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# Ocean-Based Food Security Threatened in a High CO<sub>2</sub> World

A Ranking of Nations' Vulnerability to Climate Change and Ocean Acidification



*Photo: Melanie Siggs/Marine Photobank*

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## Fish and seafood are a primary source of protein for more than one billion of the poorest people on Earth

Emissions of carbon dioxide and other greenhouse gases are disrupting ocean conditions and threatening the future of the essential food resources we receive from the oceans.

# Ocean-Based Food Security Threatened in a High CO<sub>2</sub> World

## A Ranking of Nations' Vulnerability to Climate Change and Ocean Acidification

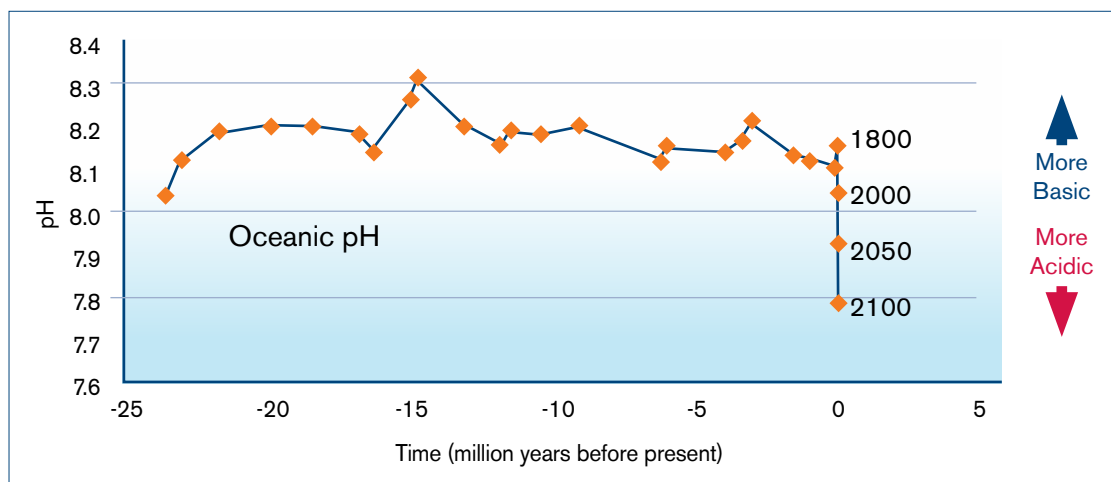
Emissions from human activities are changing the ocean's chemistry and temperature<sup>1,2</sup> in ways that threaten the livelihoods of those who depend on fish and seafood for all or part of their diets. The changes may reduce the amount of wild caught seafood that can be supplied by the oceans<sup>3</sup> and also redistribute species, changing the locations at which seafood can be caught<sup>4</sup> and creating instability for ocean-based food security, or seafood security. This report ranks nations based on the seafood security hardships they may experience by the middle of this century due to changing ocean conditions from climate change and ocean acidification. This is done by combining each nation's exposure to climate change and ocean acidification, its dependence on and consumption of fish and seafood and its level of adaptive capacity based on several socioeconomic factors. Country rankings are developed for risks from climate change and ocean acidification independently, as well as from both problems combined.

Fish and seafood are a primary source of protein for more than one billion of the poorest people on Earth.<sup>5</sup> By 2050 the global demand for seafood is expected to rise, mainly due to an increase in population to about nine billion people. The oceans can be a large part of the solution to this global food security challenge. But at the same time, emissions of carbon dioxide and other greenhouse gases are disrupting ocean conditions and threatening the

future of the essential food resources we receive from the oceans.

As a result of the increases in carbon dioxide and other greenhouse gases in the atmosphere, the oceans are warming.<sup>6</sup> This is creating changes at the base of the marine food web.<sup>7,8</sup> Because marine species and their prey are adapted to a certain temperature range, as temperatures change, their habitable ranges can change as well. Rising temperatures are shifting the locations where a given fish species can live and find food.<sup>9</sup> In general, these changes are pushing many species into deeper and colder waters towards the poles and away from the tropics.<sup>10,11</sup> Not only does this redistribution of species put the tropics at risk, but these climate-induced invasions of new habitats could have serious ecological consequences, including the extinction of native species toward the poles.<sup>12</sup>

The oceans absorb large amounts of carbon dioxide emissions each day. As a result, their pH has declined by 30 percent since the Industrial Revolution.<sup>13</sup> This rapid change in ocean chemistry, called ocean acidification, is already threatening habitats like coral reefs,<sup>14</sup> and the future of shellfish like oysters, clams and mussels is also in jeopardy.<sup>15</sup> This means that nations that rely heavily on threatened types of fisheries as a primary food source could be hit hardest.



**Figure 1.** The Rapid Change in Ocean pH since the Industrial Revolution is Likely the Fastest in Earth's History (Turley, C., et al. 2006<sup>16</sup>)



Photo: OCEANA/Silvia Garcia

Many coastal and small island developing nations depend more heavily on fish and seafood for protein than developed nations. In some places, such as the Maldives, well over half of the available food protein comes from seafood.<sup>17</sup> Other countries in which people eat large amounts of fish and seafood include Iceland, Japan, Kiribati and the Seychelles.<sup>18</sup> This report uses levels of fish and seafood consumption rates in each country as an indicator of dependence on the oceans. Higher seafood consumption suggests that a nation is more vulnerable to changing ocean conditions that could lead to a loss of seafood options. Although many countries will be affected by any losses in seafood security, the least developed nations where residents eat great quantities of fish may suffer the worst hardships because they have fewer socioeconomic resources to obtain more food to replace what is lost from the sea.

Nations that have a low gross domestic product (GDP) per capita, high population growth rates and high levels of undernourishment are considered more vulnerable to losses in ocean-based protein within this study. Using these three

indicators, the top five least adaptable coastal or island countries are Comoros, Pakistan, Eritrea, Haiti and Madagascar, which have fast growing populations with limited economic resources and high rates of undernourishment. Many individuals in these countries are earning salaries of roughly a dollar per day (USD), and thus it will be a substantial hardship for those individuals to deal with losing an inexpensive and healthy protein source like wild caught seafood.

The severity of future changes in ocean conditions will depend largely on the choices we make regarding energy use in the upcoming years and decades. Fish and seafood could be important contributors toward feeding a growing global population if we keep these resources safe. To protect this important source of food security we need to do more than just improve fisheries management. We also must protect the oceans from climate change and ocean acidification by dramatically reducing carbon dioxide emissions from our use of fossil fuels and rapidly transitioning to a clean energy economy.

## Exposure + Dependence + Lack of Adaptive Capacity = Vulnerability

**Table 1.** Vulnerability Ranking Categories and Indicators

| CATEGORY  | CLIMATE CHANGE INDICATORS   | OCEAN ACIDIFICATION INDICATORS   |
|---|---|--|
| <b>Exposure</b>   | Predicted Percentage Loss in Fisheries Catch Potential in Exclusive Economic Zone (EEZ) by 2055<br>(Cheung et al. 2010) | Acidification based on Amount of Aragonite Saturation State in EEZ by 2050<br>(Adopted from Cao and Caldeira 2007) |
|   | <b>Dependence</b>   | Fish, Seafood Consumption as a Percentage of Available Protein<br>(FAO FishStat 2000-2007)                         |
| Mollusk Consumption as a Percentage of Available Protein<br>(Cooley 2011) |   |  |
| <b>Adaptive Capacity</b>  | GDP Per Capita<br>(CIA World Factbook 2012)   | GDP Per Capita<br>(CIA World Factbook 2012)  |
|   | Population Growth Rate 2012-2050<br>(U.S. Census Bureau, International Country Database 2012)                           | Population Growth Rate 2012-2050<br>(U.S. Census Bureau, International Country Database 2012)                      |
|   | Percentage of the Population Undernourished<br>(WRI, Earthtrends from FAO Data 2003-2005)                               | Percentage of the Population Undernourished<br>(WRI, Earthtrends from FAO Data 2003-2005)                          |



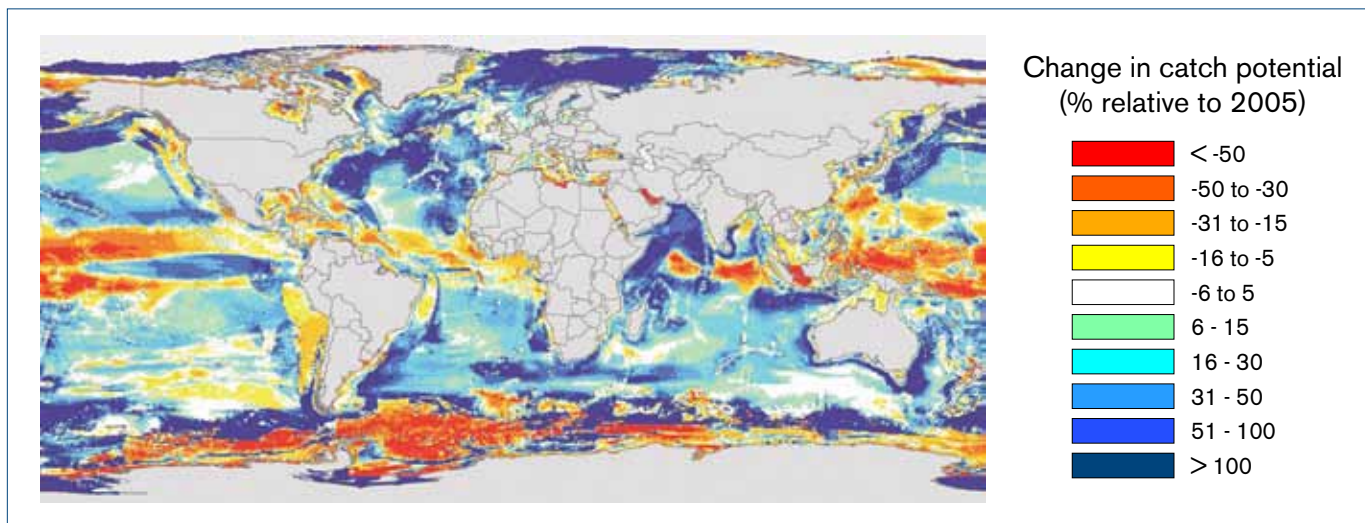
The least developed nations where residents eat large quantities of fish may suffer the worst hardships from climate change and ocean acidification because they have fewer socioeconomic resources to obtain more food to replace what is lost from the sea.

## CLIMATE CHANGE INDICATORS

### Exposure:

#### Predicted Percentage Change in Fisheries Catch Potential in EEZ by 2055

The temperature of the ocean is changing,<sup>19</sup> which may alter ocean circulation, in turn affecting the availability of nutrients to support the base of the marine food web<sup>20</sup> and ultimately the productivity of fisheries. Marine fish and invertebrates tend to shift towards the poles and into deeper waters during times of rising temperatures. The results from a model<sup>21</sup> were applied in this analysis to incorporate the impacts of the redistribution of fisheries due to climate change. This model predicts the likely changes in distribution for 1,066 species that are commercially caught, given projections from climate change models out to the year 2055. The model shows some areas in the poles gaining fish, but that losses of up to 40 percent of catch potential can be expected in the tropics. Nations without large industrialized fishing fleets will be unlikely to follow these shifting resources around the world. In this analysis, higher predicted losses in fisheries catch potential from the model by the year 2055 represented higher vulnerability.



**Figure 2.** Shifting Fisheries Catch Potential Due to Rising Ocean Temperatures by 2055 Threatens Seafood Security

(Adapted from Cheung, et al. 2010)

### Dependence:

#### Fish and Seafood Consumption as a Percentage of Available Protein

Fish provide 16 percent of annual protein consumption for about three billion people worldwide.<sup>22</sup> But consumption rates of fish and seafood vary greatly among nations. The highest seafood consumption per capita generally occurs in coastal and island nations largely provided by small scale fisheries. In some developing countries, fish is the cheapest and most available source of animal protein. This analysis uses average fish and seafood consumption as a percentage of total available protein (grams/capita/day)<sup>23</sup> as a measure of dependence on ocean resources that may be threatened by climate change.



# OCEAN ACIDIFICATION INDICATORS

## Exposure:

### Aragonite Saturation State in EEZ by 2050

Aragonite is an important mineral needed by many marine species for the creation of their skeletons and shells. This includes corals, some species of plankton and shellfish like mollusks. Average levels of aragonite saturation are an indicator of how easy or difficult it will be for species to build their aragonite shells and skeletons. By the year 2050<sup>24</sup> many parts of our oceans will be experiencing dangerously low levels of aragonite saturation which threatens coral reefs and mollusks. The global model used in this analysis<sup>25</sup> provides a demonstration of how open-ocean average aragonite saturation within each country's EEZ will be impacted. But aragonite saturation state can also vary along a coastline due to local oceanographic conditions and levels of coastal water pollution due to agricultural and sewage runoff. Nations with coastlines near upwellings, which bring deep, carbon-rich water to the surface, or that experience large amounts of runoff pollution may be further threatened by declines in aragonite saturation state, which was not fully shown in the model used in this analysis.

## Dependence:

### Coral Reef Fishers as a Proportion of the National Population

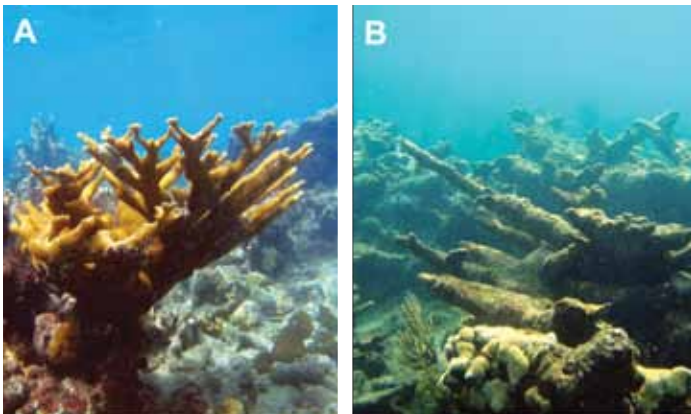
Coral reefs are vulnerable to ocean acidification from a doubling of atmospheric carbon dioxide.<sup>26</sup> The decline of coral reefs threatens many fish species and the people that depend on those fish for food and livelihoods. About a quarter of all marine fish species live on coral reefs and about 30 million people around the world

depend heavily on these fish as a stable source of protein.<sup>27</sup> The amount of reef fishers as a percentage of the national population is an indicator of how many people are dependent on reef fisheries, although the amount of people that eat fish from these reefs may be even higher. Since consumption data on reef-associated seafood is often lacking, the amount of people that catch fish on these reefs serves as an important indicator of the significance of reef fish to national food security.

## Dependence:

### Mollusk Consumption as a Percentage of Available Protein

In this analysis, mollusks are defined as a group of animals that include conchs, abalones, whelks, clams, oysters, scallops and mussels, but exclude squids and octopuses.<sup>28</sup> Mollusk consumption is used as a measure of dependence on a vulnerable resource because mollusks are a group of animals that are susceptible to the impacts of ocean acidification,<sup>29</sup> and their populations and harvest rates may be significantly affected. While mollusks may represent only a small fraction of all available protein on a global scale, they can provide 50 percent or more of the available protein in places like Aruba, Turks and Caicos Islands and the Cook Islands.<sup>30</sup> Losses in mollusk populations could impact many jobs and the global economy,<sup>31</sup> but the most significant hardships may be felt by nations that are most heavily reliant on mollusks for food.



Corals and coral reefs are severely threatened by ocean acidification:

**A**, Healthy coral reef and good water quality.

**B**, Degraded coral reef and poor water quality.

Photo: Ryan P. Moyer



Blue mussels (*Mytilus edulis*) are threatened by ocean acidification. Photo: OCEANA/Carlos Minguell



## ADAPTIVE CAPACITY INDICATORS AND RANKING METHOD

### GDP Per Capita

Gross domestic product (GDP) is an assessment of the value of goods and services provided on a countrywide scale and gives an estimate of the economic resources a country has available. This analysis used GDP per capita<sup>32</sup> because the amount of economic resources available per person is a better measure of adaptability than total national wealth. The assumption this analysis makes is that the higher the GDP per capita, the more likely a nation will be able to develop or import more food to compensate any losses in seafood protein. Low GDP per capita represents higher vulnerability.

### Population Growth Rate 2012-2050

By the middle of the century roughly nine billion people will be living on Earth, but countries currently differ significantly in their population growth rates. Nations with high population growth rates from 2012-2050<sup>33</sup> are assumed to have a higher growing demand for protein sources. In this assessment, a higher population growth rate for a nation is considered to increase vulnerability.

### Percentage of the Population Undernourished

Some nations already have problems feeding their populations, indicating that they may experience greater food security problems in the future from any losses in seafood protein. This analysis assigned higher vulnerability values to nations with more than five percent of their population defined as undernourished. In some nations, like Comoros, more than 50 percent of the population is undernourished, representing hundreds of thousands of hungry individuals.<sup>34</sup>

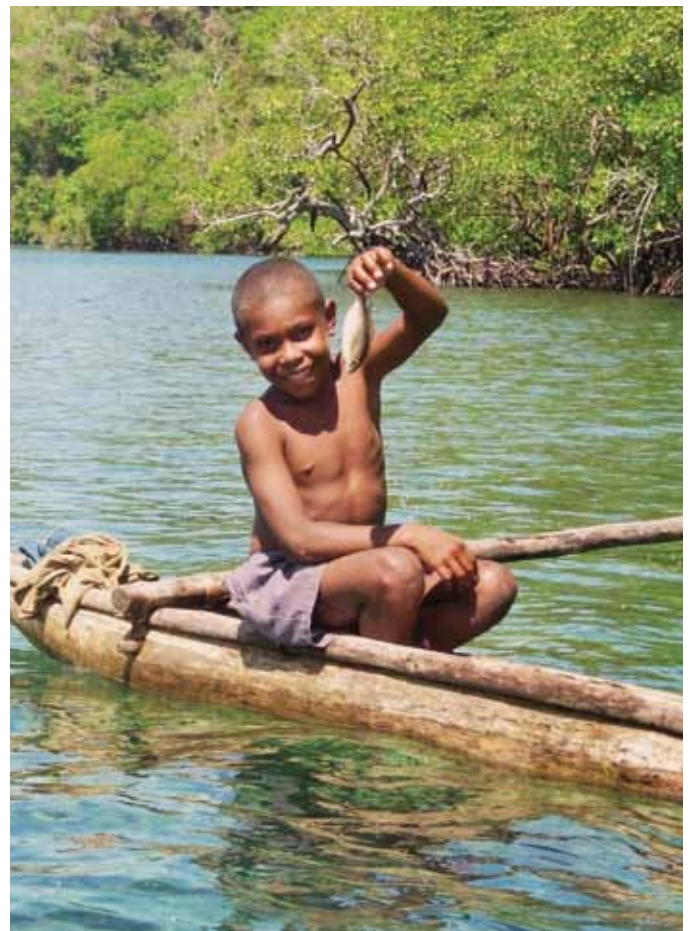
### Ranking Method

This analysis ranks countries in order of how vulnerable each nation is to threats from climate change and ocean acidification in terms of seafood security. The ranking was based on the following function:

$$\text{Exposure} + \text{Dependence} + \text{Lack of Adaptive Capacity} = \text{Vulnerability}^{35}$$

Three different rankings were generated that ranked countries threatened by climate change, ocean acidification, and then both combined. Each of the indicators described in Table 1 (and the previous section) were considered: exposure, dependence and adaptive capacity. Each of the indicators was normalized, and averaged when there was more than one indicator in a category. For instance, under the dependence category for ocean acidification, the indicators ‘mollusk consumption as a percentage of available protein’ and ‘coral reef fishers as a

proportion of the national population’ were averaged together to measure dependence on resources that are threatened by ocean acidification. Vulnerability was calculated by adding together the following three categories: exposure, dependence and adaptive capacity, which are detailed in Table 1. Each category had an equal weighting. The final model provided an estimate of combined vulnerability by averaging values for exposure and dependence for both climate change and ocean acidification, and then adding that value to adaptive capacity. Some coastal and island nations were excluded from this analysis due to gaps in available data.<sup>36</sup>



Nations that have a low (GDP) per capita, high population growth rates and high levels of undernourishment are considered more vulnerable to losses in ocean-based protein within this study.

*Photo: Jan Hasselberg/Marine Photobank*

Wild caught seafood is often one of the healthiest and most accessible options for protein in coastal and small island nations. Any reduction in seafood availability could threaten food security for these communities.



Photo: Tony Rath/Naturalight Productions

**Table 2.** Most Vulnerable Nations to Food Security Threats Due to Climate Change Impacts on Fisheries

| Vulnerability Ranking to Climate Change | Country              | Ocean Region         |
|---|----------------------|----------------------|
| 1                                       | Maldives             | Indian Ocean         |
| 2                                       | Togo                 | South Atlantic Ocean |
| 3                                       | Comoros              | Indian Ocean         |
| 4                                       | Iran                 | Persian Gulf         |
| 5                                       | Libya                | Mediterranean        |
| 6                                       | Singapore            | South China Sea      |
| 7                                       | Kuwait               | Persian Gulf         |
| 8                                       | Guyana               | North Atlantic       |
| 9                                       | Indonesia            | Indian Ocean         |
| 10                                      | United Arab Emirates | Persian Gulf         |

Source: OCEANA

**Table 3.** Most Vulnerable Nations to Food Security Threats from Ocean Acidification

| Vulnerability Ranking to Ocean Acidification | Country                  | Ocean Region                   |
|--|--------------------------|--------------------------------|
| 1  | Cook Islands             | South Pacific Ocean            |
| 2  | New Caledonia            | Southwest Pacific Ocean        |
| 3  | Turks and Caicos Islands | Caribbean                      |
| 4  | Comoros                  | Indian Ocean                   |
| 5  | Kiribati                 | Central Tropical Pacific Ocean |
| 6  | Aruba                    | Southern Caribbean             |
| 7  | Faroe Islands            | North Atlantic Ocean           |
| 8  | Pakistan                 | Arabian Sea                    |
| 9  | Eritrea                  | Red Sea                        |
| 10   | Madagascar               | Indian Ocean                   |

Source: OCEANA



This local fisherman in Mozambique could lose a primary food source and his job due to climate change and ocean acidification. Mozambique is #6 in the combined ranking for vulnerability from climate change and ocean acidification.

*Photo: OCEANA/Nuria Abad*

**Table 4.** Combined Vulnerability to Food Security Threats from Climate Change and Ocean Acidification Impacts on Seafood Availability

| Vulnerability Ranking to Climate Change and Ocean Acidification Combined | Country                  | Ocean Region          |
|--|--------------------------|-----------------------|
| 1  | Comoros                  | Indian Ocean          |
| 2  | Togo                     | South Atlantic Ocean  |
| 3  | Cook Islands             | South Pacific Ocean   |
| 4  | Kiribati                 | Central Pacific Ocean |
| 5  | Eritrea                  | Red Sea               |
| 6  | Mozambique               | Indian Ocean          |
| 7  | Madagascar               | Indian Ocean          |
| 8  | Pakistan                 | Arabian Sea           |
| 9  | Sierra Leone             | North Atlantic Ocean  |
| 10   | Thailand                 | Gulf of Thailand      |
| 11   | Algeria                  | Mediterranean Sea     |
| 12   | Guyana                   | North Atlantic Ocean  |
| 13   | Haiti                    | Caribbean             |
| 14   | Turks and Caicos Islands | Caribbean             |
| 15   | Libya                    | Mediterranean         |
| 16   | Croatia                  | Adriatic Sea          |
| 17   | Tonga                    | South Pacific Ocean   |
| 18   | Mauritania               | North Atlantic Ocean  |
| 19   | Guinea-Bissau            | North Atlantic Ocean  |
| 20   | Grenada                  | Caribbean             |
| 21   | New Caledonia            | South Pacific Ocean   |
| 22   | Angola                   | South Atlantic Ocean  |
| 23   | Indonesia                | Indian/Pacific Ocean  |
| 24   | Palau                    | North Pacific Ocean   |
| 25   | North Korea              | North Pacific Ocean   |

Source: OCEANA

**Table 4. Continued**

| Vulnerability Ranking to Climate Change and Ocean Acidification Combined | Country              | Ocean Region            |
|--|----------------------|-------------------------|
| 26   | Maldives             | Indian Ocean            |
| 27   | Iran                 | Persian Gulf            |
| 28   | The Gambia           | North Atlantic Ocean    |
| 29   | Ecuador              | Eastern Central Pacific |
| 30   | Sudan                | Red Sea                 |
| 31   | Senegal              | North Atlantic Ocean    |
| 32   | Liberia              | North Atlantic Ocean    |
| 33   | Dominica             | Caribbean               |
| 34   | Philippines          | North Pacific Ocean     |
| 35   | China                | North Pacific Ocean     |
| 36   | Djibouti             | Red Sea                 |
| 37   | Cameroon             | North Atlantic Ocean    |
| 38   | Tanzania             | South Indian Ocean      |
| 39   | Saint Lucia          | Caribbean               |
| 40   | Guinea               | North Atlantic Ocean    |
| 41   | Aruba                | Caribbean               |
| 42   | Kenya                | South Indian Ocean      |
| 43   | Peru                 | South Atlantic Ocean    |
| 44   | United Arab Emirates | Persian Gulf            |
| 45   | Cambodia             | Gulf of Thailand        |
| 46   | South Africa         | South Atlantic Ocean    |
| 47   | Faroe Islands        | North Atlantic Ocean    |
| 48   | Papua New Guinea     | South Pacific Ocean     |
| 49   | American Samoa       | South Pacific Ocean     |
| 50   | Montserrat           | Caribbean               |

Source: OCEANA



Fish markets provide cheap and healthy food in the Philippines. The Philippines is #35 in the combined ranking for vulnerability from climate change and ocean acidification.

Photo: Wolcott Henry 2005/Marine Photobank



Photo: OCEANA/Ana de la Torre

Coastal and small island developing nations are vulnerability hotspots to food security risks from climate change, ocean acidification and both combined. Many of the high-ranking nations based on climate change indicators are located in the tropics and low latitudes. This reflects the general trend that fish species are predicted to be migrating toward the poles as water temperatures continue to rise. Tropical countries are the most dependent on coral reef fisheries which are severely threatened. Island and coastal nations depend more heavily on fish for protein, especially the poorest nations, increasing their vulnerability. Many of the poorest places are already struggling with hunger issues which will be made worse with high population growth rates and limited additional options for food.

Wild caught seafood is often one of the healthiest and most accessible options for protein in coastal and small island nations. Losing this resource may mean more dependence on less healthy processed foods that are imported from abroad. Communities that have recently made a shift from eating traditional seafood items to importing cheap, processed foods have suffered widespread health problems. For example, in Pacific Island nations about 40 percent of the population has been diagnosed with diabetes, cardiovascular diseases or hypertension.<sup>37</sup> Losing seafood accessibility due to changing ocean conditions may further expand these nationwide health crises.

Several big oil-producing nations rank in the top ten for seafood security threats from climate change. The Persian Gulf is a region that is expected to lose a high percentage of wild caught fisheries due to climate change.<sup>38</sup> In one of the rankings (Table 2), Iran, Libya, Kuwait and the United Arab Emirates placed in the top ten nations most likely to be affected by potential food security risks due to the redistribution of seafood species. These nations are also in the top twenty in terms of oil-producing nations and provide significant subsidies to their oil and gas industries. The combination of growing populations and losses in seafood resources could make these nations more dependent upon food imports, and the loss of fisheries would have the most serious impacts for some of the poorest artisanal fishermen within these countries.

Millions of small-scale fishermen depend on the capture of seafood not just for a food source for their families, but also as a source of income. Many nations have also benefited from marine tourism jobs associated with coral reefs and abundant marine life. This multi-billion dollar industry could also be threatened by climate change. Therefore, further assessments should incorporate the risks to food security that come from losses in income due to the disappearance of fisheries and tourism related jobs. Local changes to marine resources from ocean acidification and climate change could ripple up through the global economy.<sup>39</sup>

## U.S. FISHERIES IN JEOPARDY FROM CLIMATE CHANGE

Although the U.S. currently has the resources to adapt its national food security to losses in seafood protein that may occur from climate change and ocean acidification, the country will not go unscathed by these threats. Millions of jobs and billions of dollars in revenue are at risk if there are substantial losses in the capture, processing and sale of U.S. seafood due to regional climate impacts. Due to rising temperatures, the continental U.S. is projected to lose an average of 12 percent of its fisheries catch potential, representing a loss of more than 600,000 tons by the middle of this century.<sup>40</sup> This could have serious impacts on profitable fisheries in the Gulf of Mexico, Pacific Coast and the North and Southeast Atlantic. These regional changes can vary greatly within the same country, and they were not fully reflected by the ranking for the U.S. and other nations. Predicted regional losses in fisheries catch potential along the continental U.S. coasts range from losses of five percent to more than 50 percent in some regions. If marine species continue to move further offshore into deeper waters and higher latitudes it would significantly raise the costs of catching seafood, and this might put many small-scale fishermen out of business.

Alaska may gain fisheries catch potential due to temperature increases.<sup>41</sup> However, the redistribution of large amounts of fish to high-latitude regions could also lead to serious ecological consequences, including opening the door for harmful invasive species.<sup>42</sup> Alaska may also be one of the hardest hit regions by the impacts of ocean acidification, which will be worsened toward the poles because cold waters absorb more carbon dioxide.<sup>43</sup> Ocean acidification threatens pteropods, tiny marine snails and other small animals at the base of the food web, and losses in their populations could ripple up to impact populations of commercially important fisheries for salmon, mackerel, herring and cod.<sup>44</sup>

Modeling the comprehensive impacts of rising temperatures, acidification and lowered oxygen concentrations for marine resources is urgently needed.

### OCEAN ACIDIFICATION ALREADY HARMING COMMUNITIES

Ocean acidification has already had impacts on the U.S. economy. Oyster farms in Oregon experienced massive die-offs of oyster larvae over the past decade. This was connected to low pH coastal waters being pumped into the hatcheries.<sup>45</sup> This is one of the first identified impacts of ocean acidification on a marine resource. In the Northeast, ocean acidification and changes to oxygen concentrations are projected to reduce fisheries catch by 20 percent - 30 percent, and further changes to phytoplankton may cut catches by an additional 10 percent.<sup>46</sup>

### AS TEMPERATURES RISE, SO DO LEVELS OF HARMFUL BACTERIA IN SHELLFISH

Increasing ocean temperatures may also make U.S. seafood less safe. Higher temperatures can spread diseases like *Vibrio cholerae* in shellfish, which leads to the disease cholera in humans.<sup>47</sup> It was recently discovered that for every one degree Celsius increase in ocean temperature, the amount of *Vibrio* outbreaks in humans has risen about 200 percent. Another bacterial infection called *Vibrio parahaemolyticus* is a leading cause of seafood-associated gastroenteritis in the U.S.<sup>48</sup> This disease is connected with harvests when water temperatures are high and is becoming more prevalent as a result of climate change.<sup>49</sup>



**While the impacts of climate change and ocean acidification on fisheries, livelihoods and food security are disturbing, there are steps that we can take to minimize these impacts.**

### Reduce Carbon Dioxide Emissions

Reducing carbon dioxide emissions is the only way to address global ocean acidification and is also the primary path to ending climate change. Governments need to establish energy plans that chart a course for shifting away from fossil fuels and toward clean energy production.

### End Fossil Fuel Subsidies

A large step toward reducing emissions is to end all fossil fuel subsidies that are continuing to prevent the needed transition to clean energy. Optimally, we should invest in technologies that promise solutions to climate problems, rather than creating them.

### Stop Overfishing, Bycatch and Destructive Fishing Practices

In order to adapt to changing ocean conditions, marine fisheries need to be healthy. To ensure this is the case, we need to reduce overfishing and bycatch (discarded fish). This can be done by scientifically determining the status of fish stocks, setting appropriate catch limits on target species and creating long-term bycatch reduction plans. Stopping destructive fishing techniques such as bottom trawling, dynamite fishing and cyanide fishing will also help protect seamounts, coral reefs and other important fish habitats. Minimizing local threats may help fisheries overcome the impacts of climate change.

### Establish Marine Protected Areas

Marine protected areas that are off limits to fishing and limit local pollution may help raise the resilience of local ecosystems to climate change and ocean acidification. Protected areas can benefit both fisheries and tourism by preserving important spots of marine biodiversity and fish spawning grounds.

### Manage for Change

Fisheries managers must consider climate change and ocean acidification impacts in order to manage resources sustainability. Since some species are moving toward the poles and into international waters, there is also a need for improved multinational cooperation on fisheries management, especially in frontier areas like the Arctic, in order to prevent overfishing.



Reducing carbon dioxide emissions is the only way to limit global ocean acidification and the primary path to stop climate change.

*Photo: DOE/NREL*



Offshore wind farms are replacing fossil fuels and reducing carbon dioxide emissions in places like Denmark.

*Photo: OCEANA/Carlos Minguell*



Stopping destructive fishing techniques like this driftnet in Morocco may help marine fisheries become more resilient to climate change.

*Photo: OCEANA/Carlos Minguell*

- 1 Feely, R., S.C. Doney, and S.R. Cooley. (2009) Ocean acidification: present conditions and future changes in a high-CO<sub>2</sub> world. *Oceanography*, 22(4): 36-47.
- 2 Gleckler, P.J., B. Santer, M. Domingues, D. W. Pierce, T.P. Barnett, J.A. Church, K.E. Taylor, K.M. AchutaRao, T. P. Boyer, M. Ishii, and P.M. Caldwell. (2012) Human-induced global ocean warming on multidecadal timescales. *Nature Climate Change*, 2, 524-529.
- 3 Turley, C and Boot, K. (2011) The ocean acidification challenges facing science and society. In Gattuso, J-P & Hansson, L. (Eds.) *Ocean Acidification*. Pg. 255. Oxford Publishing.
- 4 Cheung, W.L., Lam V.W.Y., Sarmiento, J.L., Kearney K., Watson R., Zeller D., Pauly D. (2010) Large scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, 16:34-25.
- 5 FAO. 2010. The state of world fisheries and aquaculture. Food and Agriculture Organization, United Nations. Rome.
- 6 Gleckler, P.J., B. Santer, M. Domingues, D. W. Pierce, T.P. Barnett, J.A. Church, K.E. Taylor, K.M. AchutaRao, T. P. Boyer, M. Ishii, and P.M. Caldwell. (2012) Human-induced global ocean warming on multidecadal timescales. *Nature Climate Change*, 2, 524-529.
- 7 Field, D., T Baumgartner, C. Charles, V. Ferreira-Bartrina, M. Ohman. (2005). Planktonic foraminifera of the California current reflect 20th-century warming. *Science*, 311 (5757), pp 63-66.
- 8 Hoegh-Guldberg, O. J. Bruno. (2010) The impacts of climate change on the world's marine ecosystems. *Science*, 328, 1523-1528.
- 9 Perry, A.L., L. Paula, J. Ellis, J. Reynolds. (2005) Climate change and distribution shifts in marine fishes. *Science*, 308(5730): 1912-1915.
- 10 Dulvy, N.K., S.I. Rogers, S. Jennings, V. Steltzenmuller, S.R. Dye, H.R. Skjodal. (2008) Climate change and the deepening of the North Sea fish assemblage: a biotic indicator of warming seas. *Journal of Applied Ecology*, 45, 1029-1039.
- 11 Perry, A.L., L. Paula, J. Ellis, J. Reynolds. (2005) Climate change and distribution shifts in marine fishes. *Science*, 308(5730): 1912-1915.
- 12 Occhipinti-Ambrogi, A. (2007). Global change and marine communities: Alien species and climate change. *Marine Pollution Bulletin*, 55, (7-9). pp 342-352. <http://dx.doi.org/10.1016/j.marpolbul.2011.03.031>
- 13 Orr, J. et al (2005) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, 432:681-686.
- 14 De'ath, G., J.M. Lough, and K.E. Fabricius. (2009) Declining coral calcification on the Great Barrier Reef. *Science*, 323:116-119.
- 15 Gazeau, F., C. Quiblier, J. M. Jansen, J.-P. Gattuso, J. J. Middelburg, and C. H. R. Heip (2007) Impact of elevated CO<sub>2</sub> on shellfish calcification. *Geophys. Res. Lett.*, 34, L07603, doi:10.1029/2006GL028554.
- 16 Turley, C., et al. (2006). Reviewing the Impact of Increased Atmospheric CO<sub>2</sub> on Oceanic pH and the Marine Ecosystem, in *Avoiding Dangerous Climate Change*, 65-70, Cambridge University Press.
- 17 FAO FishStat Data. Average Fish, Seafood Consumption Between 2000-2007.
- 18 Id.
- 19 Gleckler, P.J., B. Santer, M. Domingues, D. W. Pierce, T.P. Barnett, J.A. Church, K.E. Taylor, K.M. AchutaRao, T. P. Boyer, M. Ishii, and P.M. Caldwell. (2012) Human-induced global ocean warming on multidecadal timescales. *Nature Climate Change*, 2, 524-529.
- 20 IPCC (2007) Summary for Policymakers. In: *Climate Change 2007 – the Physical Science Basis*. Working Group I Contribution to the Fourth Assessment of the IPCC. (eds. Solomon S, Qin D, Manning M et al.) pp. 1-8. Cambridge University Press, Cambridge.
- 21 Cheung, W.L., Lam V.W.Y., Sarmiento, J.L., Kearney K., Watson R., Zeller D., Pauly D. (2010) Large scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, 16:34-25.
- 22 FAO (2003). Assessment of the world food security situation. 29th Session of the Committee on World Food Security, 12–16 May 2003. Available at: <http://www.fao.org/unfao/bodies/cfs/cfs29/CFS2003-e.htm>. Referenced by: Turley, C and Boot, K. (2011) The ocean acidification challenges facing science and society. In Gattuso, J-P & Hansson, L. (Eds.) *Ocean Acidification*. Pg. 255. Oxford Publishing.
- 23 FAOSTAT (2012). Fish & Seafood Consumption as a Percentage of Average Total Protein from 2000-2007. Items: (Fish, Seafood + (Total)) / (Grand total + (Total)), Element: (g/capita/day). Available at: <http://faostat.fao.org/site/610/DesktopDefault.aspx?PageID=610#ancor>
- 24 Feely, R., S.C. Doney, and S.R. Cooley. (2009) Ocean acidification: present conditions and future changes in a high-CO<sub>2</sub> world. *Oceanography*, 22(4): 36-47.
- 25 Cao, L. and K. Caldeira (2007) Atmospheric CO<sub>2</sub> Stabilization and Ocean Acidification. *Geophysical Research Letters*, 35:L19609
- 26 Silverman, J., B. Lazar, L. Cao, K. Caldeira and J. Erez (2009). Coral reefs may start to dissolving when atmospheric CO<sub>2</sub> doubles. *Geophysical Research Letters*, 36:L05606.
- 27 Wilkinson, C. (2008) Status of the Coral Reefs of the World: 2008. Global Coral Reef Monitoring Network and Rainforest Research Centre, Townsville, Australia.
- 28 Cooley, S.R., Lucey, N., Kite-Powell, H., Doney, S.C. (2011) Nutrition and income from mollusks today imply vulnerability to ocean acidification tomorrow. *Fish and Fisheries*, DOI: 10.1111/j.1467-2979.2011.00424.x
- 29 Talmage, C. and Gobler, C. (2010). Effects of past, present, and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish. *PNAS*, 107(40), pp 17246-17251.
- 30 Cooley, S.R., Lucey, N., Kite-Powell, H., Doney, S.C. (2011) Nutrition and income from mollusks today imply vulnerability to ocean acidification tomorrow. *Fish and Fisheries*, DOI: 10.1111/j.1467-2979.2011.00424.x
- 31 Harrould-Kolieb, E., M., Hirshfield, A., Brosius. (2009). Major emitters among the hardest hit by ocean acidification. *Oceana*.
- 32 CIA. The World Factbook. GDP Per Capita (PPP). <https://www.cia.gov/library/publications/the-world-factbook/rankorder/2004rank.html>. July 2012.
- 33 U.S. Census Bureau International Programs, International Database Country Rankings. 2012 - 2050 population growth rate estimates. <http://www.census.gov/population/international/data/idb/informationGateway.php>
- 34 World Resources Institute, Earthtrends. Percentage of Population Undernourished, 2003-2005 Averaged. <http://www.wri.org/project/earthtrends/>
- 35 The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2001b, Glossary).
- 36 Nations not included in analysis due to data gaps of one or more indicators: Afghanistan, Andorra, Armenia, Austria, Azerbaijan, Bahrain, Belarus, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Burkina Faso, Burma, Burundi, Central African Republic, Chad, Congo (Kinshasa), Curacao, Czech Republic, Equatorial Guinea, Ethiopia, Gibraltar, Hungary, Iraq, Jersey, Jordan, Kazakhstan, Kosovo, Kyrgyzstan, Laos, Liechtenstein, Luxembourg, Macau, Macedonia, Malawi, Marshall Islands, Mayotte, Moldova, Monaco, Mongolia, Montenegro, Nepal, Niger, Oman, Paraguay, Qatar, Romania, Rwanda, Saint Barthelemy, Saint Helena, Saint Martin, Saint Pierre and Miquelon, Sint Maarten, Slovakia, Slovenia, Somalia, Swaziland, Switzerland, Taiwan, Tajikistan, Tokelau, Turkmenistan, Uganda, Uzbekistan, Wallis and Futuna, Western Sahara, Zambia, Zimbabwe.
- 37 World Health Organization (WHO), July 2010. Pacific Islanders pay the price for abandoning traditional diet. Volume 88: 7, 481-560.
- 38 Cheung, W.L., Lam V.W.Y., Sarmiento, J.L., Kearney K., Watson R., Zeller D., Pauly D. (2010) Large scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, 16:34-25.
- 39 Harrould-Kolieb, E., M., Hirshfield, A., Brosius. (2009). Major emitters among the hardest hit by ocean acidification. *Oceana*.
- 40 Cheung, W.L., Lam V.W.Y., Sarmiento, J.L., Kearney K., Watson R., Zeller D., Pauly D. (2010) Large scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, 16:34-25.
- 41 Id.
- 42 Occhipinti-Ambrogi, A. (2007). Global change and marine communities: Alien species and climate change. *Marine Pollution Bulletin*, 55, (7-9). pp 342-352. <http://dx.doi.org/10.1016/j.marpolbul.2011.03.031>
- 43 Watson, S attitude, temperature and carbonate saturation: implications for global change and ocean acidification. *Global Change Biology*, DOI: <http://dx.doi.org/10.1111/j.1365-2486.2012.02755.x>
- 44 Fabry, V.J., J.B. McClintock, J.T. Mathis and J.M. Grebmeier. (2009) Ocean acidification at high latitudes: the bellwether. *Oceanography*, 22(4):160-171.
- 45 Burton, A, B. Hales, G. Waldbusser, C. Langdon, R. A. Feely. (2012). The Pacific oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. *Limnology and Oceanography*; 57 (3): 698 DOI: 10.4319/lo.2012.57.3.0698
- 46 Cheung, W., et al (2011). Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential in the Northeast Atlantic. *ICES J. Mar. Sci.* 68(6):1008-1018.
- 47 Rose, J.B., P. Epstein, E. K. Lipp, B.H. Sherman, S. M. Bernard, J.A. Patz (2001). Climate variability and change in the United States potential impacts on waterborne and foodborne diseases caused by microbiological agents. *Env. Health Persp.* 109(2): 211-220.
- 48 Baker-Austin, C. J. Trinanen, N. Taylor, R. Hartnell, A. Siitonen, J. Martinez-Urtaza. (2012). Emerging *Vibrio* risk at high latitudes in response to ocean warming. *Nature Climate Change*, doi:10.1038/nclimate1628
- 49 Id.