50</sup> *Id.*

<sup>51</sup> *Id.*

<sup>52</sup> See Jennifer Vargas, *Gulf Wildlife 'Dead Zone' Keeps Growing*, DISCOVERY NEWS (May 7, 2010), <http://news.discovery.com/animals/gulf-dead-zone-oil-spill.html>.

Mississippi River drains 41 percent of the United States and dumps 1.6 million tons of nitrogen per year into the Gulf, three times as much as forty years ago.<sup>53</sup>

Dead zones are now common throughout the world's coastal regions, often impinging on fisheries.<sup>54</sup> The number of dead zones in the world's seas has doubled every decade since 1960 as a result of increasing marine pollution, and a study that appeared in *Science* in 2008 identified more than 400 dead zones throughout the world.<sup>55</sup> The world's biggest dead zone is in the Baltic Sea, where sewage and nitrogen fallout from the burning of fossil fuels combine with fertilizer runoff to over-enrich this small, contained marine environment.<sup>56</sup> More precisely, the Baltic Sea "is now home to seven of the world's ten largest marine dead zones."<sup>57</sup> Perhaps most disturbingly, dead zones are missing biomass according to what would be expected, suggesting that the oxygen deprivation can have long-term effects on the region's biodiversity and productivity.<sup>58</sup>

Legacy pollution from ocean dumping remains a concern, even though most such dumping is now prohibited under international law.<sup>59</sup> As the MEA noted, for example, "the estimated 313,000 containers of low-intermediate emission radioactive waste dumped in the Atlantic and Pacific Oceans since the 1970s pose a significant threat to deep-sea ecosystems should the containers leak, which seems likely over the long term."<sup>60</sup>

Plastic pollution is causing its own problems. Most plastic does not biodegrade;<sup>61</sup> instead, it photodegrades, breaking down into ever-smaller particles in the sun.<sup>62</sup> In addition, most plastic floats. In 1997, sailor Charles Moore

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<sup>53</sup> National Research Council, *Mississippi River Water Quality and the Clean Water Act: Progress, Challenges, and Opportunities*, THE NAT'L ACAD. PRESS, 21, 38–40 (2008), <http://www.nap.edu/catalog/12051.html>.

<sup>54</sup> See Diaz & Rosenberg, *supra* note 49, at 926 ("[D]ead zones have developed in continental seas, such as the Baltic, Kattegat, Black Sea, Gulf of Mexico, and East China Sea, all of which are major fishery areas.").

<sup>55</sup> *Id.* at 926, 928.

<sup>56</sup> James Owen, *World's Largest Dead Zone Suffocating Sea*, NAT'L GEOGRAPHIC NEWS (Mar. 5, 2010), <http://news.nationalgeographic.com/news/2010/02/100305-baltic-sea-algae-dead-zones-water/>.

<sup>57</sup> *Id.*

<sup>58</sup> See Diaz & Rosenberg, *supra* note 49, at 927.

<sup>59</sup> Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (The London Convention), Dec. 29, 1972, T.I.A.S. No. 8165, 26 U.S.T. 2403 (entered into force Aug. 30, 1975).

<sup>60</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 483 (citations omitted).

<sup>61</sup> DEPARTMENT OF BOATING & WATERWAYS, STATE OF CALIFORNIA, FACTS ABOUT MARINE POLLUTION 2 (2007), available at <http://www.dbw.ca.gov/Pubs/Pollute/MarinePollution.pdf>.

<sup>62</sup> Richard Grant, *Drowning in Plastic: The Great Pacific Garbage Patch Is Twice the Size of France*, TELEGRAPH (U.K.) (Apr. 24, 2009), available at <http://www.telegraph.co>.

discovered what has come to be known as the Great Pacific Garbage Patch,<sup>63</sup> an area (actually, two areas) of the northern Pacific Ocean near Hawai'i where a gyre of ocean currents has collected plastic from throughout the Pacific Rim, concentrating it in an area twice the size of Texas.<sup>64</sup> Large pieces of plastic float on the surface of the water, while the much smaller pieces of photodegraded plastic hover just below the surface, suspended in a plastic soup and easily consumed by fish and seabirds.<sup>65</sup> Estimates of just how much plastic is concentrated in this soup vary, but median estimates are that plastic outnumbers the plankton by a ratio of at least six to one.<sup>66</sup> While the Great Pacific Garbage Patch is the largest of these concentrations, similar garbage patches have been found in the North Atlantic Ocean and the Indian Ocean, while land-derived trash and plastic are found in all of the world's oceans.<sup>67</sup>

While marine pollution is a significant stressor to most marine ecosystems, overfishing and its attendant problem of by-catch may be worse.<sup>68</sup> Overfishing is generally considered the primary threat to marine biodiversity, especially when fishing methods also destroy habitat, as is true with blast fishing and ocean trawling.<sup>69</sup> Overfishing can also interact synergistically with other stresses, such as marine pollution, to destroy the productivity of a particular marine area.<sup>70</sup> As a result, the MEA concluded in 2005 that “[a]ll oceans are affected by humans to various degrees, with overfishing having the most widespread and dominant direct impact on food provisioning services, which will affect future generations.”<sup>71</sup> Its summary continued:

Recent studies have demonstrated that global fisheries landings peaked in the late 1980s and are now declining despite increasing fishing effort, with little evidence that this trend is reversing under current practices. Fishing pressure is so strong in some marine systems that the biomass of some targeted species, especially larger high-value fish and those caught

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uk/earth/environment/5208645/Drowning-in-plastic-The-Great-Pacific-Garbage-Patch-is-twice-the-size-of-France.html; Jacob Silverman, *Oceanography: Why Is The World's Biggest Landfill in the Pacific Ocean?*, HOW STUFF WORKS, <http://science.howstuffworks.com/environmental/earth/oceanography/great-pacific-garbage-patch1.htm> (last visited Dec. 2, 2010).

<sup>63</sup> Grant, *supra* note 62.

<sup>64</sup> Silverman, *supra* note 62.

<sup>65</sup> Grant, *supra* note 62.

<sup>66</sup> Silverman, *supra* note 62.

<sup>67</sup> See Katherine Butler, *Wilderness & Resources: New Ocean Garbage Patch Discovered*, MOTHER NATURE NETWORK (Aug. 4, 2010), <http://www.mnn.com/earth-matters/wilderness-resources/stories/new-ocean-garbage-patch-discovered>.

<sup>68</sup> See MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 479.

<sup>69</sup> *Id.*

<sup>70</sup> See, e.g., Owen, *supra* note 56 (noting that overfishing in the Baltic Sea has intensified the problems caused by the dead zones there).

<sup>71</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 479.

incidentally (the “bycatch”), has been reduced to one tenth or less of the level that existed prior to the onset of industrial fishing. In addition, the average trophic level of global landings is declining, which implies that we are increasingly relying on fish that originate from the lower part of marine food webs.<sup>72</sup>

Moreover, while marine and coastal fisheries landed, on average, 82.4 million tons of fish a year in the years 1991 to 2000, total global catch is now declining despite increased investment in fishing effort, another indication that the world’s supplies of wild fish are disappearing.<sup>73</sup>

Reports from the United Nations Food and Agriculture Organization (FAO) confirm the devastating impact of overfishing on marine sustainability. The FAO concurs with the MEA that, despite increased fishing effort, world capture fishing has leveled off or even started to decline.<sup>74</sup> In its latest (2009) report, for example, the FAO noted that “[g]lobal marine capture production was 81.9 million tonnes in 2006, the third lowest since 1994.”<sup>75</sup> In addition, about 80 percent of the world’s fish species are either fully exploited (52 percent), overexploited (19 percent), depleted (8 percent), or recovering from depletion (1 percent).<sup>76</sup>

The FAO’s assessments paint a grim picture, but probably not grim enough. Given the FAO’s methodologies—for example, the FAO ignores fisheries that are no longer fished because the stocks collapsed to commercial extinction in prior decades<sup>77</sup>—its assessments are almost certainly overly conservative in terms of describing overall marine ecosystem health, because the history of the world’s fishing practices has been one of progressive overexploitation. In general, “[w]ithin 10–15 years of their arrival at a new fishing ground, new industrial fisheries usually reduce the biomass of the resources they exploit by an order of magnitude.”<sup>78</sup> In 2005, the MEA identified capture fisheries as one of the two global ecosystem services that is already being used at levels far beyond what is sustainable even for current demands, let alone for future demands, which are only expected to increase with increasing populations.<sup>79</sup> Five years later, UNEP announced that 30 percent of global fish stocks are “collapsed”—that is, operating at 10 percent or less of their original potential.<sup>80</sup>

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<sup>72</sup> *Id.*

<sup>73</sup> *Id.* at 479, 481–82.

<sup>74</sup> U.N. FOOD & AGRIC. ORG., THE STATE OF THE WORLD FISHERIES AND AQUACULTURE 2008 6 fig.3 (2009), available at <ftp://ftp.fao.org/docrep/fao/011/i0250e/i0250e.pdf> [hereinafter 2009 FAO FISHERIES REPORT].

<sup>75</sup> *Id.* at 10.

<sup>76</sup> *Id.* at 7.

<sup>77</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 482.

<sup>78</sup> *Id.* at 503 (citations omitted).

<sup>79</sup> MEA 2005: SYNTHESIS REPORT, *supra* note 26, at 6.

<sup>80</sup> *Turning the Tide on Falling Fish Stocks*, UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP) (May 17, 2010), <http://unep.org/Documents.Multilingual/Default.asp?DocumentID=624&ArticleID=6566&l=en&t=long>.

Overfishing also causes more widespread damage to ocean ecosystems. As the MEA noted, “[o]ver much of the world, the biomass of fish targeted in fisheries (including that of both the target species and those caught incidently [sic]) has been reduced by 90% relative to levels prior to the onset of industrial fishing, and the fish being harvested are increasingly coming from the less valuable lower trophic levels as populations of higher trophic level species are depleted . . . .”<sup>81</sup> As such, “overfishing results in altered ecological states that may be impossible to restore to former conditions.”<sup>82</sup>

In perhaps the greatest indication of the unsustainability of humans’ use of the oceans to date, researchers projected in *Science* in 2006 that, given current trends, *all* species in the oceans would be collapsed by the middle of the twenty-first century.<sup>83</sup> This potential global elimination of fisheries threatens crises for humans as well as for marine ecosystems. According to GRID-Adrenal, an official UNEP collaborating center, about 10 percent of the world’s human caloric intake comes from aquaculture, freshwater fisheries, and marine fisheries.<sup>84</sup> These sources of food are likely to decline in the future, with especially acute human nutrition problems predicted for Africa and Southeast Asia.<sup>85</sup>

Coastal development and habitat destruction, marine pollution, and overfishing are long-term, cumulative stressors to ocean ecosystems. Marine disasters punctuate their impacts. Large oil spills are one such infrequent but potent disaster. In the United States, the 2010 oil spill resulting from the collapse of the Deepwater Horizon oil platform in the Gulf of Mexico became the largest in the nation’s history,<sup>86</sup> while oil from the 1989 *Exxon Valdez* grounding continues to contaminate Prince William Sound, Alaska.<sup>87</sup> Internationally, China also experienced its largest ever marine oil spill in the summer of 2010 after a fire at an oil depot at the port city of Dalian—which sits on a bay that opens to the Yellow Sea near North Korea, South Korea, and Japan—released hundreds of thousands of gallons of crude oil into the water.<sup>88</sup> Both the BP spill and the China spill closed fisheries, although the long-term impacts remain to be seen.

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<sup>81</sup> MEA 2005: SYNTHESIS REPORT, *supra* note 26, at 15.

<sup>82</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 488 (citation omitted).

<sup>83</sup> Boris Worm et al., *Impacts of Biodiversity Loss on Ocean Ecosystem Services*, 314 *SCI.* 787, 790 (2006).

<sup>84</sup> United Nations Environment Programme, *World Food Supply*, THE ENVIRONMENTAL FOOD CRISIS, UNEP/GRID-ARENDA, <http://www.grida.no/publications/rr/food-crisis/page/3562.aspx> (last visited Dec. 2, 2010).

<sup>85</sup> *Id.*

<sup>86</sup> Michael Grunwald, *The BP Spill: Has the Damage Been Exaggerated?*, *TIME* (July 29, 2010), <http://www.time.com/time/nation/article/0,8599,2007202,00.html>.

<sup>87</sup> Bill Capo, *Effects of Exxon Valdez Still Felt 21 Years Later*, *WWLTV.COM* (Aug. 1, 2010), <http://www.wwltv.com/news/Effects-of-Exxon-Valdez-still-felt-21-years-later-99727389.html>.

<sup>88</sup> Chris Hogg, *China Struggles to Recover from ‘Worst Ever’ Oil Spill*, *BBC NEWS* (July 30, 2010), <http://www.bbc.co.uk/news/world-asia-pacific-10819987>.

Coral bleaching events are another type of disaster that punctuates the cumulative degradation of the oceans. Most surface coral species rely on symbiotic zooxanthellae, a type of algae contained within the coral polyps' tissues, to supplement their nutrition.<sup>89</sup> However, when water temperatures warm, corals expel their zooxanthellae, turning white (hence the term "coral bleaching") and potentially dying, especially if the bleaching event is prolonged or repeated.<sup>90</sup> Mass coral bleaching events occurred in 1982–1983 in Panama and the Galapagos Islands and again in 1997–1998 across the globe; both were associated with strong El Niño currents, which elevated sea surface temperatures (SSTs) in much of the world.<sup>91</sup> In the 1982–1983 event, coral reef mortalities in the Galapagos Islands reached 99 percent;<sup>92</sup> in the 1997–1998 event, "[c]oral reefs suffered mortalities of up to 95% in Kenya, Tanzania, the Maldives, the Seychelles, Sri Lanka, and India."<sup>93</sup>

Finally, outbreaks of marine disease signal that the world's marine resources are over-stressed and vulnerable. For example, according to research published in 2004, disease outbreaks are increasing among sea turtles, corals, marine mammals, sea urchins, and marine mollusks.<sup>94</sup> UNEP considers the number of outbreaks of marine disease in the last few decades and the resulting mortalities to be "unprecedented."<sup>95</sup>

## II. THE ADDITION OF CLIMATE CHANGE

The oceans play a significant role in climate change impacts, and understanding the interactions between the atmosphere and the oceans is widely acknowledged to be critical to understanding and modeling climate change impacts on land. A recent NOAA report explains:

Most of incoming solar energy absorbed by Earth is absorbed at the top ocean layer, but not all the absorbed heat is stored and transported by the oceans. Over 80% of the heat is released back to the atmosphere by two heat exchange processes at the air-sea interface: evaporation that releases latent heat and conduction, and convection that releases sensible heat.

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<sup>89</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 523.

<sup>90</sup> *Id.*

<sup>91</sup> *Coral Bleaching*, NOAA'S CORAL HEALTH AND MONITORING PROGRAM, [http://www.coral.noaa.gov/index.php?option=com\\_content&view=article&id=132&Itemid=166](http://www.coral.noaa.gov/index.php?option=com_content&view=article&id=132&Itemid=166) (last visited Dec. 2, 2010).

<sup>92</sup> *Id.*

<sup>93</sup> *Climate Change and Marine Diseases: The Socio-Economic Impact*, UNITED NATIONS ENVIRONMENT PROGRAMME WORLD CONSERVATION MONITORING CENTER, 5 (2009), [http://www.unep-wcmc.org/marine/pdf/Epublication\\_V3\\_23092009.pdf](http://www.unep-wcmc.org/marine/pdf/Epublication_V3_23092009.pdf) (current version as of Sept. 30, 2010) [hereinafter *Climate Change and Marine Diseases*].

<sup>94</sup> Jessica R. Ward & Kevin D. Lafferty, *The Elusive Baseline of Marine Disease: Are Diseases in Ocean Ecosystems Increasing?*, 2(4) PLOS BIOLOGY 542, 542–43 (Apr. 2004).

<sup>95</sup> *Climate Change and Marine Diseases*, *supra* note 93, at 1.

The amount of heat being exchanged is called heat flux. Latent and sensible heat fluxes from the oceans are significant energy sources for global atmospheric circulation, and their changes on short- and long-term timescales have important implications for global weather and climate patterns.<sup>96</sup>

Thus, the interactions of the oceans and the atmosphere create the heat circulation and the wind and weather patterns that in turn express the realities of climate change and determine its impacts on all terrestrial life.<sup>97</sup>

Climate change will also increase the challenges to using the oceans sustainably. First, climate change is already creating new stressors for ocean ecosystems, such as increasing temperature, changing current patterns, and ocean acidification.<sup>98</sup> In addition, ocean salinity patterns also appear to be changing in response to changes in global precipitation patterns, but the trend data is too short to be sure of that connection.<sup>99</sup> These new stressors compound the problems already facing marine ecosystems and will generally further limit the uses that humans can sustainably make of them.

Second, climate change is likely to exacerbate existing stressors on the oceans. For example, climate change impacts, such as increased heat and greater runoff events, in many places are likely to increase the size and severity of many ocean dead zones<sup>100</sup> and will almost certainly increase the frequency and severity of coral bleaching events.<sup>101</sup> In addition, mercury methylation and the consequent bioaccumulation of mercury in marine organisms appears to be temperature-dependent, with the result that mercury contamination of fish and marine mammals is likely to increase as ocean temperatures increase in response to climate change.<sup>102</sup> Finally, as UNEP reported in 2009, climate change is likely to increase outbreaks of marine diseases:

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<sup>96</sup> Joel M. Levy ed., *Global Oceans*, in STATE OF THE CLIMATE IN 2009, 91(7) BULL. OF THE AM. METEOROLOGICAL ASS'N. S53, S59, S61 (July 2010) [hereinafter Levy] (citations omitted).

<sup>97</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 498.

<sup>98</sup> Levy, *supra* note 96, at S53–61.

<sup>99</sup> *Id.* at S63–S64.

<sup>100</sup> Diaz & Rosenberg, *supra* note 49, at 929. *See also* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT 47, 49 fig.3.3 (Nov. 2007) (noting that there will likely be increases in precipitation in the tropics and at the poles, but likely mostly decreases in precipitation at the mid-latitudes of the oceans, with corresponding increases and decreases of runoff into the oceans) [hereinafter 2007 IPCC SYNTHESIS REPORT].

<sup>101</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 523.

<sup>102</sup> Shawn Booth & Dirk Zeller, *Mercury, Food Webs, and Marine Mammals: Implications of Diet and Climate Change for Human Health*, 113(5) ENVTL. HEALTH PERSP. 521, 525 (May 2005).

Climate change has resulted in rising sea temperatures and levels, changes in ocean circulation, pH and salinity, and has exposed the world's oceans to increasing levels of ultraviolet radiation. These physical and chemical changes influence the prevalence and potency of marine pathogens and biotoxins, with serious ecological and socio-economic ramifications.<sup>103</sup>

Among other things, an increase in marine diseases has direct implications for human health, in the form of shellfish contamination and increased outbreaks of cholera.<sup>104</sup> Marine disease also threatens the sustainability of marine aquaculture and tourism.<sup>105</sup>

One of the most direct impacts of increasing global average atmospheric temperatures is increasing SSTs and ocean heat content (OHC), both of which contribute significantly to ocean currents and world weather patterns. As NOAA recently noted, “[t]he long-term increase in OHC has an important contribution to sea level rise, reflects a first-order estimate of Earth’s radiation balance, and provides a powerful constraint on model projections of future surface temperature rise.”<sup>106</sup> Moreover, it reported that “upper-ocean heat content for the last several years have reached values consistently higher than for all prior times in the record, demonstrating the dominant role of the oceans in the Earth’s energy budget.”<sup>107</sup>

While SSTs in specific oceans can vary noticeably from year to year as a result of changes in current patterns, such as El Niño and La Niña events,<sup>108</sup> the overall trend of SSTs since 1950 is up.<sup>109</sup> Indeed, in 2007, the Intergovernmental Panel on Climate Change (IPCC) indicated that most regions of the ocean have already experienced SST increases of between 0.2 and 1.0 degrees Celsius.<sup>110</sup> It predicted that, under its “business-as-usual” scenario, ocean temperatures would increase by another 0.5 to 1.0 degree Celsius by 2029 and by up to 4 degrees Celsius by 2099, with warming continuing for at least another century thereafter.<sup>111</sup> However, research by an international team of scientists and reported in June 2008 indicated “that ocean temperature and associated sea level increases between 1961 and 2003 were 50 percent larger than estimated in the 2007 Intergovernmental

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<sup>103</sup> *Climate Change and Marine Diseases*, *supra* note 93, at 1.

<sup>104</sup> *Id.* at 2.

<sup>105</sup> *Id.* at 4–5.

<sup>106</sup> Levy, *supra* note 96, at S59.

<sup>107</sup> *Id.* at S53; *see also id.* at S58 fig.3.7 (graphing upward trend of ocean heat content since 1994).

<sup>108</sup> *Id.* at S53–55.

<sup>109</sup> *Id.* at S55 fig.3.3.

<sup>110</sup> *See* 2007 IPCC SYNTHESIS REPORT, *supra* note 100, at 32 fig.1.2.

<sup>111</sup> *Id.* at 46 fig.3.2.

Panel on Climate Change report.”<sup>112</sup> Moreover, scientists have detected temperature increases almost two miles below the ocean’s surface.<sup>113</sup>

Increasing ocean temperatures can directly affect marine ecosystems. For example, the IPCC projected increasing coral bleaching events even at current levels of SST increases.<sup>114</sup> Widespread coral mortality is likely to begin occurring if SSTs increase by approximately 2.5 to 3.0 degrees Celsius.<sup>115</sup>

Changes in ocean temperatures also cause temperature-sensitive species to migrate poleward,<sup>116</sup> and such migrations have already been detected. In November 2009, for example, researchers at NOAA reported that about half of the commercially important fish stocks in the western North Atlantic Ocean, such as cod and haddock, had been shifting north in response to rising sea temperatures.<sup>117</sup> Unfortunately, temperature-sensitive species at the poles have nowhere to go.<sup>118</sup>

A few marine species may go extinct because of temperature-induced changes in their habitat or food supply.<sup>119</sup> More importantly, climate change will have direct impacts on marine biodiversity<sup>120</sup> and on fishing and fish stocks.<sup>121</sup> As the

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<sup>112</sup> *Ocean Temperatures and Sea Level Increases 50 Percent Higher than Previously Estimated*, SCIENCE DAILY, (June 19, 2008), <http://www.sciencedaily.com/releases/2008/06/080618143301.htm>.

<sup>113</sup> See Tim P. Barnett, David W. Pierce & Reiner Schnur, *Detection of Anthropogenic Climate Change in the World’s Oceans*, 292 SCIENCE 270, 271 & fig.2 (2001) (reporting detection of increases in some oceans’ temperatures to depths of at least 3000 meters, when there are 1609.344 meters in a mile).

<sup>114</sup> 2007 IPCC SYNTHESIS REPORT, *supra* note 100, at 51 fig.3.6.

<sup>115</sup> *Id.*

<sup>116</sup> 2009 FAO FISHERIES REPORT, *supra* note 74, at 87.

<sup>117</sup> Shelley DaWicki, *North Atlantic Fish Populations Shifting as Ocean Temperatures Warm*, NORTHEAST FISHERIES SCI. CENTER, NOAA, (Nov. 2, 2009) [http://www.nefsc.noaa.gov/press\\_release/2009/SciSpot/SS0916/](http://www.nefsc.noaa.gov/press_release/2009/SciSpot/SS0916/). See also B. Planque & T. Frédou, *Temperature and the Recruitment of Atlantic Cod (Gadus morhua)*, 56 CANADIAN J. FISHERIES & AQUATIC SCI. 2069 (1999) (reporting similar results for cod).

<sup>118</sup> See Julie M. Roessig et al., *Effects of Global Climate Change on Marine and Estuarine Fishes and Fisheries*, 14 REVIEWS IN FISH BIOLOGY & FISHERIES 251, 262–63 (2004) (explaining the limited options for polar fish species). According to the MEA, “[c]limate change, acting through changes in sea temperature and especially wind patterns, will disturb and displace fisheries. Disruptions in current flow patterns in marine and estuarine systems, including changes to freshwater inputs as predicted under climate change, may cause great variations in reproductive success.” MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 498.

<sup>119</sup> The MEA indicated that marine extinctions resulting directly from climate change will probably be rare, although local extirpations are likely. MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 490. Instead, indirect effects are likely to be more important. For example, “[r]ecent results from monitoring sea temperatures in the North Atlantic suggest that the Gulf Stream may be slowing down and affecting abundance and seasonality of plankton that are food for larval fish. Declining larval fish populations and ultimately lower adult stocks of fish will affect the ability of overexploited stocks to recover.” *Id.* (citation omitted).

<sup>120</sup> *Id.* at 489.

FAO noted in 2009, “[c]limate change is a compounding threat to the sustainability of capture fisheries and aquaculture development.”<sup>122</sup> A study published in *Nature* in late July 2010 suggests that the magnitude of the problem is even greater than suspected, finding ocean temperature to be a major determinant of marine biodiversity and concluding that changes in ocean temperature “may ultimately rearrange the global distribution of life in the ocean.”<sup>123</sup>

Temperature changes also affect ocean currents.<sup>124</sup> The science-fiction movie “The Day After Tomorrow” capitalized on projected changes to one of the largest of the ocean currents, known as the Great Ocean Conveyor. This global “pump” depends on the sinking of cold water in the North Atlantic Ocean, which in turn pulls warm water from the tropics up the coast of the eastern United States and across the Atlantic Ocean to Europe.<sup>125</sup> The Wood Hole Oceanographic Institution has explained the importance of this global conveyor system:

The phenomenon has far-reaching impacts on climate. It transports tropical heat to the North Atlantic region, keeping winters there much warmer than they would be otherwise. And it draws down the man-made buildup of carbon dioxide from air to surface waters and eventually into the depths, where the greenhouse gas is stored for centuries and offset[s] global warming.<sup>126</sup>

In the fifteen years prior to 2009, cold water in the North Atlantic was not sinking at the rates previously experienced, leading to speculation that the Great Ocean Conveyor was shutting down<sup>127</sup>—the basic premise of the overly dramatic “The Day After Tomorrow.” However, the sinking of cold water “resumed vigorously” in the winter of 2008–2009, surprising scientists and underscoring just how complex climate change predictions are.<sup>128</sup>

Nevertheless, even if the Great Ocean Conveyor remains intact, more limited changes in ocean current patterns can still disrupt marine ecosystems at the local or regional scale. For example, much of the northwest coast of the United States, Canada, and Alaska benefits from nutrient-rich upwelling currents that support numerous species of fish—and strong fishing industries—in the northern Pacific Ocean. However, at the beginning of the twenty-first century, a mysterious dead

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<sup>121</sup> See generally Roessig et al., *supra* note 119 (comprehensively reviewing climate change’s impacts on fisheries).

<sup>122</sup> 2009 FAO FISHERIES REPORT, *supra* note 74, at 87.

<sup>123</sup> Derek P. Tittensor et al., *Global Patterns and Predictors of Marine Biodiversity Across Taxa*, 466 NATURE 1098 (Aug. 26, 2010).

<sup>124</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 490.

<sup>125</sup> *Ocean Conveyor’s ‘Pump’ Switches Back On*, WOODS HOLE OCEANOGRAPHIC INSTITUTION, <http://www.whoi.edu/page.do?pid=12455&tid=282&cid=54347> (last updated Nov. 19, 2010).

<sup>126</sup> *Id.*

<sup>127</sup> *Id.*

<sup>128</sup> *Id.*

zone began forming, and growing, off the coasts of Oregon and Washington.<sup>129</sup> This dead zone, which occurs in the middle of a commercially important fishery, has been attributed to climate change—specifically, to changing interactions of wind and offshore currents that prevent the normal dissipation of oxygen-deprived waters.<sup>130</sup> Three other such climate change-related dead zones have been detected, one off the coast of Chile and Peru in South America and one each off the west and east coasts of Africa.<sup>131</sup>

As climate change impacts become more pronounced, even more dramatic ecosystem impacts as a result of changing ocean currents are also possible. In 2007, for example, the IPCC projected widespread ecosystem changes as a result of changes in major marine currents beginning at about the point when global average temperatures increase by about 2.5 to 3.0 degrees Celsius.<sup>132</sup>

Thermal expansion of ocean waters and melting ice contribute about equally to sea-level rise, another component of global climate change with implications for ocean sustainability. According to NOAA in 2010, “[t]he rate of global mean sea level (GMSL) rise is estimated currently to be  $3.1 \pm 0.4$  mm yr<sup>-1</sup> (3.4 mm yr<sup>-1</sup> with correction for global isostatic adjustment).”<sup>133</sup> Sea-level rise has multiple impacts on coastal ecosystems, especially with respect to highly productive—but also highly sensitive—estuaries.<sup>134</sup>

Increasing concentrations of carbon dioxide in the atmosphere have led to increasing absorption of carbon dioxide by the oceans, resulting in a phenomenon known as “ocean acidification.” The oceans absorb about one-quarter of the anthropogenic emissions of carbon dioxide;<sup>135</sup> NOAA recently confirmed significantly increased rates of ocean uptake and storage of carbon throughout the 1990s and 2000s.<sup>136</sup> Moreover, it appears that the ocean’s capacity to absorb atmospheric carbon dioxide may be waning:

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<sup>129</sup> *Oregon Dead Zone Blamed on Climate Change*, ENVIRONMENT NEWS SERVICE (Oct. 8, 2009), <http://www.ens-newswire.com/ens/oct2009/2009-10-08-092.asp>.

<sup>130</sup> *Id.*

<sup>131</sup> *Id.*

<sup>132</sup> 2007 IPCC SYNTHESIS REPORT, *supra* note 100, at 51 fig.3.6.

<sup>133</sup> Levy, *supra* note 96, at S70 & fig.3.23 (citations omitted). *See also* 2007 IPCC SYNTHESIS REPORT, *supra* note 100, at 31 fig.1.1 (showing the increase in global average sea level).

<sup>134</sup> *Coastal Zones and Sea-Level Rise*, U.S. ENV’T’L PROTECTION AGENCY, <http://www.epa.gov/climatechange/effects/coastal/index.html> (last updated Aug. 19, 2010).

<sup>135</sup> Richard A. Feeley, Scott C. Doney, & Sarah R. Cooley, *Ocean Acidification: Present Conditions and Future Changes in a High-CO<sub>2</sub> World*, 22 OCEANOGRAPHY 36, 37 (Dec. 2009). A little less than half of the anthropogenic carbon dioxide remains in the atmosphere; the rest is divided between the oceans and terrestrial plants. Scott C. Doney et al., *Ocean Acidification: A Critical Emerging Problem for the Ocean Sciences*, 22 OCEANOGRAPHY 16, 16 (Dec. 2009).

<sup>136</sup> Levy, *supra* note 96, at S53.

[E]stimates suggest that the annual rate of ocean carbon storage has grown every year since the late 1700s, but the rate increased sharply in the 1950s in response to faster growth in atmospheric CO<sub>2</sub>. In recent decades, however, the rate of increase in ocean carbon storage has not been able to keep pace with the atmospheric growth rate. The percentage of annual anthropogenic CO<sub>2</sub> emissions stored in the ocean in 2008 was as much as 10% smaller than the percentages of the previous decade, although significant uncertainties remain which preclude a more definitive statement. The rapid growth in emissions over the past 10 years relative to the previous decade is one important factor in the reduction in the ocean's relative uptake of anthropogenic CO<sub>2</sub> emissions. Another key factor is the decreasing ability of the seawater to store the CO<sub>2</sub> as dissolved inorganic carbon. This reduced capacity is a natural and predictable consequence of ocean carbon chemistry that, in the absence of changes in large-scale circulation or ocean biology, will become more significant with time.<sup>137</sup>

Even so, ocean absorption of carbon dioxide is changing the ocean's chemistry and will continue to do so for some time. Average ocean pH, which hovered around 8.2 in preindustrial times, has already decreased 0.1 units.<sup>138</sup> In 2007, the IPCC projected that average ocean pH would drop by 0.14 to 0.35 units by 2100, varying according to the carbon dioxide emissions scenarios.<sup>139</sup> More recently, scientists have predicted that if the world continues to emit carbon dioxide in a "business-as-usual" mode and if atmospheric carbon dioxide concentrations reach 800 parts per million (ppm) (the current concentration is 387 ppm), "surface water pH will drop from a pre-industrial value of about 8.2 to about 7.8 . . . by the end of this century, increasing the ocean's acidity by 150% relative to the beginning of the industrial era"<sup>140</sup> and increasing the concentration of hydrogen ions in the oceans by 250 percent.<sup>141</sup>

While the impact of ocean acidification on marine organisms and ocean ecosystems is not yet fully understood, it is expected to be substantial. Some of the most direct effects will occur in calcifying organisms, such as coral, mussels, clams, and a variety of types of plankton, that rely on calcium carbonate to build their shells. Decreasing ocean pH changes the chemistry of calcium carbonate and its associated nutrients, calcite and aragonite, reducing the availability of these minerals to the organisms that need them.<sup>142</sup> One recent study projects that aragonite undersaturation—a condition in which aragonite becomes largely unavailable to biological processes such as shell formation—could begin to occur

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<sup>137</sup> *Id.* at S75 (citation omitted).

<sup>138</sup> Feeley, Doney & Cooley, *supra* note 136, at 37; 2007 IPCC SYNTHESIS REPORT, *supra* note 100, at 52.

<sup>139</sup> 2007 IPCC SYNTHESIS REPORT, *supra* note 100, at 52.

<sup>140</sup> Feeley, Doney & Cooley, *supra* note 136, at 37.

<sup>141</sup> *Id.*

<sup>142</sup> *Id.* at 37–41.

in the Arctic Ocean as early as 2020 and in the Southern Ocean around Antarctica by 2050.<sup>143</sup>

Ocean acidification is thus likely to result in “potentially dramatic responses in corals and coral reef communities and planktonic organisms.”<sup>144</sup> In particular, corals and their associated calcifying macroalgae are predicted to “calcify 10–50% less relative to pre-industrial rates by the middle of this century,” leading to declines in coral reef ecosystems and associated loss of marine habitat and biodiversity.<sup>145</sup>

However, the impacts of ocean acidification on marine ecosystems—and human well-being—are likely to be much broader. At the level of marine biochemistry, “the pH gradient across cell membranes is coupled to numerous critical physiological/biochemical reactions within marine organisms, ranging from such diverse processes as photosynthesis, to nutrient transport, to respiratory metabolism.”<sup>146</sup> At the physical level, decreasing pH levels decrease the oceans’ ability to absorb sound, and the resulting increased noise in the ocean may impact acoustically sensitive whales and dolphins, while decreasing concentrations of calcium carbonate allow for more light penetration, with unknown impacts.<sup>147</sup> Ecosystem impacts could be tremendous, resulting in loss of commercially important fisheries, locally important fisheries, and coastal protection from storms.<sup>148</sup> As researcher Scott Doney and his colleagues emphasized in 2009, “[u]nless there are dramatic changes in fossil fuel use, projected human-driven ocean acidification over this century will be larger and more rapid than anything affecting sea life for tens of millions of years.”<sup>149</sup> The economic and cultural costs for humans, especially those in developing nations or coastal countries, could be enormous.<sup>150</sup>

As a harbinger of things to come, climate change impacts, especially increases in SSTs and ocean acidification, are already interacting synergistically to impair the ocean’s primary production for food webs. Phytoplankton—tiny plants that generally float near the surface of the world’s oceans—are critical to marine ecosystems.<sup>151</sup> As NOAA recently explained:

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<sup>143</sup> *Id.* at 42.

<sup>144</sup> Doney et al., *supra* note 136, at 18.

<sup>145</sup> Joan A. Kleypas & Kimberly K. Yates, *Coral Reefs and Ocean Acidification*, 22 OCEANOGRAPHY 108, 109 (Dec. 2009).

<sup>146</sup> Doney et al., *supra* note 136, at 18.

<sup>147</sup> *Id.*

<sup>148</sup> *Id.* See also Sarah R. Cooley, Hauke L. Kite-Powell & Scott C. Doney, *Ocean Acidification’s Potential to Alter Global Marine Ecosystem Services*, 22 OCEANOGRAPHY 172, 172–76 (Dec. 2009) (detailing these ecosystem impacts).

<sup>149</sup> Doney et al., *supra* note 136, at 24.

<sup>150</sup> See generally Cooley, Kite-Powell & Doney, *supra* note 149, at 172–76 (detailing the value of marine ecosystem services that could be impacted by ocean acidification).

<sup>151</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 484.

Photosynthesis by the free-floating, single-celled phytoplankton of the upper-sunlit “photic” layer of the global ocean is the overwhelmingly dominant source of organic matter fueling marine ecosystems. Phytoplankton contribute roughly half of the annual biospheric (i.e., terrestrial and aquatic) net primary production . . . , and their photosynthetic carbon fixation is the primary conduit through which atmospheric CO<sub>2</sub> is transferred into the ocean’s organic carbon pools. These tiny suspended ocean “plants” play a vital role on the Earth’s biogeochemical cycles, and are the very base of the oceanic food chain.<sup>152</sup>

Chlorophyll provides a measure of plant life in the ocean.<sup>153</sup> According to NOAA, “[t]he downward trend in global chlorophyll observed since 1999 has continued through 2009, with current chlorophyll stocks in the central stratified oceans now approaching record lows since 1997.”<sup>154</sup> Chlorophyll, and hence phytoplankton growth, is inversely correlated temperature changes, meaning that as SSTs increase, phytoplankton growth decreases.<sup>155</sup>

### III. THE STATUS OF THE WORLD’S OCEANS AND SUGGESTIONS FOR THE FUTURE

Humans are not using the oceans sustainably. As the FAO reported in 2009, fully 80 percent of the world’s fished stocks are fully exploited, overexploited, depleted, or recovering from depletion, and that statistic does not include stocks that have been overfished to the point of commercially inviability.<sup>156</sup> Marine habitats have been degraded or destroyed on a widespread scale. As the MEA emphasized in 2005, for example, “[a]pproximately 20% of the world’s coral reefs were lost and an additional 20% degraded in the last several decades of the twentieth century, and approximately 35% of mangrove area was lost during this time (in countries for which sufficient data exist, which encompass about half of the area of mangroves).”<sup>157</sup> Marine diseases are on the increase, and some of them, such as ciguatera, directly threaten human health as well.<sup>158</sup> Harmful algal blooms are also increasing in frequency and intensity around the world, and in “a particularly severe outbreak in Italy in 1989, harmful algal blooms cost the coastal aquaculture industry \$10 million and the Italian tourism industry \$11.4 million” as a result of toxicity and aesthetics.<sup>159</sup>

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<sup>152</sup> Levy, *supra* note 96, at S75.

<sup>153</sup> *Id.*

<sup>154</sup> *Id.* at S53. *See also id.* at S78 & fig.3.33 (“From 1999 onward, an overall progressive decrease in chlorophyll is observed and coincident with a general increasing trend in surface-ocean temperature . . .”).

<sup>155</sup> *Id.* at S77–S78.

<sup>156</sup> *See* 2009 FAO FISHERIES REPORT, *supra* note 74, at 7.

<sup>157</sup> MEA 2005: SYNTHESIS REPORT, *supra* note 26, at 2.

<sup>158</sup> *Id.* at 9.

<sup>159</sup> *Id.*

To be sure, there have been some improvements in how we manage our uses of the oceans, but these are almost always limited and qualified successes. For example, the whaling moratorium<sup>160</sup> imposed through the International Convention for the Regulation of Whaling<sup>161</sup> probably prevented the extinction of the large baleen whales and has even allowed some, such as the gray whale and the minke whale, to recover somewhat.<sup>162</sup> Nevertheless, the existence of right whales and the largest baleen whales remains precarious, with their populations still far below pre-whaling status.<sup>163</sup> Moreover, all whales appear to be impacted by marine pollution, to the extent that minke whale meat sold in Japan may not satisfy Japan's domestic health regulations.<sup>164</sup>

Similarly, international regulation of vessel pollution through the increasingly stringent provisions of MARPOL 73/78<sup>165</sup> has significantly reduced this source of ocean pollution. According to UNEP, oil discharges and spills into the oceans are down 63 percent compared to the mid-1980s, while tanker accidents are down 75

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<sup>160</sup> See Virginia Morell, *International Deal to Tighten Whaling Quotas Collapses: Moratorium Holds*, SCIENCEINSIDER (June 23, 2010 5:16 PM). <http://news.sciencemag.org/scienceinsider/2010/06/international-deal-to-tighten-wh.html>.

<sup>161</sup> See International Convention for the Regulation of Whaling, Dec. 2, 1946, 62 Stat. 1716, 161 U.N.T.S. 72.

<sup>162</sup> The gray whale recovered from near extinction to a population high of 26,600 whales in the 1990s. Kenneth R. Weiss & Karen Kaplan, *Gray Whale Recovery Called Incorrect*, L.A. TIMES, Sept. 11, 2007, at A10. However, genetic studies have called the status of the whale's "recovery" into question. *Id.* In addition, rising sea temperatures appear to be interfering with the whales' food supplies. Juliet Eilperin, *Warming May Be Hurting Gray Whales' Recovery*, WASH. POST, Sept. 11, 2007, at A12.

In turn, minke whales have become so abundant that scientists suggested the "Krill Surplus Hypothesis" to explain their recovery. Kristen C. Ruegg et al., *Are Antarctic Minke Whales Unusually Abundant Because of 20th Century Whaling?*, 19 MOLECULAR ECOLOGY 281, 281 (Jan. 2010). Under this hypothesis, minke whales have benefited from the near-extermination of other, larger whales in the form of much greater supplies of food. *Id.* Recent research, however, suggests that this hypothesis is incorrect and that the world's oceans once supported even more minkes as well as large populations of other whale species. See generally *id.*

<sup>163</sup> See, e.g., *Fact Sheet: Blue Whale*, AMERICAN CETACEAN SOCIETY, <http://www.acsonline.org/factpack/bluewhl.htm> (last visited Oct. 1, 2010) (noting that blue whale recovery has been slow); *Fact Sheet: Fin Whale*, AMERICAN CETACEAN SOCIETY, <http://www.acsonline.org/factpack/finwhl.htm> (last visited Dec. 2, 2010) (noting that fin whale populations remain only a fraction of what they were before whaling); *North Atlantic Right Whale*, OFFICE OF PROTECTED RESOURCES - NOAA FISHERIES [http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/rightwhale\\_northatlantic.htm](http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/rightwhale_northatlantic.htm) (last visited Dec. 2, 2010) (noting that the right whale remains critically endangered).

<sup>164</sup> *Gourmet Food Fears: CAUTION: Whale Meat Is Hazardous to Your Health*, WHALES ON THE NET, May 16, 2002, <http://www.whales.org.au/news/afoodfear.html> (republishing an article from the Shanghai Star).

<sup>165</sup> International Maritime Organization, International Convention for the Prevention of Pollution from Ships, Nov. 2, 1973, as modified by the Protocol of 1978 relating thereto, Feb. 17, 1978, 34 U.S.T. 3407, 1340 U.N.T.S. 184.

percent.<sup>166</sup> However, vessel pollution has always been a rather small percentage of marine pollution, and, despite the number of treaties designed to address the problem, the world has had very little effect in preventing the far more prevalent land-based pollution, either runoff or atmospheric deposition, from contaminating the oceans.<sup>167</sup> The doubling of ocean dead zones every decade and the repeated discoveries of ocean “garbage patches” are testimony to this failure.

Four decades of fisheries collapses provide further evidence of unsustainable ocean use. As the MEA summarized in 2005:

The first fisheries collapse with global impact on prices of fishmeal and its substitutes was the Peruvian anchoveta, in 1971/72, which fell from an official catch of 12 million tons annually in the 1972–73 season (in reality, probably 16 million tons annually . . .) to 2 million tons in 1973, ushering in two decades of slow growth and then stagnation in global fish catches.<sup>168</sup>

It further warned:

The supply of wild marine fish as a cheap source of protein for many countries is declining. Per capita fish consumption in developing countries (excluding China) has declined from 9.4 kilograms per person in 1985 to 9.2 kilograms in 1997. In some areas, fish prices for consumers have increased faster than the cost of living. Fish products are heavily traded, and approximately 50% of fish exports are from developing countries. Exports from developing countries and the Southern Hemisphere presently offset much of the demand shortfall in European, North American, and East Asian markets.<sup>169</sup>

The United Nations Convention on the Law of the Sea has done little to reverse widespread overfishing.<sup>170</sup> Similarly, “[t]he implementation of North Atlantic agreements is among the best funded and supported administratively, and yet fisheries in the North Atlantic continue to decline.”<sup>171</sup> While documented global extinctions of marine species remain rare (although several may have occurred before the relevant species was even identified to science), scientists now suspect

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<sup>166</sup> United Nations Environment Programme, *What Is Marine Pollution and How Does It Affect Marine Life*, UNEP/GRID-ARENDAL, <http://www.grida.no/publications/rr/our-precious-coasts/page/1292.aspx> (last visited Dec. 2, 2010).

<sup>167</sup> See Daud Hassan, *International Conventions Relating to Land-Based Sources of Marine Pollution Control: Applications and Shortcomings*, 16 GEO. INT’L ENVTL. L. REV. 657, 676–77 (2004).

<sup>168</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 481 (citations omitted).

<sup>169</sup> *Id.* at 479.

<sup>170</sup> *Id.* at 499.

<sup>171</sup> *Id.* at 501.

that marine species may be far less resilient to changes in their environment than has been assumed in the past on the basis of reproductive fecundity.<sup>172</sup>

Nor does the world have the luxury of hashing out policies for the sustainable use of marine ecosystems in a static world. First, climate change poses several new threats to marine biodiversity, marine ecosystem structure and function, and, as a result, marine ecosystem services and the humans that depend upon them. As discussed, these include changes in precipitation patterns, which in turn can affect pollution levels (caused by runoff) and marine salinity, changes in ocean temperatures, change in ocean current patterns, and ocean acidification.

Second, humans are finding new uses for the oceans, the effects of which—especially in a climate change era—are far from well understood. These new uses include deepwater offshore oil drilling, ocean ranching, bioprospecting, seabed mining, and use of the oceans for carbon sequestration, such as through iron fertilization.<sup>173</sup> According to the MEA,

[t]he gas and oil industry is worth more than \$132 billion annually, and the potential for further development is considered high. Current levels of development in the deeper ocean environments are low, but future rises in the price of carbon-based fuels could make the extraction of crude oil and gas further offshore financially feasible.<sup>174</sup>

Relatedly, “[m]ining in shallow offshore coastal areas for gold, diamonds, and tin is already under way and there is little doubt that the technology can be developed for deeper mining for a range of minerals, including manganese nodules, cobalt, and polymetallic sulfides, given appropriate economic incentives.”<sup>175</sup>

New methods of ocean aquaculture, dubbed “ocean ranching,” seek to exploit the deep ocean to grow larger species of fish, such as tuna, for human consumption. One such experiment, using huge OceanSpheres, is occurring in Hawai’i.<sup>176</sup> Ocean ranching avoids some of the problems of more traditional coastal aquaculture, such as destruction of coastal habitat (often mangroves) and concentration of wastes.<sup>177</sup> However, it potentially creates new ones in the form of spreading disease or contributions to overfishing to provide food for the predators being raised.<sup>178</sup>

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<sup>172</sup> *Id.* at 488.

<sup>173</sup> *Id.* at 482.

<sup>174</sup> *Id.* at 482 (citation omitted).

<sup>175</sup> *Id.* (citation omitted).

<sup>176</sup> *First Tuna Farm in U.S. Approved by Hawaii Regulators*, NAT’L GEOGRAPHIC (Oct. 29, 2009), <http://blogs.nationalgeographic.com/blogs/news/chieffeditor/2009/10/first-tuna-farm-in-us-approved.html>.

<sup>177</sup> RACHEL BORGATTI & EUGENE H. BUCK, CONG. RESEARCH SERV., OPEN OCEAN AQUACULTURE 8–9 (Dec. 13, 2004), *available at* <http://ncseonline.org/nle/crsreports/04dec/RL32694.pdf>.

<sup>178</sup> *Id.* at 10–12.

People attempting to mitigate climate change have suggested turning to the ocean for solutions. The most widely supported proposal is to “fertilize” large areas of the ocean with micronutrients, predominantly iron, the lack of which otherwise stunts the growth of phytoplankton.<sup>179</sup> The goal is to stimulate the growth of these microscopic plants, which will uptake carbon dioxide and then carry it to the bottom of the ocean when they die.<sup>180</sup> Much remains to be learned about iron fertilization, but there is reason to be skeptical of both its potential to mitigate climate change and its supposed lack of impact on marine function. As the MEA noted, “[t]he net effect of this process on carbon sequestration is not clear, however, because localized algal outbursts can also lead to anoxia and the production of methane, a powerful greenhouse gas.”<sup>181</sup>

This second set of challenges to marine sustainability reflects the fact that very few people view the oceans as an exhaustible resource, instead pursuing the paradigm of inexhaustibility that has characterized marine resource management almost from the beginning of human civilization.<sup>182</sup> While focusing on fisheries, the MEA in 2005 aptly described the basic need for a paradigm shift:

Marine systems are still considered a new frontier for development by some people, and therefore a number of choices and trade-offs over fisheries will need to be made in the future. History has shown that once humans exhaust resources on land they look to the sea for alternatives. In repeating history, coastal environments are becoming degraded . . . and biodiversity is declining, beginning with the loss of large predators at high trophic levels. Now areas deeper and further offshore are increasingly exploited for fisheries and other resources such as oil and gas.<sup>183</sup>

So what should that paradigm shift look like? Given the pervasive impacts of climate change on the ocean, marine resources, marine ecosystems, and marine ecosystem services, we need to jump start a new paradigm for climate change adaptation, one I have described elsewhere as “principled flexibility.”<sup>184</sup> Under this new model,

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<sup>179</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 505.

<sup>180</sup> *Id.*

<sup>181</sup> *Id.*

<sup>182</sup> Robin Kundis Craig, *Protecting International Marine Biodiversity: International Treaties and National Systems of Marine Protected Areas*, 20 J. LAND USE & ENVTL. L. 333, 338–39 (2005).

<sup>183</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 492 (citations omitted).

<sup>184</sup> Robin Kundis Craig, “Stationarity Is Dead”—*Long Live Transformation: Five Principles for Climate Change Adaptation Law*, 34 HARV. ENVTL. L. REV. 9, 17–18 (2010).

both the law and regulators (1) distinguish in legally significant ways uncontrollable climate change impacts from controllable anthropogenic impacts on species, resources, and ecosystems that can and should be actively managed and regulated, and (2) implement consistent principles for an overall climate change adaptation strategy, even though the application of those principles in particular locations in response to specific climate change impacts will necessarily encompass a broad and creative range of adaptation decisions and actions.<sup>185</sup>

Moreover, I have previously identified five general principles for shifting legal and regulatory attention to increasing resilience and adaptive capacity.<sup>186</sup>

Many of these principles are relevant to the pursuit in the twenty-first century of truly sustainable use of the oceans, because climate change impacts will increasingly define what counts as “sustainable.” As President Obama recognized in July 2010 in his ocean policy executive order, “America’s stewardship of the ocean, our coasts, and the Great Lakes is intrinsically linked to environmental sustainability, human health and well-being, national prosperity, *adaptation to climate and other environmental changes*, social justice, international diplomacy, and national and homeland security.”<sup>187</sup>

First, under the principle of “[m]onitor and [s]tudy [e]verything [a]ll the [t]ime,”<sup>188</sup> we need to greatly improve our understanding of the oceans and how climate change is affecting its components.<sup>189</sup> The recently completed—and still being analyzed—decade-long Census of Marine Life<sup>190</sup> is one example of the simultaneously comprehensive and detailed accumulation of relatively basic knowledge about the oceans. Moreover, data from the Census provided the groundwork for the study that appeared in *Nature* in July 2010 about the potential increasing-ocean temperatures have to change everything about marine biodiversity.<sup>191</sup> Increasing scientific understanding of the oceans is also a prominent focus of President Obama’s new ocean policy.<sup>192</sup>

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<sup>185</sup> *Id.*

<sup>186</sup> *See id.* at 40–70.

<sup>187</sup> Exec. Order No. 13,547, §1, Stewardship of the Ocean, Our Coasts, and the Great Lakes, 75 Fed. Reg. 43,023, 43,023 (July 19, 2010) (emphasis added).

<sup>188</sup> Craig, *supra* note 184, at 40.

<sup>189</sup> The MEA, for example, noted that “[p]olicies will need to deal with the uncertainty of potential impacts and the limited understanding of marine biodiversity.” MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 493 (citations omitted).

<sup>190</sup> *Making Ocean Life Count*, CENSUS OF MARINE LIFE, <http://www.coml.org/> (last visited Dec. 2, 2010).

<sup>191</sup> Tittensor et al., *supra* note 124.

<sup>192</sup> Specifically, the “policy” section of President Obama’s Executive Order states that it is U.S. policy to, *inter alia*:

The second highly relevant principle is to “[e]liminate or [r]educe [n]on-[c]limate [c]hange [s]tressors and [o]therwise [p]romote [r]esilience.”<sup>193</sup> Land-based pollution is an obvious target for applying this principle,<sup>194</sup> and much work is being done in this area.<sup>195</sup> With respect to overfishing, there is wide agreement that regulations based on “maximum sustainable yield” in fact lead to unsustainable fishing<sup>196</sup> and that governments need to stop subsidizing their fishing industries<sup>197</sup> and prohibit destructive fishing practices.<sup>198</sup> Finally, increased and science-based use of marine zoning, marine managed areas, marine protected areas, and marine reserves—collectively, marine spatial planning—would help to foster resilience by reducing fishing pressure, protecting key habitat, and giving migrating species places to relocate.<sup>199</sup>

Marine spatial planning also helps to implement the third principle: “[p]lan for the [l]ong [t]erm with [m]uch [i]ncreased [c]oordination [a]cross [m]edia, [s]ectors, [i]nterests, and [g]overnments.”<sup>200</sup> Simply by setting aside areas for marine life, marine zoning and marine protected areas acknowledge potential

(viii) increase scientific understanding of ocean, coastal, and Great Lakes ecosystems as part of the global interconnected systems of air, land, ice, and water, including their relationships to humans and their activities;

(ix) improve our understanding and awareness of changing environmental conditions, trends, and their causes, and of human activities taking place in ocean, coastal, and Great Lakes waters; and

(x) foster a public understanding of the value of the ocean, our coasts, and the Great Lakes to build a foundation for improved stewardship.

Exec. Order No. 13,547, § 1, Stewardship of the Ocean, Our Coasts, and the Great Lakes, 75 Fed. Reg. 43,023, 43,024 (July 19, 2010).

<sup>193</sup> Craig, *supra* note 185, at 43.

<sup>194</sup> See *id.* at 45–46 (discussing the need to decontaminate resources); see also *supra* notes 34–67 & accompanying text (discussing the various forms and impacts of land-based pollution in the marine environment).

<sup>195</sup> See generally David VanderZwaag, *A Global Treaty to Address Land-Based Sources of Marine Pollution*, 12 OCEAN & COASTAL L.J. 355 (2007) (reviewing DAUD HASSAN, PROTECTING THE MARINE ENVIRONMENT FROM LAND-BASED SOURCES OF POLLUTION: TOWARDS EFFECTIVE INTERNATIONAL COOPERATION (2006)).

<sup>196</sup> Craig, *supra* note 185, at 46–48.

<sup>197</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 490–91 (citations omitted); *Turning the Tide on Falling Fish Stocks—UNEP-Led Green Economy Charts Sustainable Investment Path*, UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP) (May 17, 2010), <http://unep.org/Documents.Multilingual/Default.asp?DocumentID=624&ArticleID=6566&l=en&t=long>. See also Craig, *supra* note 185, at 48–51 (noting in general the benefits of eliminating maladaptive incentives and subsidies).

<sup>198</sup> MEA 2005: CURRENT STATE AND TRENDS, *supra* note 11, at 495.

<sup>199</sup> *Id.* at 493, 495, 501–02, 504–05. See also Craig, *supra* note 185, at 51–53 (discussing in general the value of protected areas to climate change adaptation).

<sup>200</sup> Craig, *supra* note 185, at 53.

conflicts between humans and marine species—generally, between ocean species and fishers.<sup>201</sup> In the climate change era, pressures on fisheries are only likely to increase, as noted, requiring increased legal measures to prevent the complete decimation of fish stocks and their attendant marine ecosystems.<sup>202</sup> Notably, President Obama made marine spatial planning a significant focus of his ocean policy executive order, emphasizing the coordinative role of such planning:

This order also provides for the development of coastal and marine spatial plans that build upon and improve existing Federal, State, tribal, local, and regional decisionmaking and planning processes. These regional plans will enable a more integrated, comprehensive, ecosystem-based, flexible, and proactive approach to planning and managing sustainable multiple uses across sectors and improve the conservation of the ocean, our coasts, and the Great Lakes.<sup>203</sup>

In addition, the executive order fosters improved coordination<sup>204</sup> by creating a National Ocean Council<sup>205</sup> and requiring federal agencies to subordinate their actions to the Council's priorities and approved marine spatial plans, to the extent that the law otherwise allows.<sup>206</sup>

The fourth principle advocates that the law “[p]romote [p]rincipled [f]lexibility in [r]egulatory [g]oals and [n]atural [r]esource [m]anagement.”<sup>207</sup> To promote sustainable use of the oceans in the twenty-first century, this principle counsels in favor of a strong precautionary principle in fisheries management and flexibility in marine spatial planning. Both can be promoted through an ecosystem-based approach to managing the oceans that incorporates a strong commitment to adaptive management to respond to new scientific information and unexpected ecosystem responses to climate change.<sup>208</sup>

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<sup>201</sup> Robin Kundis Craig, *Taking Steps Toward Marine Wilderness Protection? Fishing and Coral Reef Marine Reserves in Florida and Hawaii*, 34 MCGEORGE L. REV. 155, 167–73 (2003).

<sup>202</sup> See Craig, *supra* note 185, at 55–57 (discussing the need to not forget species' adaptation requirements while pursuing human needs).

<sup>203</sup> Exec. Order No. 13,547, § 1, Stewardship of the Ocean, Our Coasts, and the Great Lakes, 75 Fed. Reg. 43,023, 43,023 (July 19, 2010).

<sup>204</sup> As I have noted repeatedly, marine regulation in the United States suffers badly from regulatory fragmentation, both regarding upstream resources and among marine resources. Robin Kundis Craig, *Climate Change, Regulatory Fragmentation, and Water Triage*, 79 U. COLO. L. REV. 825, 833–69 (2008); Robin Kundis Craig, *Regulation of U.S. Marine Resources: An Overview of the Current Complexity*, 19 NAT. RESOURCES & ENVT. 3, 3–9 (2004).

<sup>205</sup> Exec. Order No. 13,547, § 4, Stewardship of the Ocean, Our Coasts, and the Great Lakes, 75 Fed. Reg. 43,023, 43,024–25 (July 19, 2010).

<sup>206</sup> *Id.* § 6, 75 Fed. Reg. at 43,025–26.

<sup>207</sup> Craig, *supra* note 185, at 63.

<sup>208</sup> Karen L. McLeod & Heather M. Leslie, *Why Ecosystem-Based Management?*, in ECOSYSTEM-BASED MANAGEMENT FOR THE OCEANS 3, 3–8 (2009) (“Sustaining the long-

Finally, managers need to accept “[t]hat [c]limate [c]hange [a]daptation [w]ill [o]ften [b]e [p]ainful.”<sup>209</sup> Unsustainable pre-climate change use of the oceans has already put marine-related food supplies at risk world-wide. Climate change will almost certainly exacerbate that trend with respect to wild fish and seafood. Whether marine aquaculture can provide a sustainable replacement remains an open question.<sup>210</sup> The long-term survival of the planet’s coral reefs is also in doubt.<sup>211</sup>

Of course, mitigating climate change would also improve the long-term sustainability of the oceans, although climate change impacts will continue to occur for at least the next century or two.<sup>212</sup> Importantly, moreover, the oceans provide the irrefutable argument for the need to reduce atmospheric concentrations of carbon dioxide, rather than rely on some technological form of mitigation, or geoengineering, such as spraying sulfate aerosols<sup>213</sup> or increasing the reflectivity of urban areas<sup>214</sup> to reduce air temperatures; such methods do nothing to reduce ocean acidification, regardless of the other improvements that they might bring.

#### CONCLUSION

To discuss “oceans” and “sustainability” in the same sentence is inherently oxymoronic, even before climate change impacts become a prominent stressor to the oceans. Climate change, in turn, demands that ocean law and policy categorically shift from allowing this unsustainable use to adaptation-minded, ecosystem-focused, resilience-promoting adaptive management. Now (yesterday, if possible).

The trade-offs will probably be painful, particularly with respect to world food supply and ocean-based (especially coral reef-based) tourism. In light of the fact that carbon dioxide absorption and climate change impacts will continue for at least a century or two even if the world adopts an effective climate change

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term capacity of systems to deliver ecosystem services is the core goal of ecosystem-based management (EBM) for the oceans” (p.3); “EBM is fundamentally a place-based approach” (p.4); EBM requires a recognition that systems are constantly changing, and “an adaptive management framework is recommended” (p.8).

<sup>209</sup> Craig, *supra* note 185, at 69.

<sup>210</sup> Carlos M. Duarte et al., *Will the Oceans Help Feed Humanity?*, 59 *BIOSCIENCE* 967, 973–74 (2009) (acknowledging the issues but providing several suggestions to make mariculture sustainable).

<sup>211</sup> “According to scientists, 70 percent of the world’s coral reefs may be lost by 2050.” The Nature Conservancy, *Ensuring Coral Reef Survival* 1 (Oct. 2008), available at [http://www.nature.org/initiatives/marine/files/tnc\\_coral\\_1006\\_final1.pdf](http://www.nature.org/initiatives/marine/files/tnc_coral_1006_final1.pdf).

<sup>212</sup> Craig, *supra* note 185, at 23, and sources cited therein.

<sup>213</sup> Sharon Begley, *The Geo-Engineering Scenario*, *NEWSWEEK* (Nov. 23, 2007), <http://www.newsweek.com/2007/11/22/the-geo-engineering-scenario.html>.

<sup>214</sup> *Geo-Engineering: Climate Solution or Dangerous Distraction?*, *ECOLOGIST* (Sept. 1, 2009), [http://www.theecologist.org/News/news\\_round\\_up/312138/geoengineering\\_climate\\_solution\\_or\\_dangerous\\_distraction.html](http://www.theecologist.org/News/news_round_up/312138/geoengineering_climate_solution_or_dangerous_distraction.html).

mitigation plan tomorrow, what the oceans need most is to be left alone, relieved of as many non-climate change stressors—overfishing, pollution, habitat destruction—as possible. If the oceans are to survive, protected areas like the Papahānaumokuākea Marine National Monument may have to become the norm, rather than the exception.

On the other hand, *not* acting has its own painful trade-offs. World food production will not improve if global fish stocks collapse by 2050. Coral reef tourism will die as the reefs do.

The jellyfish, however, will thrive.<sup>215</sup>

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<sup>215</sup> “Unlike sharks, orcas and other aggressive carnivores, jellyfish thrive in ecosystems damaged by human activity. From the Gulf of Mexico to the Sea of Japan, oceanographers have found a common symptom among places where overfishing, chemical pollution and rising sea temperatures have killed off other species: more jellyfish.” Drew FitzGerald, *The New Ocean Predator: Jellyfish?*, GLOBALPOST (Nov. 29, 2009), <http://www.globalpost.com/dispatch/study-abroad/091022/the-new-ocean-predator-jellyfish>.