Re-Tooling Marine Food Supply Resilience in a Climate Change Era: Some Needed Reforms

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ABSTRACT

Ocean fisheries and marine aquaculture are an important but often overlooked component of world food security. For example, of the seven billion (and counting) people on the planet, over one billion depend on fish as their primary source of protein, and fish is a primary source of protein (30 percent or more of protein consumed) in many countries around the world, including Japan, Greenland, Taiwan, Indonesia, several countries in Africa, and several South Pacific island nations.

Marine fisheries and marine aquaculture have been subject to a number of stressors that can undermine world food security, including overfishing, habitat destruction, and pollution. However, climate change poses new and significant threats to marine fisheries and aquaculture that could both reduce the global marine food resource base and render ineffective current fisheries management. As a result, the resilience of the marine food supply into the future is very much in question, threatening food security in sometimes insidious ways. This Article first explores humans' dependence on wild-caught marine fish and marine aquaculture before examining the emerging threats that climate change poses to wild fish stocks, marine aquaculture, and fisheries management. It then examines six ways that governments could internationally and individually re-tool marine-related governance systems to adapt to this climate change era, particularly by recognizing that fish stocks are increasingly likely to shift their ranges from historical norms and by recognizing that marine

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aquaculture may not be possible in all places. The Article concludes, however, that while productive re-tooling is still possible, the world also needs to face the probability that marine fish and marine aquaculture will become increasingly unreliable sources of food and that resilience-focused governance policies for marine aquaculture in particular will become increasingly important.

I. INTRODUCTION

Marine fisheries play a critical role in world food security. In general, "food security" refers to the state of having secure access to enough food for a given population at all times.[1] Given that definition, therefore, defining the relevant human population can be important, but in almost all situations there are special concerns when dealing with food security issues for the poor and other vulnerable populations.[2] For example, marine fish and shellfish have long been important sources of protein for these populations, particularly coastal populations.[3]

People addressing issues of food security globally almost always focus on land-based crops and livestock.[4] However, global fish and shellfish production is also critically important to the issue of food security. Of the seven billion (and counting) people who live on the planet, one billion rely on fish as their primary source of protein.[5] As of 2010, 2.9 billion people get about 20 percent of their protein from fish, while 4.3 billion people—well over half the world's human population—get at least 15 percent of their protein from fish.[6] In addition, fish is a critical source of protein (30 percent or more of protein consumed) in many countries around the world, including Japan, Greenland, Taiwan, Indonesia, several countries in Africa, and several South Pacific island nations.[7]

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1. *Food Security*, WORLD HEALTH ORG., http://www.who.int/trade/glossary/story028/en/ (last visited Feb. 12, 2015) [hereinafter WHO, *Food Security*].

2. *See id.*

3. *Fish as Food*, MARINE STEWARDSHIP COUNCIL, http://www.msc.org/healthy-oceans/the-oceans-today/fish-as-food (last visited Feb. 12, 2015) [hereinafter MSC, *Fish as Food*].

4. The World Health Organization, for example, emphasizes:

> Agriculture remains the largest employment sector in most developing countries and international agriculture agreements are crucial to a country's food security. Some critics argue that trade liberalization may reduce a country's food security by reducing agricultural employment levels.

WHO, *Food Security*, *supra* note 1.

5. MSC, *Fish as Food*, *supra* note 3. This figure includes consumption of both marine fish and freshwater fish.

6. *Id.*

7. *Id.*

Thus, any comprehensive discussion of world food security needs to include the availability of fish, particularly marine fish. However, the harvest of wild marine fish has essentially leveled off since about 1990 despite increased fishing effort, and there is reason to suspect that global fish stocks are declining at an ever-faster rate.[8] In addition, climate change poses new threats both to this global wild food source and to the marine aquaculture (mariculture) that increasingly seeks to complement wild fish supplies.[9] As a result, the resilience of the marine food supply into the future is very much in question, threatening food security in sometimes insidious ways.

This Article first explores humans' dependence on wild-caught marine fish and marine aquaculture in Part II before examining the emerging threats that climate change poses to wild fish stocks, marine aquaculture, and fisheries management in Part III. These threats derive, for the most part, from changing water temperatures in the world's oceans, changing ocean currents, and ocean acidification. In Part IV, this Article examines some of the ways that governments could internationally and individually re-tool fisheries management to adapt to this climate change era, particularly by recognizing that fish stocks are increasingly likely to shift their ranges from historical norms and by recognizing that marine aquaculture may not be possible in all places. The Article concludes, however, that while productive re-tooling is still possible, the world also needs to face the probability that marine fish and marine aquaculture will become increasingly unreliable sources of food, particularly for some of the world's impoverished coastal populations, and that world food policy should begin planning for that new reality.

II. HUMANS' DEPENDENCE ON MARINE FOOD AND THE STATE OF WORLD FISHERIES AND AQUACULTURE

Marine fish and shellfish have long been important sources of food to human populations, particularly coastal populations. Now, however, marine fisheries are a global enterprise, entwining importing and exporting nations into a global market of marine food supply. Internationally, the United Nations Food and Agriculture Organization (FAO) compiles fishing and fish marketing statistics on a continual basis.[10] Domestically

8. "The year of Peak Ocean Fish was 1996. Crews hauled in 87.7 million tonnes of wriggling protein. The total sea catch has since fallen to about 80 million tonnes and stabilised." Roger Harrabin, *Shortages: Fish on the Slide*, BBC NEWS (June 18, 2012), http://www.bbc.com/news/science-environment-18353964.

9. *See infra* Parts II.A.3 and II.C.

10. *See infra* Part II.A.

in the United States, the most overarching studies of fishing and fish markets come from the National Oceanic and Atmospheric Administration (NOAA) within the U.S. Department of Commerce.[11] Together, reports from these two agencies provide the best overall snapshot of humans' global and domestic dependence on marine fisheries and marine aquaculture.

A. United Nations Food & Agriculture Organization 2014 Report

1. Overview: Fisheries Production, Food, and Trade

Every two years, the FAO publishes a report entitled *The State of World Fisheries and Aquaculture*.[12] The latest of these reports appeared in 2014[13] and provides one of the most authoritative assessments of the world's ocean-based food supply and of the humans who depend on that food supply. It summarizes the current and future challenges as follows:

> In a world where more than 800 million continue to suffer from chronic malnourishment and where the global population is expected to grow by another 2 billion to reach 9.6 billion people by 2050—with a concentration in coastal urban areas—we must meet the huge challenge of feeding our planet while safeguarding its natural resources for future generations.[14]

Importantly, fish consumption has grown from representing 29 percent of animal-based protein sources in 1989 to 31 percent in 2012.[15]

As the FAO reports, "Global fish production has grown steadily in the last five decades . . . with food fish supply increasing at an average annual rate of 3.2 percent, outpacing world population growth at 1.6 percent. World per capita apparent fish consumption increased from an average of 9.9 kg in the 1960s to 19.2 kg in 2012 (preliminary estimate)."[16] However, the FAO's summary also reveals that most of the increase comes from aquaculture; the capture of wild fish leveled off in about 1990, while aquaculture production has grown significantly, especially in

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11. *See infra* Part II.B.

12. *See* Fisheries & Aquaculture Dep't, *Publications*, FOOD & AGRIC. ORG. OF THE UNITED NATIONS, http://www.fao.org/fishery/publications/sofia/en (last visited Feb. 9, 2015) (listing reports from 1994 to 2014).

13. FOOD & AGRIC. ORG. OF THE UNITED NATIONS, THE STATE OF WORLD FISHERIES AND AQUACULTURE (2014) [hereinafter 2014 FAO FISHERIES REPORT], *available at* http://www.fao.org/3/a-i3720e.pdf.

14. *Id.* at iii.

15. *Id.* at 67 fig.32.

16. *Id.* at 3.

China.[17] Specifically, wild capture of marine fish has been holding relatively steady at about 80 million tonnes per year, while marine aquaculture production increased from 20 million tonnes per year in 2007 to 24.7 million tonnes per year in 2012, the last year for which data is available.[18]

The majority of fish captured are used for human food supply.[19] Indeed, the FAO noted that "[t]he proportion of fisheries production used for direct human consumption increased from about 71 percent in the 1980s to more than 86 percent (136 million tonnes) in 2012, with the remainder (21.7 million tonnes) destined to non-food uses (e.g. fishmeal and fish oil)."[20] Moreover, as more fish becomes available, people worldwide, on average, are consuming more fish.[21] As such, any reduction in the amount of fish available could threaten food supplies and reduce food security.

Fish are also one of the most internationally traded commodities.[22] "In 2012, about 200 countries reported exports of fish and fishery products. The fishery trade is especially important for developing nations, in some cases accounting for more than half of the total value of traded commodities."[23] The economics of the fishery trade are shifting as well: "China is, by far, the largest exporter of fish and fishery products. However, since 2011, it has become the world's third-largest importing country, after the United States of America and Japan. The European Union (Member Organization) is the largest market for imported fish and fishery products, and its dependence on imports is growing."[24] Globally, Asian nations dominate marine fisheries catches, and they "have shown considerable increases in marine catches in the last 10 years, with the exception of Japan and Thailand, which have registered decreases, and

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17. *Id.* at 3 & fig.1.

18. *Id.* at 4 tbl.1.

19. *Id.* at 7.

20. *Id.* Broken down in finer detail:

> Fish production can be utilized for food and other non-food uses. Since the early 1990s, the proportion of fisheries production used for direct human consumption has been increasing. In the 1980s, about 71 percent of the fish produced was destined for human consumption, this share grew to 73 percent in the 1990s, and to 81 percent in the 2000s. In 2012, more than 86 percent (136 million tonnes) of world fish production was utilized for direct human consumption.

Id. at 42.

21. *Id.* at 62. "The driving force behind this impressive surge has been a combination of population growth, rising incomes, and urbanization interlinked to the strong expansion of fish production and modern distribution channels." *Id.*

22. *Id.* at 7.

23. *Id.*

24. *Id.* at 8.

the Philippines and the Republic of Korea, whose catches have grown slightly."[25] "Reflecting the extensive fishing by Asian countries, the Northwest and Western Central Pacific are the areas with highest and still-growing catches."[26]

2. Marine Wild-Capture Fisheries

While there have been increased catches in areas of the Pacific, total wild capture of marine fish has held steady despite expanding catch effort, a reflection of the fact that many commercially important fish stocks worldwide are in trouble. As the FAO reported, "the world's marine fisheries expanded continuously to a production peak of 86.4 million tonnes in 1996 but have since exhibited a general declining trend."[27] In addition, "[t]he proportion of assessed marine fish stocks fished within biologically sustainable levels declined from 90 percent in 1974 to 71.2 percent in 2011, when 28.8 percent of fish stocks were estimated as fished at a biologically unsustainable level and, therefore, overfished."[28] Another 61.3 percent of assessed fish stocks are considered fully fished, while only 9.9 percent of fished stocks are underfished.[29]

To put these figures in perspective, "[t]he ten most productive species accounted for about 24 percent of world marine capture fisheries production in 2011. Most of their stocks are fully fished and some are overfished."[30] Thus, the fish stocks most responsible for supplying human food are at—and increasingly often over—their productivity limits,[31] suggesting that better management of fisheries will be necessary for future global food security. Indeed, the FAO noted that "[r]ebuilding overfished stocks could increase production by 16.5 million tonnes and annual rent by US$32 billion."[32]

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25. *Id.* at 10.

26. *Id.* at 11.

27. *Id.* at 37.

28. *Id.* at 7; *see also id.* at 37. As the FAO further explains, "Stocks fished at biologically unsustainable levels have an abundance lower than the level that can produce the maximum sustainable yield (MSY) and are therefore overfished. They require strict management plans to rebuild them to full and biologically sustainable productivity." *Id.*

29. *Id.* Fully fished stocks, or "[s]tocks fished at the MSY level[,] produce catches that are at or very close to their maximum sustainable production. Therefore, they have no room for further expansion in catch, and require effective management to sustain their MSY. Stocks with a biomass considerably above the MSY level (underfished stocks) may have some potential to increase their production." *Id.*

30. *Id.*

31. *See id.* at 38.

32. *Id.* at 41.

Nevertheless, the lack of solid scientific data regarding important fish stocks remains an impediment to improved management. For example, "[i]llegal, unreported and unregulated (IUU) fishing remains a major threat to marine ecosystems."[33] IUU fishing is a pervasive problem that

> undermin[es] national and regional efforts to manage fisheries sustainably and conserve marine biodiversity. Motivated by economic gain, IUU fishing takes advantage of corrupt administrations and exploits weak management regimes, especially those of developing countries lacking the capacity and resources for effective MCS. It is found in all types and dimensions of fisheries, occurs both on the high seas and in areas under national jurisdiction, concerns all aspects and stages of the capture and utilization of fish, and may sometimes be associated with organized crime.[34]

Furthermore, "[i]t is well known that IUU fishing has escalated in the past 20 years, especially in high seas fisheries. However, its dynamic, adaptable, highly mobile and clandestine nature prevents a straightforward estimation of its impacts. Rough estimates indicate that IUU fishing takes 11–26 million tonnes of fish each year, for an estimated value of US$10–23 billion."[35]

Similarly, "bycatch" (the unintentional catch of unwanted or non-target species) and discards of unwanted catches are also concerns.[36] As one example, "the longline fishery for mahi mahi in Costa Rica" has inflicted "collateral damage over a decade[,] includ[ing] 402 silky sharks, 625 stingrays and 1348 olive ridley turtles."[37]

However, even with good science, market forces can continue to drive overfishing. Tuna provide an important example. According to the FAO:

> Among the seven principal tuna species, *one-third of the stocks were estimated as fished at biologically unsustainable levels*, while 66.7 percent were fished within biologically sustainable levels (fully fished or underfished) in 2011. The landings of skipjack tuna plateaued at 2.6 million tonnes in 2010–11, after peaking at 2.7 million tonnes in 2009. Only for very few stocks of the principal tuna species is their status unknown or very poorly known. *Market demand for tuna is still high and the significant overcapacity of tuna*

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33. *Id.* at 9.
34. *Id.* at 84.
35. *Id.*
36. *See id.* at 7.
37. Harrabin, *supra* note 8.

> *fishing fleets remains*. Effective management plans need to be implemented to prevent deterioration of tuna stocks.[38]

In addition, stock assessments based on single species can obscure ecosystem impacts that affect other species. As one example, according to the FAO, "it is ecologically impossible to harvest all species at the MSY [maximum sustainable yield] level simultaneously. Therefore, some stocks may need to have their abundance maintained above the MSY level to avoid ecosystem overfishing."[39]

3. Aquaculture

Aquaculture has been a significant food supplement to wild fish capture.[40] According to the FAO, in 2012,

> world aquaculture production attained another all-time high of 90.4 million tonnes (live weight equivalent) in 2012 (US$144.4 billion), including 66.6 million tonnes of food fish (US$137.7 billion) and 23.8 million tonnes of aquatic algae (mostly seaweeds, US$6.4 billion). In addition, some countries also reported collectively the production of 22 400 tonnes of non-food products (US$222.4 million), such as pearls and seashells for ornamental and decorative uses.[41]

Moreover, aquaculture production continues to rise:

> According to the latest information, FAO estimates that world food fish aquaculture production rose by 5.8 percent to 70.5 million tonnes in 2013, with production of farmed aquatic plants (including mostly seaweeds) being estimated at 26.1 million tonnes. In 2013, China alone produced 43.5 million tonnes of food fish and 13.5 million tonnes of aquatic algae.[42]

Notably, "Asia account[s] for about 88 percent of world aquaculture production by volume."[43]

However, aquacultured species and locations vary considerably from country to country.[44] According to the FAO, "more than 600 aquatic species are cultured worldwide for production in a variety of farming systems and facilities of varying input intensities and technological so-

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38. 2014 FAO FISHERIES REPORT, *supra* note 13, at 38 (emphasis added).
39. *Id.* at 41.
40. *Id.* at 64.
41. *Id.* at 18.
42. *Id.*
43. *Id.* at 21.
44. *Id.* at 21–22.

phistication, using freshwater, brackish water and marine water."[45] Only a relatively small proportion of these aquacultured fish and shellfish are grown in the world's oceans and coasts—24.7 million tonnes compared to almost 42 million tonnes aquacultured in inland waters.[46] Moreover, not all countries that rely on freshwater aquaculture lack coasts; as the FAO noted, "India, Bangladesh, Egypt, Myanmar and Brazil rely very heavily on inland aquaculture of finfish while their potential for mariculture production of finfish remains largely untapped."[47] China also has yet to fully tap its marine environments for aquaculture despite being the world's largest producer of aquacultured fish and shellfish:

> China is very diversified in terms of aquaculture species and farming systems, and its finfish culture in freshwater forms the staple supply of food fish for its domestic market. Its finfish mariculture subsector, especially marine cage culture, is comparatively weak, with only about 38 percent (395 000 tonnes) being produced in marine cages.[48]

However, "[w]orld production of farmed seaweeds more than doubled from 2000 to 2012," especially in Indonesia and China.[49]

In 1980, freshwater aquaculture and mariculture production were roughly equal.[50] However, "inland aquaculture growth has since outpaced mariculture growth, with average annual growth rates of 9.2 and 7.6 percent, respectively. As a result, inland aquaculture steadily increased its contribution to total farmed food fish production from 50 percent in 1980 to 63 percent in 2012."[51] Nevertheless, mariculture is a higher-value enterprise:

> Although finfish species grown from mariculture represent only 12.6 percent of the total farmed finfish production by volume, their value (US$23.5 billion) represents 26.9 percent of the total value of all farmed finfish species. This is because finfish grown from mariculture include a large proportion of carnivorous species, such as

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45. *Id.* at 24.

46. *Id.* at 23 tbl.8. According to the FAO, "Mariculture includes production operations in the sea and intertidal zones as well as those operated with land-based (onshore) production facilities and structures." *Id.* at 22.

47. *Id.* at 21.

48. *Id.* at 22.

49. *Id.* at 25.

50. *Id.* at 22.

51. *Id.*

> Atlantic salmon, trouts[,] and groupers, that are higher in unit value than most freshwater-farmed finfish.[52]

B. NOAA's Reviews of Fishing in the United States

Under the United States' Magnuson–Stevens Fishery Conservation and Management Act (Magnuson–Stevens Act or MSA),[53] NOAA must report to Congress each year on the status of U.S. fish stocks and fisheries.[54] Under this statute, the United States manages fisheries in federal waters[55] at both the national and regional levels. At the regional level, the MSA creates eight Regional Fisheries Management Councils (FMCs),[56] each with the responsibility to create Fishery Management Plans (FMPs) "for each fishery under its authority that requires conservation and management . . . ."[57] At the national level, NOAA Fisheries (also referred to as the National Marine Fisheries Service or NMFS) oversees the regional FMCs[58] by ensuring that the FMPs meet the national standards for such plans.[59]

Importantly, since the 2006 amendments to the MSA, NOAA Fisheries and the FMCs have explicit duties to prevent overfishing and to rebuild overfished stocks.[60] Among other things, the amendments required annual catch limits (ACLs) for federally managed fisheries by 2007.[61] In addition, these amendments have led to other kinds of fish conservation measures that fishers have repeatedly considered too draconian, including temporary shutdowns of certain fisheries, leading to several legal challenges. However, the federal courts have largely upheld these measures. For example, in *North Carolina Fisheries Association v.*

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52. *Id.* at 23.

53. 16 U.S.C. §§ 1801–1891 (2012).

54. *Id.* § 1854(e)(1).

55. *See id.* § 1856(a)(2) (extending state authority to the limits of the United States' territorial sea as defined by the 1958 Geneva Convention on the Territorial Sea and Contiguous Zone, which was three nautical miles).

56. *Id.* § 1852(a).

57. *Id.* § 1852(h)(1).

58. *Id.* § 1854(a)–(c).

59. *Id.* § 1851(a).

60. Magnuson–Stevens Fishery Conservation and Management Reauthorization Act of 2006, Pub. L. No. 109-479, § 104, 120 Stat. 3575 (2007); *see also* 16 U.S.C. § 1801(a)(6) (stating that the MSA was "necessary to prevent overfishing, to rebuild overfished stocks, to insure conservation, to facilitate long-term protection of essential fish habitats, and to realize the full potential of the Nation's fishery resources").

61. NOAA FISHERIES, NAT'L OCEANIC & ATMOSPHERIC ADMIN., STATUS OF STOCKS 2013: ANNUAL REPORT TO CONGRESS ON THE STATUS OF U.S. FISHERIES 2 (2014) [hereinafter 2013 NOAA FISH STOCK REPORT], *available at* http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/archive/2013/status_of_stocks_2013_web.pdf.

Gutierrez,[62] the U.S. District Court for the District of Columbia applied the new amendments to uphold significant restrictions on the harvest of snowy grouper, vermillion snapper, and black sea bass despite uncertainties in the science, holding that "the Secretary [of Commerce] was not obliged to 'sit idly by' when faced with overfishing and overfished stocks simply because the data available to him may have been less than perfect."[63]

The amended MSA is also arguably starting to improve both the regulators' knowledge regarding commercial fisheries in the United States and the status of various fish stocks within U.S. waters. In 2007, the first year during which the 2006 amendments were in effect, NMFS analyzed whether only 244 of 528 federally managed fish stocks were subject to overfishing. Of those, 41 stocks, or 17 percent of those assessed, were subject to overfishing, a decrease from 48 stocks in 2006.[64] Similarly, NMFS analyzed whether only 190 of the stocks were overfished, concluding that 45 stocks, or 24 percent of those assessed, were overfished, a decrease from 47 overfished stocks in 2006.[65]

NOAA Fisheries published its latest report to Congress, entitled *Status of Stocks 2013*, on April 29, 2014,[66] which assesses fish stocks and reports better status numbers. As of 2013, there were 478 fisheries stocks and stock complexes managed through 46 federal FMPs.[67] NOAA Fisheries had enough information to assess overfishing status for 300 of these stocks and stock complexes and to assess overfished status for 230.[68] However, not all stocks are equally important to American fisheries, and "[o]f those stocks that contribute approximately 90 percent of total fishery landings, the overfishing status is known for 85 percent and overfished status is known for 79 percent."[69]

The difference between "subject to overfishing" and "overfished" is legally important under the MSA. As NOAA Fisheries explains,

> A stock that is subject to *overfishing* has a fishing mortality (harvest) rate higher than the rate that produces MSY [maximum sustainable yield]. A determination of overfishing does not necessarily

62. N.C. Fisheries Ass'n v. Gutierrez, 518 F. Supp. 2d 62 (D.D.C. 2007).
63. *Id.* at 85 (citations omitted).
64. 2013 NOAA FISH STOCK REPORT, *supra* note 61, at 1.
65. *Id.*
66. *Id.*
67. *Id.* at 2, 3.
68. *Id.* at 2.
69. *Id.*

> mean that the fishery is not sustainable or that the stock or its ecosystem is being impaired.[70]

However, fisheries that are subject to overfishing over a long period of time without proper management are likely to become overfished.[71]

A total of 28 federally managed stocks, or 9 percent of the 300 assessed stocks, are considered subject to overfishing, a decrease from 10 percent in 2012.[72] Most of these species are found in the New England (9 stocks) or South Atlantic (6 stocks) regions or are highly migratory species such as various species of tuna, marlin, and shark (8 stocks).[73] Seven fish stocks are no longer considered subject to overfishing as of 2013, a testament to improved fisheries management[74]: white hake in the Gulf of Maine/Georges Bank; red grouper along the Southern Atlantic Coast; black sea bass along the Southern Atlantic Coast; gag in the Gulf of Mexico; gray triggerfish in the Gulf of Mexico; greater amberjack in the Gulf of Mexico; and Bering Sea/Aleutian Islands Octopus Complex.[75] However, another six were added to the "subject to overfishing" list, including four stocks for which status information was previously unknown[76]: thorny skate in the Gulf of Maine; winter skate on the Georges Bank/Southern New England; Gulf of Mexico hogfish; South Atlantic blueline tilefish; the Gulf of Mexico Jacks Complex; and striped marlin in the Western and Central North Pacific.[77]

Overfished, in contrast, means that a fish stock is actually in trouble. More precisely,

> [a] stock that is *overfished* has a biomass level depleted to a degree that the stock's capacity to produce the MSY is jeopardized. In some cases overfishing is the main cause for depletion of the stock, but other factors can affect the abundance of a fish stock and lead to an overfished listing. These factors include abnormal levels of disease, extreme population cycles, habitat degradation, and environmental changes such as climate, ocean acidification, and land- based pollution.[78]

70. *Id.* at 6.
71. *Id.*
72. *Id.* at 2.
73. *Id.* at 4.
74. *Id.* at 2.
75. *Id.* at 3.
76. *Id.* at 2.
77. *Id.* at 3.
78. *Id.* at 6.

As NOAA Fisheries explains, overfished federally managed stocks are subject to rebuilding plans:

> When it is determined that a stock is overfished, the relevant Council must implement a rebuilding plan. A typical rebuilding plan allows fishing to continue, but at a reduced level so that the stock will increase to its target level and can produce the [MSY]—the largest long-term average catch that can be taken from a stock under prevailing environmental and fishery conditions. Fifty stocks and stock complexes currently are under rebuilding plans, including 13 stocks that are no longer on the overfished list because they have increased in abundance and are not yet at the target level that supports MSY.[79]

Of the 230 federally managed fish stocks assessed in 2013 for whether they are overfished, NOAA Fisheries concluded that 40, or 17 percent, were overfished, down from 19 percent in 2012.[80] Most of these overfished species are found in the New England region (12 stocks) or are highly migratory species (9 stocks), but there are also four overfished stocks in each of the Gulf of Mexico, South Atlantic, and Caribbean regions.[81] NOAA Fisheries removed four fish stocks from the "overfished" list in 2013[82]: the Sacramento River fall Chinook salmon (also rebuilt); white hake in the Gulf of Maine/Georges Bank; red grouper along the Southern Atlantic Coast; and cowcod along the Pacific Coast.[83] However, another three fish stocks were added to the "overfished" list, including two stocks for which status information was previously unknown[84]: Pacific bluefin tuna; striped marlin in the Western and Central North Pacific Oceans; and South Atlantic blueline tilefish.[85]

As noted, NOAA Fisheries and the regional FMCs must create plans to rebuild any overfished species. "A rebuilt stock is one that was previously overfished and that has increased in abundance to the target level that supports its MSY."[86] NOAA Fisheries deemed two federally managed fish stocks "rebuilt" in 2013[87]: black sea bass along the Southern Atlantic Coast and Sacramento River fall Chinook salmon.[88] These

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79. *Id.* at 2.
80. *Id.*
81. *Id.* at 5.
82. *Id.* at 2.
83. *Id.* at 3.
84. *Id.* at 2.
85. *Id.* at 3.
86. *Id.* at 6.
87. *Id.* at 2.
88. *Id.* at 3.

conclusions brought the total number of fish stocks rebuilt since 2000 up to 34.[89]

The rebuilding process generally inflicts short-term pain on fishers in particular fisheries in order to increase harvests over the long run. As one example, the rebuilding plan for the black sea bass—now considered a rebuilt stock—began in 2006.[90] As NOAA Fisheries explained, reduced catch limits and shortened fishing seasons can now both be increased:

> The rebuilding of South Atlantic black sea bass illustrates the lows and highs of a stock in transition. As black sea bass started to rebuild, there was pressure to increase the catch limits. People were seeing more fish and they wanted to catch them. Because catch was held constant during the rebuilding years, the stock rebuilt early, and catch limits have more than doubled from levels set in the beginning of the rebuilding plan. For the fishermen who had to live with low limits so that black sea bass could rebuild, the new catch limits will be good news. Last year, both the recreational and commercial seasons ended by early fall. This year, fishermen should be able to fish much later into the winter.[91]

As this example shows, rebuilt stocks have more general advantages for U.S. fisheries. Specifically, "U.S. fisheries play an enormous role in the nation's economy. When stocks are rebuilt, they provide more economic opportunities for commercial, recreational, and subsistence fishing. Rebuilt stocks also contribute to a healthy ecosystem."[92] They also increase the availability of fish for food supply.

C. Projections for the Future

As NOAA Fisheries recognized in 2013, improved fisheries management is both intensely scientific and dependent on the resilience and health of marine ecosystems more generally; "resilient ecosystems and habitat form the foundation for robust fisheries and fishing jobs."[93] Thus, ensuring a resilient and dependable marine food supply into the future requires attention to the health and well-being of the marine environment. From a governance standpoint, therefore, efforts to improve marine food security should incorporate not only improved fisheries man-

89. *Id.* at 2.
90. *Id.* at 7.
91. *Id.*
92. *Id.* at 8.
93. *Id.*

agement but also greater attention to marine pollution, coastal development and habitat degradation, and protection of marine ecosystems.[94]

However, while marine-based food supplies are grounded in biological and ecological realities, both economics and developing technologies, such as aquaculture, play important roles in future food security. Emphasizing these socioeconomic dimensions of food supply, in December 2013, the World Bank issued its projections for world fisheries through 2030.[95] Like the FAO, it began by noting the "daunting challenges" of world population growth:

> Feeding an expected global population of 9 billion by 2050 is a daunting challenge that is engaging researchers, technical experts, and leaders the world over. A relatively unappreciated, yet promising, fact is that fish can play a major role in satisfying the palates of the world's growing middle income group while also meeting the food security needs of the poorest. Already, fish represents 16 percent of all animal protein consumed globally, and this proportion of the world's food basket is likely to increase as consumers with rising incomes seek higher-value seafood and as aquaculture steps up to meet increasing demand.[96]

However, it also acknowledged that "supplying fish sustainably—producing it without depleting productive natural resources and without damaging the precious aquatic environment—is a huge challenge. We continue to see excessive and irresponsible harvesting in capture fisheries and in aquaculture."[97]

The World Bank identified three drivers of future fisheries production: "[S]tagnant global capture fisheries, rapid expansion of aquaculture, and the rise of China in the global seafood market."[98] With respect to the first driver, it accepted that wild capture fisheries, particularly marine fisheries, no longer respond to market prices because of biological limitations.[99] As a result, aquaculture will play an ever-increasing role in

94. *See, e.g.*, ROBIN KUNDIS CRAIG, COMPARATIVE OCEAN GOVERNANCE: PLACE-BASED PROTECTIONS IN AN ERA OF CLIMATE CHANGE 25–46 (2012) (discussing in detail these current threats to marine ecosystems and marine biodiversity).

95. WORLD BANK, FISH TO 2030: PROSPECTS FOR FISHERIES AND AQUACULTURE (2013) [hereinafter 2013 WORLD BANK FISH PROJECTIONS], *available at* http://www.fao.org/docrep/019/i3640e/i3640e.pdf.

96. *Id.* at vii.

97. *Id.*

98. *Id.* at 1.

99. *Id.* at 7 ("[G]iven relatively stable capture fisheries in the last decades and the fact that dynamic biological processes determine the amount of fish stock available for harvest, modeling of price-responsive capture supply in a static sense seems unrealistic.").

world food fish supply. Specifically, under the World Bank's predicted baseline scenario:

> [T]he total fish supply will increase from 154 million tons in 2011 to 186 million tons in 2030. Aquaculture's share in global supply will likely continue to expand to the point where capture fisheries and aquaculture will be contributing equal amounts by 2030. However, aquaculture is projected to supply over 60 percent of fish destined for direct human consumption by 2030. It is projected that aquaculture will expand substantially, but its growth will continue to slow down from a peak of 11 percent per year during the 1980s. The global production from capture fisheries will likely be stable around 93 million tons during the 2010–30 period.[100]

Moreover, "China will likely increasingly influence the global fish markets. According to the baseline model results, in 2030 China will account for 37 percent of total fish production (17 percent of capture production and 57 percent of aquaculture production), while accounting for 38 percent of global consumption of food fish."[101] In contrast, sub-Saharan Africa is likely to experience increasing food stress related to fish.[102] "As a result, the region's dependency on fish imports is expected to rise from 14 percent in 2000 to 34 percent in 2030."[103]

Notably, despite the fact that the World Bank held wild fisheries constant in its baseline scenario, it did also model a future where the nations of the world allow marine fish stocks to recover and rebuild, increasing wild fish abundance in the long run (absent climate change impacts).[104] It based this scenario on studies that

> estimated that successfully restored and managed world fisheries would sustainably provide 10 percent more yield annually relative to the 2004 harvest level. Restoring and improving the productivity of stressed capture fisheries will be possible in many cases if correct actions are taken by country governments, marine resource managers, and the fishing fleets and communities.[105]

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100. *Id.* at xiv–xv.

101. *Id.* at xv (emphasis omitted).

102. *Id.* Specifically, "per capita fish consumption in Sub-Saharan Africa is projected to decline at an annual rate of 1 percent to 5.6 kilograms during the 2010–30 period. However, due to rapid population growth, which is estimated at 2.3 percent annually during the 2010–30 period, total food fish consumption demand would grow substantially (by 30 percent between 2010 and 2030). On the other hand, projected production increase is only marginal." *Id.*

103. *Id.* at xvi.

104. *Id.* at xviii.

105. *Id.* at 66.

As a governance matter, this scenario depends on a variety of improvements in fisheries management, including "proper tenure reforms to reduce fishing effort, letting the aquatic ecosystems and stocks recover, reducing the open-access nature of fisheries, and sustainably managing their productivity."[106] Modeling of this scenario assumed "exogenous annual growth rates of capture production by 0.6 percentage points" applied to all current trends for particular fish stocks, so that "those capture fisheries modeled as declining in the baseline specification would decline more slowly, recovering or growing fisheries would grow faster, and stagnant fisheries would grow exactly at the annual rate of 0.6 percent under this scenario."[107]

Importantly, despite these limitations in assumptions, the "better fisheries management" scenario projects a very different world fisheries-based food supply by 2030 than the baseline scenario:

> The improvement in capture fisheries productivity allows the global capture production level to reach more than 105 million tons by 2030, which represents a 13 percent increase over the level under the baseline case. Under this scenario, aquaculture still grows at an impressive rate over the projection period, but it does not quite reach the baseline 2030 level due to lower market prices resulting from the additional supply from capture fisheries. Furthermore, under this scenario global capture fisheries would supply 15 million tons more than aquaculture would in 2030, whereas capture and aquaculture production would contribute essentially an equal amount to the global supply in 2030 under the baseline case.[108]

While the World Bank acknowledged that this scenario smoothed over many biological differences among fish stocks and regions, it nevertheless concluded that its "results demonstrate that a recovery of global capture fisheries can have varied but potentially substantial impacts on regional seafood sectors and on food security" and that "[b]y illustrating the considerable gains that can be enjoyed at the regional level, these results are consistent and in support of the benefit of regional cooperation in fisheries reform."[109]

However, even without climate change, marine fisheries face a variety of threats. Since the end of World War II, fishing effort has been increasing worldwide.[110] Industrial fishing methods and large factory

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106. *Id.*
107. *Id.*
108. *Id.* at 66–67.
109. *Id.* at 68.
110. *Overfishing: Plenty of Fish in the Sea? Not Always*, NAT'L GEOGRAPHIC, http://ocean.

ships that can process fish caught at sea for market freshness allow fishers to fish in all of the world's oceans, often for months at a time.[111] Their equipment can include longlines that can stretch for twenty to forty miles[112] and trawl nets big enough to hold thirteen jumbo jets.[113] At the same time, on-shore development has also harmed ocean fisheries. As the BBC summarized:

> Many of the world's great rivers carry so much nutrient run-off from farms that the seas by the river mouths are virtually biologically dead. The coral reefs and mangroves which serve as nurseries for fish in the tropics are being eroded by development, pollution and silt. Predator fish accumulate man-made chemicals in their bodies passed up through the food chain—polychlorinated biphenyls, flame retardants, endocrine disrupters.[114]

As a result, not all scientists agree that marine fisheries could recover; indeed, marine scientists and others have repeatedly expressed concern that widespread collapses in a variety of marine fisheries stocks are imminent or already occurring. For example, scientific studies published in 2003 concluded that, compared to historic levels, "industrial fishing had reduced the number of large ocean fish to just 10 percent of their pre-industrial population."[115] Boris Worm and his colleagues made world news headlines in 2006 when their research published in *Science* traced the increasing collapses of world fisheries and projected "the global collapse of all taxa currently fished by the mid-21st century."[116] In 2011, a study published in the *Proceedings of the National Academy of Sciences* concluded that species collapses are occurring among all trophic levels of fish species, not just among the large apex predator species that tend to be the direct targets of commercial fishing.[117] In June 2012, the BBC announced that "[t]he sea exemplifies the world's on-

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nationalgeographic.com/ocean/critical-issues-overfishing/ (last visited Feb. 12, 2015).

111. *E.g.*, Andrew Tarantola, *The World's Largest Floating Fish Factory*, GIZMODO (Oct. 3, 2011), http://gizmodo.com/5845939/the-worlds-largest-floating-fish-factory.

112. *Pelagic Longlining*, BLUE WATER FISHERMEN'S ASS'N, http://www.bwfa-usa.org/our-fishery/pelagic-longlining (last visited Feb. 13, 2015).

113. Selina Haefeli, *Can Australia's Shores Cope With a Super-Trawler?*, SCI. ILLUSTRATED (Sept. 12, 2012), http://scienceillustrated.com.au/blog/features/can-australias-shores-cope-with-a-super-trawler/.

114. Harrabin, *supra* note 8.

115. *Overfishing: Plenty of Fish in the Sea?*, *supra* note 110.

116. Boris Worm et al., *Impacts of Biodiversity Loss on Ocean Ecosystem Services*, 314 SCIENCE 787, 790 (2006).

117. Malin L. Pinsky et al., *Unexpected Patterns of Fisheries Collapse in the World's Oceans*, 108:20 PNAS 8317, 8317 (2011).

going failure to govern shared natural resources."[118] Drawing from the then-current FAO report, the BBC emphasized "that globally about 85% of stocks are said to be fully exploited, over-exploited, depleted or slowly recovering" and that in England and Wales, due to "over 118 years of industrial fishing, the productivity of [the bottomfish] fishery dropped by 94%. Not to 94% but by 94%."[119]

As both the FAO and World Bank have recognized, aquaculture offers a potential substitute to wild-caught fisheries: "Of the fish we eat 25% are now farmed; in China it's 80%."[120] However, the type of aquaculture matters in terms of producing a net increase in overall food supply. For example, aquaculture of fish predators, like salmon, generally results in a net *decrease* in marine fish.[121] However, attempts to address that food supply problem can cause problems with nutritional quality: "If you feed salmon a vegetarian diet they don't produce the omega 3 oils we value. Biologists are now working to synthesise [sic] omega 3 oils to keep farmed salmon tasting like salmon."[122]

III. CLIMATE CHANGE IMPACTS ON FISHING AND MARINE AQUACULTURE

In October 2013, the International Programme on the State of the Ocean (IPSO) released its latest *State of the Ocean Report* compiling and analyzing the latest scientific evidence regarding ocean conditions.[123] Overall, IPSO stressed that the world's oceans are increasingly degraded in the face of relentless impacts from climate change:

> The scientific evidence that marine ecosystems are being degraded as a direct result of human activities is overwhelming; and the consequences both for the vital and valuable ocean goods and services we rely on, including for the maintenance of a healthy Earth system, are alarming. Recent assessments by the UN's climate change panel the IPCC, for example, show that these changes are progressive and relentless: whilst terrestrial temperature increases may be experienc-

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118. Harrabin, *supra* note 8.

119. *Id.*

120. *Id.*

121. *See id.* (noting that "carnivorous fish like salmon eat several times their weight in other fish, which then have to be caught").

122. *Id.*

123. INT'L PROGRAMME ON THE STATE OF THE OCEAN, THE STATE OF THE OCEAN 2013: PERILS, PROGNOSES AND PROPOSALS (2013) [hereinafter 2013 IPSO STATE OF THE OCEAN REPORT], *available at* http://www.stateoftheocean.org/pdfs/IPSO-Summary-Oct13-FINAL.pdf.

> ing a pause this is not true for the ocean, which continues to warm regardless.[124]

Moreover, its report emphasizes three central and disturbing messages: that "risks to the ocean and the ecosystems it supports have been significantly underestimated; that the extent of marine degradation as a whole is greater than the sum of its parts; and that it is happening at a much faster rate than previously predicted."[125]

While all of climate change's impacts on the oceans can significantly affect fisheries, and while it is important to consider the synergies between climate change impacts and existing stressors to marine ecosystems,[126] three impacts of climate change pose particular risks to marine fisheries and aquaculture. These three primary risks include ocean warming, changes in ocean currents, and ocean acidification.

A. Ocean Warming and Fish Stock Migration

One of the most direct impacts on the oceans from increasing global average atmospheric temperatures resulting from climate change is increasing surface sea temperatures (SSTs) and ocean heat content (OHC).[127] As NOAA noted in 2010, "[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."[128] Moreover, NOAA 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."[129]

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124. *Id.* at 1.

125. *Id.*

126. *Id.* at 1–2 ("The ocean is shielding us from the worst effects of accelerating climate change by absorbing excess CO_2 and heat from the atmosphere. The twin effects of this—acidification and ocean warming—are combining with increased levels of deoxygenation, caused by nutrient run-off from agriculture near the coast, and by climate change offshore, to produce what has become known as the ocean's 'deadly trio' of threats whose impacts are potentially far greater because of the interaction of one on another. The scale and rate of this change is unprecedented in Earth's known history and is exposing organisms to intolerable and unpredictable evolutionary pressure.").

127. Joel M. Levy ed., *Global Oceans*, *in* STATE OF THE CLIMATE IN 2009, 91(7) BULL. OF THE AM. METEOROLOGICAL ASS'N S53–55, S59 (July 2010), *available at* http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-91-7-StateoftheClimate.

128. *Id.* at S59 (citations omitted).

129. *Id.* at S53; *see also id.* at S58 fig.3.7 (graphing upward trend of ocean heat content since 1994).

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,[130] the overall trend of SSTs since 1950 is upward.[131] Indeed, in 2007, the IPCC indicated that most regions of the ocean have already experienced SST increases of between 0.2 and 1.0 degrees Celsius.[132] The IPCC 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 four degrees Celsius by 2099, with warming continuing for at least another century thereafter.[133] However, in June 2008, research by an international team of scientists indicated "that ocean temperature and associated sea level increases between 1961 and 2003 were 50 percent larger than estimated in the 2007 Intergovernmental Panel on Climate Change report."[134] Moreover, scientists have detected temperature increases almost two miles below the ocean's surface.[135] IPSO concluded in 2013 that rising ocean temperatures are significant and are already inducing a number of physical changes to ocean habitats:

> The average temperature of the upper layers of the ocean has increased by 0.6°C over the last 100 years, with direct and well-documented physical and biogeochemical consequences. The impacts which continued warming is projected to have in the decades to 2050 include: reduced seasonal ice zones, including the disappearance of Arctic summer sea ice; increasing stratification of ocean layers, leading to oxygen depletion; increased venting of the GHG methane from the Arctic seabed; and increased incidence of anoxic and hypoxic (low oxygen) events.[136]

Changes in ocean temperatures cause temperature-sensitive species to migrate poleward and, to a certain extent, deeper.[137] Scientists expect marine fish stocks to migrate 30 to 130 kilometers poleward and 3.5 me-

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130. *Id.* at S53–55.

131. *Id.* at S55 fig.3.3.

132. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT 32 fig.1.2 (2007) [hereinafter 2007 IPCC SYNTHESIS REPORT], *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

133. *Id.* at 46 fig.3.2.

134. *Ocean Temperatures and Sea Level Increases 50 Percent Higher Than Previously Estimated*, SCI. DAILY (June 19, 2008), http://www.sciencedaily.com/releases/2008/06/080618143301.htm.

135. *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 3,000 meters, when there are 1609.344 meters in a mile).

136. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 4.

137. FOOD & AGRIC. ORG. OF THE UNITED NATIONS, THE STATE OF WORLD FISHERIES AND AQUACULTURE 2008, at 87 (2009).

ters deeper each decade that climate change continues to increase the oceans' temperatures.[138] Indeed, 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.[139] More comprehensively, in May 2013, William Cheung, Reg Watson, and Daniel Pauly published research in *Nature* that concluded that increasing SSTs are already affecting fisheries in fifty-two large marine ecosystems across the world.[140] Such changes could become particularly devastating for tropical and subtropical coastal fishing communities, many of which are already vulnerable to climate change.[141]

Unfortunately, temperature-sensitive species at the poles have nowhere to go,[142] and IPSO predicts "increased extinctions, with ice-dependent polar species such as seals and penguins at greatest risk . . . ."[143] However, polar ecosystems are not the only marine ecosystems likely to suffer. Commercial fishing and climate change can have synergistic effects, and IPSO expects "loss of 60% of present biodiversity of exploited marine fish and invertebrates, including numerous local extinctions . . . ."[144]

Finally, the world's coral reefs—some of the most productive fishing grounds—are also likely to be hard hit by warming ocean temperatures. Climate change will almost certainly increase the frequency and severity of coral bleaching events.[145] Coral bleaching events are a type of disaster that punctuates the cumulative degradation of the oceans. Most

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138. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 4.

139. Ne. Fisheries Sci. Ctr., *North Atlantic Fish Populations Shifting as Ocean Temperatures Warm*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (Nov. 2, 2009), 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).

140. *See* William W.L. Cheung, Reg Watson & Daniel Pauly, *Signature of Ocean Warming in Global Fisheries Catch*, 497 NATURE 365 (2013).

141. *Id.* at 368.

142. *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).

143. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 4.

144. *Id.* Similarly, a study published in *Nature* in late July 2010 suggests that the magnitude of the problem is even greater than suspected; it stated that ocean temperature is a major determinant of marine biodiversity and concluded that changes in ocean temperature "may ultimately rearrange the global distribution of life in the ocean." Derek P. Tittensor et al., *Global Patterns and Predictors of Marine Biodiversity Across Taxa*, 466 NATURE 1098, 1098 (2010).

145. Tundi Agardy et al., *Coastal Systems*, *in* 1 ECOSYSTEMS AND HUMAN WELL-BEING: CURRENT STATE AND TRENDS 513, 523 (Rashid Hassan et al. eds., 2005).

surface coral species rely on symbiotic zooxanthellae, a type of algae contained within the coral polyps' tissues, to supplement their nutrition.[146] 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.[147] 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 SSTs in much of the world.[148] In the 1982–1983 event, coral reef mortalities in the Galapagos Islands reached 99 percent;[149] 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."[150]

In 2007, the IPCC projected increased numbers of coral bleaching events even at current levels of SST increases.[151] Widespread coral mortality is likely to begin occurring if SSTs increase by approximately 2.5 to 3.0 degrees Celsius.[152] According to IPSO, the combination of increased ocean warming and ocean acidification (see Part III.C) could doom most coral reef ecosystems:

> [M]ass coral bleaching [will lead] to increased coral reef mortality, and a . . . phase shift from coral domination to algal domination [is predicted for] the Great Barrier Reef and Caribbean reefs. The synergistic effect of acidification and warming are considered likely to lead to rapid and terminal decline of tropical coral reefs by 2050.[153]

All of the referenced studies indicate that ocean warming resulting from climate change is already altering marine fishing throughout the world. Moreover, as species shift their ranges, the tropical and subtropical oceans will become increasingly barren wastelands, particularly as

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146. *Id.*

147. *Id.*

148. *Coral Bleaching—Background*, NOAA CORAL HEALTH & MONITORING PROGRAM, http://www.coral.noaa.gov/index.php?option=com_content&view=article&id=132&Itemid=166 (last visited Dec. 2, 2010).

149. *Id.*

150. UNITED NATIONS ENV'T PROGRAMME WORLD CONSERVATION MONITORING CTR., CLIMATE CHANGE AND MARINE DISEASES: THE SOCIO-ECONOMIC IMPACT 5 (2009) [hereinafter CLIMATE CHANGE AND MARINE DISEASES], *available at* http://www.unep-wcmc.org/system/dataset_file_fields/files/000/000/125/original/Climate_Change_Marine_Diseases.pdf?1398683242 (current version as of Sept. 30, 2010).

151. 2007 IPCC SYNTHESIS REPORT, *supra* note 132, at 51 fig.3.6.

152. *Id.*

153. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 4.

coral reef ecosystems degrade and die.[154] While fishing will probably remain viable in more polar latitudes,[155] the species will be changing and food webs altering, with largely unpredictable—and probably undesirable—results. As commercially important fish stocks shift their ranges, it is an open question whether fisheries managers can keep pace and whether *any* current marine fishery can be maintained at anything close to current levels of harvest.

B. Changing Currents

In addition to its noticeable effect on marine species migration, ocean temperature changes also affect marine currents.[156] One of the largest of the ocean currents is 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.[157] The Wood Hole Oceanographic Institution has explained the importance of this global conveyor system as follows:

> 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.[158]

In the fifteen years prior to 2009, cold water in the North Atlantic was not sinking as fast as it used to, leading to speculation that the Great Ocean Conveyor was shutting down.[159] 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.[160]

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154. *Id.* ("It is predicted that the redistribution of commercial fish species through range shifts will lead to a 40% decrease in catch potential in the tropics by 2050 . . . .").

155. *Id.* ("It is predicted that the redistribution of commercial fish species through range shifts will lead to a . . . 30–70% increase in the high-latitude zones—where richer societies and more industrialised [sic] fisheries are located.").

156. Daniel Pauly et al., *Marine Fisheries Systems*, *in* 1 ECOSYSTEMS AND HUMAN WELL-BEING: CURRENT STATE AND TRENDS, *supra* note 145, at 490.

157. *Ocean Conveyor's 'Pump' Switches Back On*, WOODS HOLE OCEANOGRAPHIC INST., http://www.whoi.edu/oceanus/feature/ocean-conveyors-pump-switches-back-on (last updated Nov. 19, 2010).

158. *Id.*

159. *Id.*

160. *Id.*

Nevertheless, even if the Great Ocean Conveyor remains intact, smaller changes to ocean current patterns could still disrupt marine ecosystems at the local or regional scale. The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), for example, emphasizes the potentially drastic impact that a changing ocean current could have on local coastal ecosystems that, in turn, could impact coastal and regional fisheries. It notes that

> [a]s global climate change alters wind, precipitation[,] and temperature patterns worldwide, ocean currents will reflect these changes in often unpredictable ways. For example, increasing wind speeds arising from larger land–ocean temperature differences may drive stronger upwelling which will change near shore ecosystems and may cause hypoxic dead zones in some areas.[161]

These local changes, in turn, could alter "the transport/retention of contaminants, nutrients, and the marine larvae that sustain populations along the coast," altering both local ecosystems and, potentially, wider fisheries that depend on the larvae.[162]

Such local and regional changes in ocean currents are already affecting fisheries and the food supply. For example, much of the northwest coast of the United States (including Alaska) and Canada benefit 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 zone grew off the coasts of Oregon and Washington.[163] This dead zone, which occurs in the middle of a commercially important fishery, has been attributed to climate change—specifically, to changing interactions between wind and offshore currents that prevent the normal dissipation of oxygen-deprived waters.[164] Three other such climate change-related dead zones have been detected: one off the coast of Chile and Peru in South America, one off the west coast of Africa, and one off the east coast of Africa.[165]

Shifting ocean currents are already affecting marine aquaculture as well. As Claire Spillman and Alistair Hobday recently noted, "One wide-

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161. *Ocean Currents and Climate Change*, PARTNERSHIP FOR INTERDISC. STUD. COASTAL OCEANS (Jan. 25, 2010), http://www.piscoweb.org/research/science-by-discipline/coastal-oceanography/ocean-currents.

162. *Id.*

163. *Oregon Dead Zone Blamed on Climate Change*, ENV'T NEWS SERV. (Oct. 8, 2009), http://ens-newswire.com/2009/10/08/oregon-dead-zone-blamed-on-climate-change/.

164. *Id.*

165. *Id.*

ly farmed species considered vulnerable to rising ocean temperatures is Atlantic salmon, which is farmed in high latitude coastal waters of both hemispheres and often grown close to its thermal limits."[166] Tasmania, Australia established a salmon aquaculture industry in 1984, and that industry is now "Australia's most valuable seafood industry."[167] The young salmon are grown for six to twelve months in ponds and then moved to sea cages for the final two years of growth.[168] However, the ocean around "[s]outh-eastern Australia, including Tasmania, is a climate change 'hotspot.' Average temperatures in this region are projected to be 2.8°C higher than the 1990–2000 average by 2050, due in part to the strengthening of the [Eastern Australian Current] and increased southward flow."[169] The changing current and the hotter temperatures it brings, especially in summer months, threaten Tasmania's salmon aquaculture industry, leading to increased attempts to predict the current on a season-to-season and year-to-year basis so that salmon farmers can receive advance warning regarding whether to leave their salmon at sea.[170]

As climate change impacts increase, more dramatic ecosystem impacts resulting from changing ocean currents are likely. Indeed, in 2007, the IPCC projected widespread ecosystem changes as a result of changes in major marine currents beginning at the point when global average temperatures increase by about 2.5 to 3.0 degrees Celsius.[171]

C. Ocean Acidification

Ocean acidification is sometimes referred to as climate change's "evil twin"[172] and is a consequence of the fact that the oceans are the world's largest carbon sinks.[173] At the beginning of the twenty-first century, the oceans and land ecosystems (mostly plants) were absorbing about half of the anthropogenic emissions of CO_2[174]—roughly 25 percent

166. Claire M. Spillman & Alistair J. Hobday, *Dynamical Seasonal Ocean Forecasts to Aid Salmon Farm Management in a Climate Hotspot*, 1 CLIMATE RISK MGMT. 25, 25–26 (2014) (citations omitted), *available at* http://www.sciencedirect.com/science/article/pii/S2212096313000041#.

167. *Id.* at 26 (citation omitted).

168. *Id.* (citations omitted).

169. *Id.* (citations omitted).

170. *Id.*

171. 2007 IPCC SYNTHESIS REPORT, *supra* note 132, at 51 fig.3.6.

172. *See, e.g.*, ARC Ctr. of Excellence in Coral Reef Studies, *Ocean Acidification: 'Evil Twin' Threatens World's Oceans, Scientists Warn*, SCIENCEDAILY (Apr. 1, 2010), http://www.sciencedaily.com/releases/2010/03/100330092821.htm.

173. FRED PEARCE, WITH SPEED AND VIOLENCE: WHY SCIENTISTS FEAR TIPPING POINTS IN CLIMATE CHANGE 86 (2007).

174. Peter M. Cox et al., *Acceleration of Global Warming due to Carbon-Cycle Feedbacks in a Coupled Climate Model*, 408 NATURE 184, 184 (2000).

by land plants and 25 percent by the oceans.[175] According to NOAA oceanographers in 2006, "[o]ver the past 200 years the oceans have absorbed 525 billion tons of carbon dioxide from the atmosphere, or nearly half of the fossil fuel carbon emissions over this period."[176] The oceans continue to absorb about 22 million tons of CO_2 per day.[177]

However, because of continuing and increasing climate change impacts, the oceans appear to be losing their ability to act as carbon sinks. As a general matter, the cold water at ocean depths can sequester more CO_2 than warmer waters at the surface.[178] As a result, any process that circulates cold water to the surface—such as changes in current patterns and ocean temperatures at depth—inevitably reduces an ocean's ability to act as a carbon sink. Research published in 2009 indicated that, as a result of climate change, the Southern Indian Ocean is being subjected to stronger winds; the winds, in turn, mix the ocean waters, bringing up CO_2 from the depths, preventing the ocean from absorbing more CO_2 from the atmosphere.[179] For similar reasons, "the CO_2 sink diminished by 50% between 1996 and 2005 in the North Atlantic."[180]

The loss of the oceans' full capacity as carbon sinks could have significant implications for the progress of reversing climate change everywhere. More important for the oceans themselves, however, is the fact that the absorbed carbon dioxide undergoes a series of complex chemical reactions in ocean waters, essentially becoming carbonic acid.[181] Naturally, the world's oceans are slightly basic, with a pH of around 8.2—a chemical characteristic that has been constant for millions of years.[182] However, since the Industrial Revolution, the oceans' absorption of carbon dioxide has been lowering their pH, affecting the oceans' chemical and biological processes.[183] The BBC summarized this problem:

175 . *The Ocean Carbon Cycle*, HARVARD MAG., Nov.–Dec. 2002, *available at* http://harvardmagazine.com/2002/11/the-ocean-carbon-cycle.html.

176. RICHARD A. FEELY, CHRISTOPHER L. SABINE & VICTORIA J. FABRY, CARBON DIOXIDE AND OUR OCEAN LEGACY (2006), http://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf.

177. *Id.*

178. *See The Ocean Carbon Cycle*, *supra* note 175.

179. CNRS (Délégation Paris Michel-Ange), *Ocean Less Effective at Absorbing Carbon Dioxide Emitted by Human Activity*, SCIENCEDAILY (Feb. 23, 2009), http://www.sciencedaily.com/releases/2009/02/090216092937.htm.

180. *Id.*

181 . *Ocean Acidification: Carbon Dioxide Is Putting Shelled Animals at Risk*, NAT'L GEOGRAPHIC, http://ocean.nationalgeographic.com/ocean/critical-issues-ocean-acidification/ (last visited Feb. 14, 2015).

182. *Id.*

183. According to IPSO:

> It is now certain that the uptake of CO_2 into the ocean is outstripping its capacity to absorb it, resulting in a reduction in ocean pH (i.e. increase in acidity) coupled with a low-

> [T]he CO2 emissions that warm the planet are also dissolving into the ocean and making it less alkaline—acid ocean syndrome. The change is chemically minuscule but historically huge.
>
> There's much uncertainty how sealife will react but some scientists forecast that coral reefs in their current form won't survive. Studies suggest that pteropods—tiny swimming snails—will be badly hit because they need alkaline water to make their shells.
>
> That could matter to us because pteropods feed the salmon, herring, mackerel and cod that we like to eat.[184]

IPSO sees even greater risks from ocean acidification, noting:

> [T]he scale and rate of the present day carbon perturbation, and resulting ocean acidification, is unprecedented in Earth's known history. Today's rate of carbon release, at approximately 30 Gt of CO_2 per year, is at least 10 times faster than that which preceded the last major species extinction (the Paleocene Eocene Thermal Maximum extinction, or PETM, ca. 55 million years ago), while geological records indicate that the current acidification is unparalleled in at least the last 300 million years. We are entering an unknown territory of marine ecosystem change, and exposing organisms to intolerable evolutionary pressure. The next mass extinction event may have already begun.[185]

As with ocean warming, coral reefs—and the highly productive ecosystems that they support—are at particularly high risk from ocean acidification.[186]

Evidence indicates that ocean acidification is already undermining marine food supplies. For example, "[s]tudies have found that more acidic water in Alaska is stunting the growth of red king crabs and tanner

> ering of its CO_2 buffering capacity. Acidification is causing a substantial decline in carbonate ion concentrations and resulting in 800km^2 of the seafloor becoming exposed to waters that are unsaturated with respect to aragonite every year. The rate of acidification is 50% faster at high latitudes compared to sub-tropical waters because of the effects of temperature on ocean chemistry.

2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 3.

184. Harrabin, *supra* note 8. *See also* 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 3 ("Biological impacts are already being observed as acidification is a direct threat to all marine organisms that build their skeletons out of calcium carbonate, including reef-forming corals, crustaceans, molluscs and other planktonic species that are at the lower levels of pelagic food webs.").

185. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 3.

186. *Id.* at 3–4.

crabs."[187] A more recent NOAA study "found rural areas in southern Alaska are at high risk of losing hundreds of millions of dollars in commercial and subsistence fishing stocks. Declining seafood harvests will impact about 20 percent of Alaska's population, which relies on subsistence fishing for significant amounts of their diet . . . ."[188] On the East Coast, runoff of nutrients from land is only accelerating ocean acidification, and "[t]he Chesapeake Bay, which receives runoff from one of the most densely populated watersheds in the United States, is acidifying three times faster than the rest of the world's oceans. Long Island Sound, Narragansett Bay[,] and the Gulf of Mexico are all showing signs of rapid acidification."[189] This long-term acidification may be contributing to the drop in oyster harvests in the East.[190]

Ocean acidification has also begun to affect marine aquaculture, particularly shellfish aquaculture, around the world. For example, beginning in 2008, oyster aquaculture facilities in Puget Sound began experiencing drops in larvae production, from 7 billion larvae in 2006 and 2007 to half that in 2008, and one-third of that amount in 2009.[191] Mudflats in Maine have become acidic enough in some spots to kill young clams,[192] limiting shellfish aquaculture in that region as well.

Ocean acidification's impacts on world food supplies could become devastating. Indeed, if ocean acidification is in fact triggering the next great ocean extinction, marine fisheries and the food they supply to the world will experience great declines. Moreover, marine aquaculture will also become increasingly limited, if not impossible. Together, these impacts from ocean acidification could thoroughly undermine the World Bank's baseline projection for world fisheries and hence threaten global food security well into the future.

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187. Reid Wilson, *Marine Industries at Risk on Both Coasts as Oceans Acidify*, WASH. POST (July 30, 2014), http://www.washingtonpost.com/blogs/govbeat/wp/2014/07/30/marine-industries-at-risk-on-both-coasts-as-oceans-acidify/.

188. *Id.*

189. *Id.*

190. *Id.*

191. *Id*.

192. NATURAL RES. DEF. COUNCIL & SIGHTLINE INST., GULF OF MAINE: OCEAN ACIDIFICATION 1 (2008), *available at* http://www.nrdc.org/oceans/acidification/files/ocean-acidification-maine.pdf.

D. The World Bank's Climate Change Scenario for World Fisheries to 2030

In its December 2013 projections for world fisheries and aquaculture, the World Bank included a climate change scenario.[193] Specifically, following scientific projections, the World Bank modeled what could happen to global fisheries under two climate change futures:

> Scenario (a) may be interpreted as a case where mitigation measures would be in place so that effectively "no" additional climate change would occur beyond the level in the year 2000. On the other hand, scenario (b) may be a case where, in the absence of radical mitigation measures, the "normal" progression of environmental effects would accumulate over time, including rising ocean temperature and ocean acidification.[194]

Moreover, the World Bank's modeling built on prior studies indicating that, "in general, potential catch would increase in high-latitude regions while catch would tend to drop in the tropics. These results would hold generally under both scenarios but would be more prominent under scenario (b)."[195]

Importantly, even under scenario (a) (climate change mitigation), the World Bank's modeling "generates a gloomier picture of global capture fisheries than our baseline simulation."[196] Specifically, in most regions of the world, even mitigated climate change impacts result in a 2–31 percent reduction in capture production of fish by 2030 compared to the World Bank's baseline projections, with an overall global reduction of three percent from the baseline.[197] Climate change is projected to inhibit the growth of aquaculture, so that "the total fish supply would be lower under [scenario (a)] than under the baseline scenario."[198] Even so, the World Bank's modeling indicated that regional changes in aquaculture production and international trade would largely mask these changes at least through 2030.[199] Moreover, in this short time frame, the differences between scenario (a) and scenario (b) were negligible.[200]

Nevertheless, the World Bank was careful to emphasize that time matters with respect to climate change. Specifically,

193. 2013 WORLD BANK FISH PROJECTIONS, *supra* note 95, at 68–70.
194. *Id.* at 68.
195. *Id.*
196. *Id.* at 69.
197. *Id.*
198. *Id.*
199. *Id.* at 69–70.
200. *Id.* at 69.

> Climate change is an ongoing process whose impacts would materialize decades, even centuries, later. Readers should be reminded that the results presented in this report represent medium-term projections into 2030 and do not represent long-term impacts of climate change. Nonetheless, already by 2030, climate change will likely affect global fish markets in the form of distributional changes in the global marine fish harvest and resulting trade patterns.[201]

Its clear implication was that climate change would have even worse implications for fisheries in the future.

E. IPSO's Climate Change Projection for World Fisheries

In its 2013 *State of the Ocean* report, IPSO was far less optimistic than the World Bank regarding projections for the future of ocean fisheries in a climate change world. As it summarized:

> The global picture of ongoing depletions of fish stocks, the degradation of food webs, threats to seafood security and poor quality of most fishing management is alarming and demonstrates that recent more optimistic outlooks are misplaced. Reversing these global trends towards "despair" demands urgent, focused, innovative action to promote effective community- and ecosystem-based management.[202]

More specifically, IPSO criticized the methodology of the more optimistic studies, noting that "the analysis it is founded on was primarily based on evidence from better-managed, developing world fisheries."[203] In contrast, IPSO concluded, "[d]eeper analysis of the status of the majority of world fisheries instead confirms the previous dismal outlook: serious depletions are the norm, management quality is poor, and catch per unit effort continues to decline."[204]

Current fisheries management was one reason for IPSO's poor prognosis. As it noted, "A recent global assessment of compliance with Article 7 (fishery management) of the 1995 FAO Code of Conduct for Responsible Fisheries, awarded 60% of countries a 'fail' grade and saw no country identified as being overall 'good'. . . . The Indian Ocean and the Mediterranean scored worst of all."[205] In IPSO's view, climate

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201. *Id.* at 70.
202. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 2.
203. *Id.* at 6.
204. *Id.*
205. *Id.*

change just exacerbates an already dire crisis in fisheries management.[206] Specifically,

> [C]limate change is expected to continue to cause range shifts in important commercial species, reduce the actual body size of fishes, and make management more challenging and unpredictable. While there are still gaps in our understanding of climate change effects on fisheries, there is already sufficient scientific information highlighting the urgent need to implement mitigation and adaptation policies to minimize the impacts.[207]

IPSO predicts that without such changes, a global fisheries—and hence global food—crisis will ensue.

IV. RE-TOOLING MARINE FOOD SUPPLY RESILIENCE

As the discussions above indicate, there is wide consensus that climate change is both: (1) exacerbating existing threats to world fisheries and global marine food supplies in the form of overfishing, pollution, and habitat destruction; and (2) adding new stressors to fish stocks, such as increased temperature, changing currents, and changing ocean chemistry. The future resilience of both marine fisheries and marine aquaculture should thus be of concern to anyone interested in maintaining or improving world food security.

This Part offers seven suggestions for how to re-tool marine (and other) governance to improve the resilience of marine fisheries and marine aquaculture in response to climate change. However, it offers these suggestions from the ecological perspective of resilience, especially as embodied in the discipline of resilience thinking.[208] For purposes of this Article, the important humility that resilience thinking offers to fisheries and aquaculture management and governance systems is that transformation of ecosystems is as much a facet of ecology as the continuation of ecosystems in human-desired states.[209] In the face of climate change-induced shifts in species ranges and changes to ocean chemistry, we must approach marine global food supplies with an awareness that many of the

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206. *Id.*

207. *Id.* at 6–7.

208. *See generally, e.g.*, BRIAN WALKER & DAVID SALT, RESILIENCE THINKING: SUSTAINING ECOSYSTEMS AND PEOPLE IN A CHANGING WORLD (2006) (laying out the principles of resilience thinking).

209. *Id.* at 53–63, *especially* 53, 62–63.

supporting ecosystems will be significantly and inalterably transformed into new ecological realities.[210]

A. Get Serious About Reducing Overfishing in Light of Climate Change Impacts

The more optimistic reports about the future of marine, wild-caught fisheries like to emphasize the evidence that more stringent regulation of fishing can improve the status of commercially important food fish stocks. In 2014, for example, the FAO reported some progress worldwide in reversing overfishing of some of these species:

> In the United States of America, the Magnuson–Stevens Act and subsequent amendments have created a mandate to put overfished stocks into restoration. By 2012, 79 percent of United States fish stocks were at or above a level able to provide MSY. In New Zealand, the percentage of fish stocks having abundance above the overfishing threshold declined from 25 percent in 2009 to 18 percent in 2013. Similarly, Australia reports only 11 percent of its assessed stocks overfished in 2011. In the European Union (Member Organization), up to 70 percent of assessed stocks had either decreasing fishing rates or increasing stock abundance. Similar examples of success also exist in many other fisheries around the world. For example, Namibia has rebuilt its hake fishery and Mexico has succeeded in restoring its abalone stock.[211]

However, effective fisheries management—even without considering climate change—is far from universal. As IPSO emphasized in 2013, "While there are some promising signs that the management of some fisheries in the developed world is improving, over 80% of the world's fish are caught elsewhere, in many cases in fisheries where stocks are not assessed."[212] In addition, IPSO emphasized that few countries manage fisheries with any attention to the larger ecosystems on which marine fisheries depend[213]—i.e., very few countries engage in true ecosystem-based fisheries management. However, attention to these wider ecosystem details will be increasingly important in light of climate change impacts, which will result in shifting species. Such shifts will alter food

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210. *See, e.g.*, *id.* at 60–61 (describing regime shifts at Easter Island, in Florida Bay, and in the marine ecosystems of the Pacific Rim).

211. 2014 FAO FISHERIES REPORT, *supra* note 13, at 41.

212. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 6.

213. *Id.* (internal references omitted).

webs,[214] potentially leaving commercial fish stocks vulnerable if the species' food sources disappear, move to a different latitude, or become available at different times. In addition, species shifts will place new demands on different habitats and will create a whole host of other uncertainties about the ecological support system for fisheries that could severely reduce acceptable catch limits and undermine the sustainability of current fisheries.[215]

Thus, even developed nations can do much to improve their scientific understanding of fisheries dynamics, particularly in light of climate change impacts and synergies with other marine stressors and ecological dynamics. Throughout the world, however, reductions in the size of fisheries (as IPSO puts it, "favoring small-scale fisheries") and increased use of ecosystem-based management would be important steps forward.[216] IPSO suggests five other priority measures as well: "introducing true co-management with resource adjacent communities, eliminating harmful subsidies that drive overcapacity, protection of vulnerable marine ecosystems, banning the most destructive fishing gear, and combating IUU fishing."[217]

B. Protect Marine Fish Stocks and Ecosystems in Marine Reserves and Through Marine Spatial Planning

As IPSO noted in its 2013 *State of the Ocean* report, "protection of vulnerable marine ecosystems" is an important strategy for protecting the health of the world's oceans and the fisheries that support world food supply.[218] While climate change impacts may spell irreversible doom for some important tropical marine ecosystems such as coral reefs, others, such as kelp forests and rocky bottom habitats in more poleward latitudes, could benefit from increased legal protection from destructive human activities.

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214. As one example, the Atlantic puffin was identified in 2013 as being threatened by shifting fish stocks, which are causing the bird to starve. Associated Press, *US Atlantic Puffin Population in Peril as Fish Stocks Shift, Ocean Waters Heat Up*, FOX NEWS (June 3, 2013), http://www.foxnews.com/science/2013/06/03/us-atlantic-puffin-population-in-peril-as-fish-stocks-shift-ocean-waters-heat/.

215. *See, e.g.*, Tom Zeller Jr., *Climate Change Impacts Ripple Through Fishing Industry While Ocean Science Lags Behind*, HUFFINGTON POST (May 17, 2013), http://www.huffingtonpost.com/2013/05/17/ocean-climate-change-fishing-industry_n_3275505.html (discussing the uncertainties for both the fish species and the fishers in the context of reduced catch limits).

216. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 7.

217. *Id.*

218. *Id.*

This legal protection generally comes in the form of place-based management, including integrated coastal management, marine protected areas (MPAs), marine reserves, and marine spatial planning.[219] "The basic premise of place-based marine management is that regulators can delineate a particular area of the ocean (large or small) and create a governance regime for that area that simultaneously addresses all values to be protected and all activities of concern."[220] Integrated coastal management, for example, identifies the coast as a place worthy of legal protection, where "[t]he coastal region to be holistically managed generally includes both terrestrial and marine components and both human settlements and important ecosystems."[221] "MPAs are place-based marine management tools, roughly equivalent to state and national parks and preserves on land, that set aside, legally, certain areas of the ocean for special protection,"[222] such as restrictions on oil and gas drilling.[223] The most protective kinds of MPAs are marine reserves, which "allow no extractive uses such as fishing or harvesting; while they generally allow non-extractive recreation, such as snorkeling and scuba diving, a government will occasionally establish a marine reserve purely for scientific study."[224] However, protected areas and marine reserves are also very flexible governance tools that allow regulators to fine-tune the level and type of protection in a particular area. For example, in the United States, the Pacific Fishery Management Council (Washington, Oregon, California), in seeking to protect groundfish, envisions some marine reserves that still allow fishing for salmon and tuna while other marine reserves would prohibit all fishing.[225]

"Finally, marine spatial planning, also known as ocean zoning, is a more comprehensive planning and management tool than MPAs for implementing both [integrated coastal management] and [ecosystem-based management]."[226] Marine spatial planning is sort of like land use planning for the oceans, but it is planning that incorporates protections for ecological health as well as for human use.[227] Moreover, an increasing

219. CRAIG, *supra* note 94, at 95.

220. *Id.* at 94.

221. *Id.* at 96.

222. *Id.* at 101.

223. *Habitat and Communities: Marine Reserves and Marine Protected Areas*, PAC. FISHERY MGMT. COUNCIL, http://www.pcouncil.org/habitat-and-communities/marine-protected-areas/ (last visited Feb. 16, 2015).

224. CRAIG, *supra* note 94, at 101.

225. *Habitat and Communities: Marine Reserves and Marine Protected Areas*, *supra* note 223.

226. CRAIG, *supra* note 94, at 105.

227. *Id.* at 106.

number of researchers are working to adapt marine spatial planning to the dynamics of climate change so that this place-based tool can accommodate shifts and changes in marine species dynamics.[228]

Of particular interest to fisheries management is the use of place-based management to protect habitats that serve as breeding grounds and nurseries for various commercially important species, allow slow-growing and late breeding fish to reach maturity, provide precautionary protections for unassessed species and more general ecological functions, and reduce bycatch of sensitive species. In the United States, for example, the Pacific Fisheries Management Council has used place-based management to pursue numerous goals in the region's numerous groundfish fisheries:

> Marine reserves provide one tool to control fishing mortality. For example, a Cowcod Conservation Area protects cowcod off southern California. In this case, marine reserves were used to eliminate groundfish harvests in areas with high cowcod bycatch rates.
>
> Marine reserves can also be a valuable management tool when the status of a fish stock is uncertain. The best available scientific knowledge about stock status may also be highly uncertain and prone to significant changes as we learn more. Also, stock assessments have been done for only about 32 of the 90+ groundfish species managed by the Council, so marine reserves may offer some protection for unassessed sedentary species (those that do not move around much relative to the size of the reserve), which are not well-understood.
>
> As a harvest management tool, marine reserves can be particularly helpful for sedentary species that produce dramatically more offspring as they get older. Traditional fisheries often remove these larger, more productive fish. More mobile species may benefit if marine reserves can be used to preserve habitat from damage by fishing gear and other human activities, or to preserve ecosystems that are vital to fish survival.
>
> Marine reserves can also have educational and research value. To successfully manage these resources, managers need better knowledge of the biology, habits, and behaviors of fish stocks and the ecosystems that support them.[229]

As the Pacific Fishery Management Council suggests, increasing use of well-placed and adequately enforced MPAs and marine reserves,

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228. *Id.* at 155–69.

229. *Habitat and Communities: Marine Reserves and Marine Protected Areas*, *supra* note 223.

especially in conjunction with ecosystem-based management and dynamic marine spatial planning, could improve the resilience of many marine fisheries to both current stressors and future climate change.[230] Most nations of the world implicitly recognize this fact, because MPAs and marine reserves have been incorporated into international biodiversity goals under the Convention on Biological Diversity.[231] Specifically, Target 11 of the Strategic Plan for Biodiversity 2011–2020 seeks to have 10 percent of coastal and marine areas preserved in effective protected areas by 2020.[232] In determining the coastal and marine areas to be preserved, the focus is on including those that are important for biodiversity and ecosystem services, as well as representative of all major ecosystems.

Achievement of this biodiversity goal would almost certainly benefit future world food security as well. While it is impossible in the face of climate change, shifting species, and food webs to predict with certainty how effective place-based protections can be, legally protecting important marine habitats gives adapting species their best chance to create new but still productive species assemblages and ecosystems. As such, place-based marine protections are a key climate change adaptation strategy for world marine food supplies.

C. In the United States, Re-Tool the Magnuson–Stevens Fisheries Conservation and Management Act to Acknowledge Fish Stock Shifts and Other Climate Change Impacts

Although Congress improved fisheries management in the United States through its recent amendments to the Magnuson–Stevens Act, it still has not grappled with the changes to fisheries that climate change is bringing. In particular, the regional structure of fisheries management—particularly in the East, where fisheries management is divided among the New England, Mid-Atlantic, South Atlantic, Caribbean, and Gulf of Mexico Fishery Management Councils—may hamper smooth transitions in fisheries management as important fish stocks shift their ranges northward. In addition, climate change demands that U.S. fisheries management decisively shift to ecosystem-based management, including an awareness of how marine ecosystems are changing.

NOAA is beginning to investigate the impact of climate change and fishing on fish stock ranges, revealing—as should be expected—complex

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230. *Id.*

231. *Id.*

232. *Target 11—Technical Rationale Extended*, CONVENTION ON BIOLOGICAL DIVERSITY, http://www.cbd.int/sp/targets/rationale/target-11/ (last visited Feb. 16, 2015).

and often species-specific responses.[233] Nevertheless, Congress should amend the Magnuson–Stevens Act to require joint Council management of any fish stock known or suspected to be shifting its range in response to increasing ocean temperatures or shifting ocean currents. Such joint management should include both the Council with current jurisdiction over the fishery and any Council into whose region the fish species might shift within two or three decades, with the goal of ensuring that annual catch limits and other management measures will encompass the entire stock and all fishers throughout the species' range shift.

In addition, research funded through the Magnuson–Stevens Act should prioritize improving regulators' ability to detect such shifts and changing ecosystem and food web dynamics, which should counsel a reduction in catch limits. For example, it appears that the future of the Atlantic puffin is in doubt because the birds are starving, deprived of their normal food fish as those species shift north.[234] To the extent that the puffins' food sources are federally managed, NOAA Fisheries and the New England Fishery Management Council should be required to account for the puffin in setting annual catch limits for fishers.

D. Internationally, Expand Regional Fisheries Agreements to Acknowledge Shifting Fish Stocks and to Effectively Regulate Fishers

As the FAO described in 2014, regional cooperation for fisheries management is a duty well established in international law:

> The concept of States cooperating together, particularly at the regional level and for the purpose of fisheries management, is a prominent theme in the 1982 United Nations Law of the Sea Convention [UNCLOS], where provisions articulate specific obligations to cooperate on a variety of subjects including the conservation and management of high seas fisheries and those of EEZs [exclusive economic zones]. In addition, subsequent international law-of-the-sea and fisheries law instruments have articulated an increasingly important role for regional (and subregional) cooperation through RFBs [Regional Fisheries Bodies].
>
> Most recently, the 2013 UN General Assembly resolution on Sustainable Fisheries notes an obligation on all States, in accordance with international law, to cooperate in the conservation and management of living marine resources. All relevant States to a fishery

233. *E.g.*, Ne. Fisheries Sci. Ctr., *Distribution of Fish on the Northeast U.S. Shelf Influenced by Both Fishing and Climate*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (Dec. 19, 2014), http://www.nefsc.noaa.gov/press_release/pr2014/scispot/ss1414/.

234. Associated Press, *supra* note 214.

> are urged to give effect to their duty to cooperate by becoming members of the RFMO [Regional Fishery Management Organization] (where there is one) or to establish such an organization where none currently exists.[235]

And, indeed, as described above, a number of regional and international entities now manage certain fisheries, especially tuna and other pelagic and highly migratory species.

However, high seas fisheries are among the most imperiled in the world. As noted, highly migratory species that roam the world's oceans, like tuna, marlin, and sharks, are prominent components of the "subject to overfishing" and "overfished" categories under the Magnuson–Stevens Act. This pattern holds worldwide:

> [M]any fish stocks caught largely in the high seas, including one third of highly-migratory tuna and more than half of oceanic sharks, are over-exploited or depleted. It has also been estimated that up to half of all illegal fish catches, in terms of value, take place in the high seas.[236]

Nevertheless, in the areas of the high seas beyond national jurisdiction (i.e., more than 200 nautical miles from a coastal nation's shore), several governance gaps in fisheries management remain. In part, these gaps reflect an international law based on "freedom of the seas," particularly when it comes to fishing.[237] New gaps arise from the international community's failure to account for climate change in fisheries management. As IPSO summarized in 2013:

> The current system of high seas governance is fraught with gaps, directly leading to the mismanagement and misappropriation of living resources, and placing our ocean in peril. It is time for a new paradigm that can only come about through the fundamental reform of existing organisations and systems, overseen by a new global infrastructure to coordinate and enforce the necessary action. Crucially, the authors call for the negotiation of a new implementing agreement for the conservation and sustainable use of biodiversity in areas beyond national jurisdiction.[238]

235. 2014 FAO FISHERIES REPORT, *supra* note 13, at 81.

236. 2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 8.

237. As IPSO noted in 2013, "The high seas is often referred to as the 'the global ocean commons', a common heritage of humankind but its biodiversity is exploited predominantly by vessels from developed States and it is also subject to global problems related to climate change, pollution and large-scale human activities such as shipping." *Id.*

238. *Id.* at 2.

Moreover, the current regional fisheries management organizations vary widely in effectiveness. As IPSO extensively explained:

> Chronic mismanagement by [RFMOs], combined with excessive government subsidies spurring overcapacity in open-access fisheries, contribute to overfishing and IUU fishing in the high seas. The consequences are brought into stark relief by the recent collapse of the once highly productive jack mackerel fishery in the South Pacific in less than twenty years. While governments negotiated the creation of an RFMO in the region, and deliberated over interim measures, a "race to fish" before the agreement entered into force drove stocks from 30 million tons to just 3 million.
>
> RFMOs are the institutions legally charged with managing high seas fisheries under UNCLOS, yet a recent assessment identified that 67% of stocks (for which the status is known) under the jurisdiction of the 18 existing RFMOs are depleted or being overfished. A major problem is that the rules and decisions adopted by each RFMO apply only to its own member States while vessels owned by other States are able to fish in the region. Nearly all RFMOs are comprised primarily of States with a direct economic interest in the fishery, with delegates representing commercial fishing interests hugely outnumbering those geared towards ecological concerns. There is also wide discrepancy between the effectiveness of different RFMOs—indicating what can be achieved where political will and pressure exist. For example, the Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR) is widely praised, while the International Commission for the Conservation of Atlantic Tuna (ICCAT) has been labeled an international disgrace. At best, the pace of reform has been slow and uneven.[239]

However, as IPSO also acknowledges, the technology does exist to far more effectively monitor fishing on the high seas, and effective implementation of that technology could help to avoid the undesirable consequences of the current system in a climate change era, including "weaken[ed] ecosystem function, resilience and adaptive capacity and [exacerbation of] the effects of other marine stressors, such as warming and acidification."[240] It recommends a combination of three approaches to improve international fishing governance:

> 1) a "soft" change through a series of UN General Assembly Resolutions; 2) an enhanced regional approach focused on strengthening RFMO performance and capacity for ecosystem based management

239. *Id.* at 8.
240. *Id.* at 9.

> of living resources; and 3) an ambitious fundamental reform which would combine the two previous proposals with a global infrastructure to coordinate, ensure consistency and supervise, sanction and enforce the necessary changes.[241]

Moreover, with respect to the third approach, "[t]he key elements . . . could include the establishment of a global high seas enforcement agency to provide integrated and coordinated monitoring and enforcement for the full range of ocean security threats" and, most importantly, "a new implementing agreement for the conservation and sustainable use of biodiversity in areas beyond national jurisdiction under the auspices of UNCLOS."[242]

E. Establish a Fisheries Regime for the Arctic Before the Ice Melts

The Arctic is one of the regions of the world that is changing the most because of climate change. As the National Snow and Ice Data Center reports, "The Arctic region is warmer than it used to be and it continues to get warmer. Over the past 30 years, it has warmed more than any other region on earth."[243] Specifically, "[i]n the first half of 2010, air temperatures in the Arctic were 4° Celsius (7° Fahrenheit) warmer than the 1968 to 1996 reference period, according to NOAA."[244]

Among other changes, warming temperatures in the Arctic are melting the Arctic sea ice, potentially opening the Arctic Ocean for long periods of time to increased human activity, including fishing. "Satellite data show that over the past 30 years, Arctic sea ice cover has declined by 30 percent in September, the month that marks the end of the summer melt season."[245] Scientists now predict that the Arctic Ocean could be ice-free during the month of September as early as 2020, with the period of open ocean progressively extending thereafter.[246]

As Alaska fisheries demonstrate, the Arctic region offers rich fishing resources. However, the Arctic Ocean itself has not yet been subject to regular fishing efforts because of accessibility problems and other dangers that the ice causes, even in summer. As such, the Arctic Ocean represents a future new place for fishing, raising the specter of a mad

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241. *Id.*
242. *Id.*
243. *Climate Change in the Arctic*, NAT'L SNOW & ICE DATA CENTER, https://nsidc.org/cryosphere/arctic-meteorology/climate_change.html (last visited Feb. 16, 2015).
244. *Id.*
245. *Id.*
246. Craig Medred, *Expert Predicts Ice-Free Arctic by 2020 as UN Releases Climate Report*, ARCTIC DISPATCH NEWS (Nov. 2, 2014), http://www.adn.com/article/20141102/expert-predicts-ice-free-arctic-2020-un-releases-climate-report.

rush of unregulated and destructive fishing. It therefore behooves both the Arctic nations and the world at large to put a fishing regulatory regime in place for the Arctic Ocean *before* widespread commercial fishing in the region becomes possible.

The United States has already taken precautionary steps to protect Arctic Ocean species from unregulated fishing. In August 2009, under the Magnuson–Stevens Act, the Secretary of Commerce approved a far-sighted Fishery Management Plan for all parts of the Arctic Ocean under U.S. federal control (the Chukchi and Beaufort Seas off of Alaska).[247] This plan "initially prohibits commercial fishing in the Arctic waters of the region until more information is available to support sustainable fisheries management."[248] Other Arctic nations would be wise to follow the United States' example to keep the emerging Arctic Ocean fisheries from becoming rapidly overexploited.

F. Promote Marine Aquaculture of Heat- and pH-Tolerant Vegetarian Species in an Ecologically Responsible Manner

As both the World Bank (2013) and the FAO (2014) have suggested, as a practical matter aquaculture is likely to increasingly fill expanding gaps in the world food fish supply. The World Bank, for example, concluded expansively that:

> [I]t is clear that aquaculture will continue to fill the growing supply–demand gap in the face of rapidly expanding global fish demand and relatively stable capture fisheries. While total fish supply will likely be equally split between capture and aquaculture by 2030, the model predicts that 62 percent of food fish will be produced by aquaculture by 2030. Beyond 2030, aquaculture will likely dominate future global fish supply.[249]

As a result, governance of aquaculture should promote responsible aquaculture: "Investments in aquaculture must be thoughtfully undertaken with consideration of the entire value chain of the seafood industry."[250]

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247. *Arctic Fisheries*, NOAA FISHERIES: ALASKA REGIONAL OFFICE, http://alaskafisheries.noaa.gov/sustainablefisheries/arctic/ (last visited Feb. 16, 2015).

248. *Id.* For discussions of this closure, including a recommendation that this approach be incorporated as a climate change adaptation in fisheries management, see Sarah M. Kutil, *Scientific Certainty Thresholds in Fisheries Management: A Response to a Changing Climate*, 41 ENVTL. L. 233 (2011); Jennifer Jeffers, *Climate Change and the Arctic: Adapting to Changes in Fisheries Stocks and Governance Regimes*, 37 ECOLOGY L.Q. 917 (2010).

249. 2013 WORLD BANK FISH PROJECTIONS, *supra* note 95, at xix.

250. *Id.*

In particular, aquaculture governance should ensure that this burgeoning industry does not further stress wild populations of fish and shellfish, which should, in turn, promote a shift to vegetarian species grown in ecologically conscious ways. For example, "[s]almon aquaculture is the fastest growing food production system in the world—accounting for 70 percent (2.4 million metric tons) of the market."[251] However, salmon farming can pose numerous threats to marine biodiversity, from escapes of non-native species of farmed salmon to contamination and smothering of the environment from the penned salmon's feces, feed, and antibiotics.[252] Perhaps most importantly, salmon are carnivorous fish, generally requiring fish protein to grow. While feed practices in the salmon aquaculture industry are improving, it still requires about 2.5 kilograms of ocean forage fish such as anchovetta to produce one kilogram of aquacultured salmon.[253] Thus, farmed salmon represent a net drain on the ocean's fish stocks, even though globally, and across all species that are aquacultured, "aquaculture uses about half a metric ton of wild whole fish to produce one metric ton of farmed seafood, meaning that aquaculture is a net *producer* of protein."[254]

Aquacultured marine shrimp are another set of aquacultured species that warrant caution for the future. Like salmon, shrimp are carnivorous. Moreover, the expansion of shrimp farming in many Asian countries was strongly associated with the destruction of coastal mangrove forests, which often serve as nurseries for a variety of marine species. In 2004, for example, "[s]hrimp farming [was] worth $6.9bn (£3.8bn) at the farm gate and $50–60bn (£28-33bn) at the point of retail," and shrimp were "farmed in 50 countries, the vast majority of which [were] developing countries," especially "Thailand, China, Indonesia, India, Vietnam, Ecuador, the Philippines, Bangladesh, Mexico and Brazil."[255] However, at that time "as much as 38% of global mangrove destruction [was] linked to shrimp farm development," and shrimp farming posed other environmental problems as well, such as chemical pollution of the oceans and salt water contamination of adjacent land.[256] Recent reports tie shrimp

251. *Farmed Seafood: Farmed Salmon*, WORLD WILDLIFE FUND, http://www.worldwildlife.org/industries/farmed-salmon (last visited Feb. 16, 2015).

252. *Id*.

253. *The Fish Feed Story*, THE FISH SITE (Feb. 19, 2011), http://www.thefishsite.com/articles/1068/the-fish-feed-story.

254. *Feeds for Aquaculture*, NOAA FISHERIES, http://www.nmfs.noaa.gov/aquaculture/faqs/faq_feeds.html (last visited Feb. 16, 2015).

255. *Shrimp Farms 'Harm Poor Nations'*, BBC NEWS (May 19, 2004), http://news.bbc.co.uk/2/hi/science/nature/3728019.stm.

256. *Id*.

farming not only to environmental problems but also to human rights violations and health issues.[257]

Newer methods of shrimp aquaculture use tank-based systems on land.[258] These methods can drastically reduce the environmental impacts of shrimp farming, including the use of fish meal. For example, at the Sky8 facility in Massachusetts,

> it takes about three months to grow batches of 40,000 shrimp larvae, which feed on fish meal, algae and seaweed, to a size favored by retailers and restaurants. (Sky8 Shrimp is developing a feed that is free of fish meal.) The farm uses tanks of Atlantic Ocean water, filtered and reused from harvest to harvest. There are no antibiotics, no hormones and no pesticides, according to tests carried out at Sky8 last year by the Food and Drug Administration, which regulates shrimp. There is little risk that shrimp might escape and harm wild stocks.[259]

However, shrimp farmed this way currently sell for twice the price of imported frozen farmed shrimp, a market deterrent to investment.[260]

In contrast, "[f]armed shellfish such as oysters, clams and mussels do not need to be fed a manufactured feed. These shellfish are 'filter feeders' and consume plankton and other particles present in the water."[261] As such, shellfish aquaculture does not depend on consumption of other marine fish, and the shellfish can actually filter seawater and improve water quality in many places.[262] While shellfish are the species most vulnerable to ocean acidification—which, as discussed above, has in fact interfered with shellfish aquaculture on both coasts—many regions can still support shellfish aquaculture, and companies also are be-

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257. Specifically,

> Most of the shrimp the United States imports comes from farms in Latin America and in Southeast Asia, where environmental and human rights experts have long identified labor rights abuses, hazardous working conditions, damage to ecosystems and the use of hormones and antibiotics. Since last year, a bacterial disease has hit shrimp farms across Asia and Mexico, crippling shrimp production. Recent news reports have alleged the use of slave labor on boats that supply fish meal for shrimp farms in Thailand.

Hiroko Tabuchi, *Shrimp's New Path to the Plate*, N.Y. TIMES, July 3, 2014, at B1, *available at* http://www.nytimes.com/2014/07/03/business/with-wild-shrimp-stocks-dwindling-farmers-step-up-to-the-plate.html.

258. *Id.*

259. *Id.*

260. *Id.*

261. *Feeds for Aquaculture*, *supra* note 254.

262. *Farming the Ocean Draws Many Parallels to Farming the Land*, AM. MUSSEL HARVESTERS, INC., http://www.americanmussel.com/About_Us/Shellfish_Farming (last visited Feb. 16, 2015).

ginning to experiment with deep-sea shellfish aquaculture.[263] Moreover, in places like the Puget Sound, where shellfish aquaculture is economically important, ocean acidification issues have prompted state-level comprehensive responses.[264]

The larger point for marine food policy in the climate change era is that not all types of aquaculture are created equal and that the relevant governance systems should explicitly acknowledge that fact. To the extent that governments subsidize aquaculture, for example, they should subsidize only those types and methods of aquaculture that are relatively benign and do not further damage marine ecosystems and species. To the extent that aquaculture is a regulated and permitted activity within nations, those regulations and permit standards should favor the more environmentally benign types and methods of aquaculture and impose enforceable (and enforced) "best practices"-based requirements on aquaculture operations. Because we can predict the future importance of aquaculture as a food source, now is an excellent time to steer commercial aquaculture in directions that aid, rather than detract from, the future resilience of marine food supplies.

G. Put an Effective Climate Change Mitigation/Carbon Dioxide Reduction Treaty in Place Globally

When it comes to ocean fisheries productivity, climate change adaptation strategies are necessary but ultimately unsatisfactory—a second- or third-rate future for food security at best. Until atmospheric carbon dioxide concentrations are reduced, ocean acidification will remain a significant problem for shellfish growth (both wild and in marine aquaculture) and for marine food webs. Moreover, until greenhouse gas concentrations are reduced overall, increasing temperatures will continue to alter marine ecosystems, particularly the otherwise highly productive food ecosystems of the world's coral reefs.[265]

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263. Clare Leschin-Hoar, *This Innovative Method Could Change the Future of Shellfish Farming*, TAKE PART (Nov. 12, 2014), http://www.takepart.com/article/2014/11/12/offshore-mussel-farm.

264. *See generally* WASHINGTON STATE BLUE-RIBBON PANEL ON OCEAN ACIDIFICATION, OCEAN ACIDIFICATION: FROM KNOWLEDGE TO ACTION: WASHINGTON STATE'S STRATEGIC RESPONSE (2012), *available at* https://fortress.wa.gov/ecy/publications/publications/1201015.pdf (laying out comprehensive strategies for reducing and adapting to local ocean acidification problems).

265. As IPSO recognized in 2013:

> Coral reefs are extremely vulnerable to the impacts of climate change. It is imperative and urgent that emissions targets below 450 ppm CO_2e be agreed and implemented, combined with coordinated programmes at local and regional levels to reduce other stress factors and boost resilience; otherwise it is predicted that most reefs will be lost as effective, productive systems within a few decades.

The ultimate re-tooling of law and governance for marine food resilience, therefore, is an effective, global climate change mitigation treaty. Until all nations of the world effectively implement greenhouse gas reduction strategies, climate change will comprehensively and, because of ocean acidification, uniquely damage global marine ecosystems, as well as the fisheries and marine aquaculture that they currently support.

V. CONCLUSION

Marine fisheries and aquaculture are an important, but often overlooked, component of global food security. These industries already suffer from a number of stressors ranging from overfishing and destructive fishing practices, such as bottom trawling, to coastal habitat destruction and pollution of the marine environment from a variety of sources. Climate change is both exacerbating preexisting stressors and adding new ones, with changing ocean temperatures, currents, ocean chemistry through ocean acidification, and depletion of dissolved oxygen being especially concerning.

The future of wild-caught fisheries is, to put it bluntly, bleak. Even the World Bank's fairly optimistic projections view wild-caught fisheries as, at best, a stable constant in future decades, but one which will probably be reduced as a result of climate change impacts. Other researchers are more dire in their predictions, projecting widespread fisheries collapses among all sorts of species within the next four to six decades. Numerous marine species are already beginning to shift their traditional ranges toward the poles, disrupting food webs and further calling into question the legitimacy and sustainability of current catch limits, even where such limits exist and are enforced. As climate change impacts accelerate, market pressures to ignore any rules that do exist and fish illegally, particularly in the high seas, will only increase, even as marine species go extinct, or at least become commercially unavailable, all around the globe.

Aquaculture offers much hope and promise as a climate change adaptation strategy and potentially could do much to increase the future resilience of world food supplies to climate change and other stressors. However, as Asian shrimp farming has demonstrated, wanton investment in aquaculture can be just as environmentally damaging—and, ultimately, destructive of long-term food supplies—as overfishing. Given widespread recognition of the growing importance of aquaculture to future food supplies, now is the time for individual nations and the international

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2013 IPSO STATE OF THE OCEAN REPORT, *supra* note 123, at 2.

community as a whole to steer aquaculture onto the most climate change-adaptive and resilient paths possible. Vegetarian species of fish and shellfish, habitat-preserving techniques, reduced use of ocean-based fish meal and fish oil, and reduced use of antibiotics should all be legally encouraged, as should methods that reduce the ability of non-native species to escape into new habitats. In addition, as in the Puget Sound, the goal of keeping areas of the marine environment viable for certain kinds of aquaculture should spur more general climate change adaptation and mitigation strategies, improving the resilience not only of world food supplies but also human socio-ecological systems more generally.

As nations become increasingly aware of their dependence on ocean-based food and the growing threats to that food supply, they hopefully will also become increasingly cognizant of the ocean-specific threats that increased atmospheric concentrations of carbon dioxide pose, especially ocean acidification. While the recent history of international climate change mitigation negotiations gives little cause to hope for significant improvements in the near future, the threatened or actual loss of the world's coral reefs and marine shellfish, and the food that they provide, may finally spark an effective international response to climate change itself.