GLOBAL-WARMING INDUCED CHANGES IN THE CATCH POTENTIAL OF REGIONAL SEAS[1]

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ABSTRACT

We projected changes in global catch potential for over one thousand species of exploited marine fish and invertebrates from the early to the mid 21st century, under conservative climate change scenarios. We show that climate change will lead to large-scale redistributions of global catch potential, with an average that may reach increases of 30–70% in high-latitude regions and a drop of up to 40% in the tropics. Moreover, maximum catch potential declines considerably in the southward margins of semi-enclosed seas, while it increases in poleward tips of continental shelf margins. Such changes are most apparent in the Pacific Ocean. Among the 20 most important fishing Exclusive Economic Zone (EEZ) regions in terms of their total landings, EEZ regions with the highest increase in catch potential by mid-century include Norway, Greenland, the United States (Alaska) and Russia (Asia). On the contrary, EEZ regions with the biggest loss in maximum catch potential include Indonesia, the United States (excluding Alaska and Hawaii), Chile and China. Many highly impacted Regional Seas, particularly those in the tropics, lie adjacent to countries which are socioeconomically vulnerable to these changes.

INTRODUCTION

Marine fisheries productivity is likely to be affected by the alteration of ocean conditions, including water temperature, ocean currents and coastal upwelling, as a result of climate change (e.g., Bakun, 1990; IPCC, 2007; Diaz and Rosenberg, 2008). Such changes in ocean conditions affect primary productivity, species distribution, community and food web structure that have direct and indirect impacts on distribution and productivity of marine organisms.

Empirical and theoretical studies show that marine fish and invertebrates tend to shift their distributions according to the changing climate in a direction that is generally towards higher latitude and deeper water, with observed and projected rates of range shift of around 30-130 km·decade^{-1} towards the pole and

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3.5 $\mathrm{m \cdot decade^{-1}}$ to deeper waters (e.g., Perry *et al.*, 2005; Cheung *et al.*, 2008b, 2009; Dulvy *et al.*, 2008; Mueter and Litzow, 2008).

Relative abundance of species within assemblages may also change because of the alteration of habitat quality by climate (e.g., Przeslawski *et al.*, 2008; Wilson *et al.*, 2008). Global primary production is projected to increase by 0.7-8.1% by 2050, with very large regional differences such as decreases in productivity in the North Pacific, the Southern Ocean and around the Antarctic continent and increases in the North Atlantic regions (Sarmiento *et al.*, 2004).

Analysis of empirical data shows that maximum fisheries catch potential of exploited fishes and invertebrates is dependent on primary production and range size of the species (Cheung *et al.*, 2008a). Based on projected changes in primary production (Sarmiento *et al.*, 2004) and distribution range (Cheung *et al.*, 2009), Cheung *et al.* (2010) projected changes in maximum catch potential by 2055, relative to 2005. This index, formed by such projections, should contribute to assessments of potential climate change impacts on marine fisheries.

METHODS

Maximum catch potential is defined as the maximum exploitable catch of species combined, assuming that the geographic range and selectivity of fisheries remain unchanged from the current (year 2005) level. We include 1,066 species of marine fish and invertebrates, representing the major commercially exploited species, as reported in the FAO fisheries statistics (see http://www.fao.org), belonging to a wide range of taxonomic groups from around the world. Future distributions of these species are projected using a dynamic bioclimate envelope model under the SRES A1B scenario (see Cheung *et al.*, 2008b, 2009 for details) while primary production is projected by empirical models (Behrenfeld and Falkowski, 1997; Carr, 2002; Marra *et al.*, 2003; Sarmiento *et al.*, 2004).

Using a published empirical model described in Cheung *et al.* (2008a), we calculated the annual maximum catch potential for each of the ½° spatial cells. The empirical model estimates a species' maximum catch potential (MSY) based on the total primary production within its exploitable range (P), the area of its geographic range (A), its trophic level (λ) and includes terms correcting the biases from the observed catch potential (CT is the number of years of exploitation and HTC is the catch reported as higher taxonomic level aggregations):

$$\log_{10}MSY_t = -2.881 + 0.826 \cdot \log_{10}P_t - 0.505 \cdot \log_{10}A_t - 0.152 \cdot \lambda + 1.887 \cdot \log_{10}CT + 0.112 \cdot \log_{10}HTC_t + \varepsilon \qquad \ldots 1)$$

where t is year and ε is the error term. We assume that the proportion of exploitable range relative to the geographic range of a species remains constant in the future. Thus, P was calculated from the sum of primary production (estimated from each of the three primary production algorithms) from the exploitable range weighted by the relative abundance in each spatial cell. Range area (A) was the sum of the area of all spatial cells that contribute to 95% of the total abundance at year t from which distributions of relative abundance were simulated from the dynamic bioclimate envelope model described above. The trophic level (λ) of each species was obtained from FishBase (www.fishbase.org), SeaLifeBase (www.sealifebase.org) and the *Sea Around Us* Project databases (www.seaaroundus.org) and was assumed to be constant over time. However, change in species distributions and community structure resulting from climate change may affect the trophic level of the species. This would affect the estimated change in maximum catch potential and remains a major uncertainty of our projections. The spatial distribution of the calculated maximum catch potential was assumed to be proportional to the relative abundance of each species in each cell.

Data sources

Key information for predicting distribution maps was mainly obtained from FishBase for fish and SeaLifeBase for other taxa. Both databases contain key information on the latitudinal and depth distribution of the animals in question, and on their occurrence in various parts of the world ocean. The distribution maps are available at www.seaaroundus.org, along with their habitat preferences and other parameters used in their construction.

Indicator category (pressure/state/impact/response)

Catch potential can be seen as an impact indicator. It is developed with a ½° by ½° spatial resolution, summarized here to the level of the UNEP Regional Seas. The indicator is the projected proportional changes in maximum catch potential in each ½° cell by 2055 (10-year average) relative to 2005. The reduction in maximum catch potential indicates negative impacts of climate change on fisheries and vice versa (see Appendix 8).

RESULTS AND DISCUSSION

Overall, the index, representing the projected proportional changes in maximum catch potential by 2055 relative to 2005 (10-years average) under the SRES A1B scenario, shows that climate change may considerably alter the distribution of catch potential, particularly between tropical and high-latitude regions (Figure 1). Specifically, impacts in the Indo-Pacific region appear to be most intense, with up to 50% decrease in 10-year average maximum catch potential by 2055 under a higher greenhouse gas emission scenario (SRES A1B).

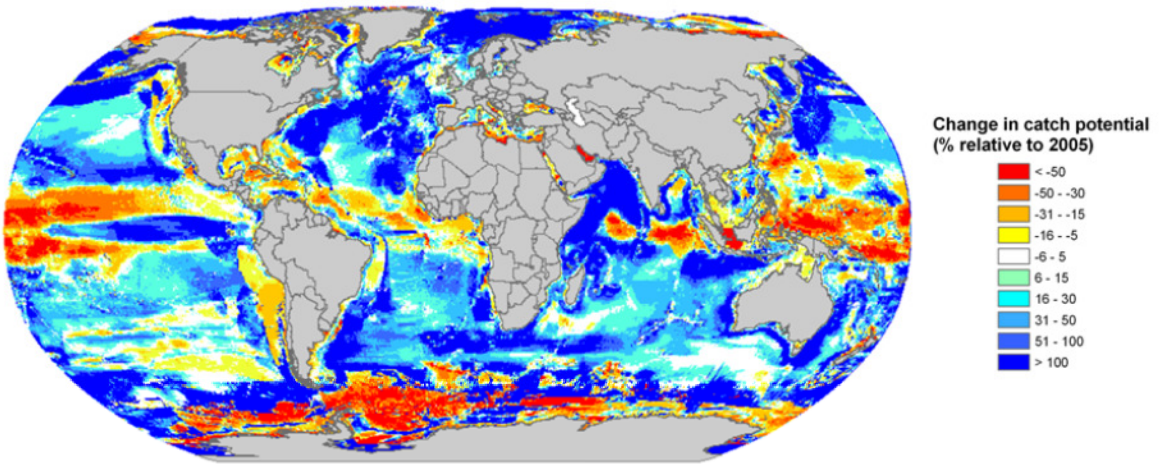

Figure 1. Projected percent change in maximum catch potential by 2055 relative to 2005 (10-year average) under the SRES A1B scenario (redrawn from Cheung *et al.*, 2010)

Simultaneously, catch potential in semi-enclosed seas such as the Red Sea and the southern coast of the Mediterranean Sea suffer from a reduction in catch potential. In fact, catch potential from many coastal regions appear to decline. In addition, maximum catch potential in the Antarctic region declines considerably. By contrast, catch potential in the higher latitudinal regions, particularly the offshore regions of the North Atlantic, the North Pacific, the Arctic and the northern edge of the Southern Ocean increase greatly by more than 50% from the 2005 level.

Specifically, we project a large reduction in catch potential in the tropics, semi enclosed seas and inshore waters, while catch potential increases largely in the North Atlantic, North Pacific (particularly the Bering Sea) and the poleward tips of continental margins such as around South Africa, southern coast of Argentina and Australia.

These results suggest that climate change will have a large impact on the distribution of maximum catch potential – a proxy for potential fisheries productivity – by 2055. The redistribution of catch potential is driven by projected shifts in species' distribution ranges and by the change in total primary production within the exploited ranges of different species. In the tropics and the southern margin of semi-enclosed seas such as the Mediterranean Sea, species are projected to move away from these regions as the ocean warms up. Thus, the catch potential in these regions decreases considerably. Simultaneously, ocean warming and the retreat of sea ice in high-latitude regions open up new habitat for lower latitude species and thus may result in a net increase in catch potential.

Moreover, catch potential increases in the poleward continental margins (e.g., southern parts of Australia and Africa), because most commercially exploited species are associated with continental shelves. Thus these continental margins represent a limit to the distribution shifts of numerous species. In subtropical and temperate regions, cold-water species are replaced by warm-water species, making the trend in catch potential changes in these regions generally weaker than in tropical, high-latitude and polar regions.

The large reduction in catch potential in the southern ocean is the result of a shift in the lower-latitude range boundary of many Antarctic species, resulting in a loss of catch potential. In addition, as species move offshore to colder refuges as the ocean warms up, catch potential also shifts to offshore regions from coastal areas. Such inshore-to-offshore shifts as estimated here corroborate observations from field studies (Dulvy *et al*., 2008).

Various uncertainties are associated with our projections. First, they do not consider the effect of changes in eco-physiology, such as the increased physiological stress resulting from ocean acidification and the predicted reduction of the dissolved oxygen content of subsurface waters, i.e., factors which are likely to have negative impacts on catch potential (Pauly 2010). Secondly, projections from dynamic bioclimate envelope models are uncertain (Cheung *et al*., 2009). However, sensitivity analysis of the dynamic bioclimate envelope model shows that its projections are generally robust to key input parameters. Also, our projected rates of range-shift for exploited fishes are of similar magnitude to the observed rates in the North Sea (Perry *et al*., 2005) and the Bering Sea (Mueter and Litzow, 2008) in recent decades; this provides support to the validity of our projections.

Distribution shifts may be influenced by evolutionary or physiological adaptation of marine species and interactions between species or anthropogenic factors that were not captured in our model. Consideration of these factors is expected to increase the rate of range shifting of the species; thus our projected distribution shifts are considered conservative (Cheung *et al*., 2009). Moreover, there are uncertainties associated with projections of ocean conditions that were applied to predict primary production and changes in species distributions. Particularly, because of the coarse resolution of the underlying oceanographic models, representation of dynamics in finer spatial resolution (e.g., coastal processes) is particularly uncertain. This is likely to affect estimated changes in the catch potential of Regional Seas, but less, we think, than caused by the non-consideration of eco-physiological processes (which we soon will remedy).

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REFERENCES

Bakun, A., 1990. Global climate change and intensification of coastal ocean upwelling. *Science* 247, 198-201.

Behrenfeld, M.J., Falkowski, P.G., 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography* 42(1), 1-20.

Carr, M.E., 2002. Estimation of potential productivity in Eastern Boundary Currents using remote sensing. *Deep Sea Research Part II* 49, 59-80.

Cheung, W.W.L., Close, C., Lam, V.W.Y., Watson, R., Pauly, D., 2008. Application of macroecological theory to predict effects of climate change on global fisheries potential. *Marine Ecology Progress Series* 365, 187-197

Cheung, W.W.L., Close, C., Kearney, K., Lam, V., Sarmiento, J., Watson, R., Pauly, D., 2009. Projections of global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10, 235-251

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D., Pauly, D., 2010. Large-scale redistribution of maximum catch potential in the global ocean under climate change. *Global Change Biology* 16, 24-35.

Dulvy, N.K., Rogers, S.I., Jennings, S., Vanessa, S., Dye, S.R., Skjoldal, H.R., 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. *Journal of Applied Ecology* 45, 1029-1039.

Diaz, R.J., Rosenberg, R., 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321, 926-929.

IPCC, 2007. Summary for Policymakers. In: Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M.M.B., Miller, H.L. Jr., Chen, Z. (eds.), *Climate Change 2007: The Physical Science Basis*, pp. 1-18. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Marra, J., Ho, C., Trees, C.C., 2003. *An Algorithm for the Calculation of Primary Productivity from Remote Sensing Data*. Lamont-Doherty Earth Obs., Palisades, New York. 27 p.

Mueter F.J., Litzow, M.A., 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. *Ecological Applications* 18, 309–320.

Pauly, D., 2010. *Gasping Fish and Panting Squids: Oxygen, Temperature and the Growth of Water-Breathing Animals*. Excellence in Ecology (22), International Ecology Institute, Oldendorf/Luhe, Germany, xxviii + 216 p.

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D., 2005. Climate change and distribution shifts in marine fishes. *Science* 308, 1912-1915.

Przeslawski, R., Ahyong, S., Byrne, M., Wörheide, G., Hutchings, P., 2008. Beyond corals and fish: the effects of climate change on noncoral benthic invertebrates of tropical reefs. *Global Change Biology* 14, 2773-2795.

Sarmiento, J.L., Slater, R., Barber, R., Bopp, L., Doney, S.C., Hirst, A.C., Kleypas, J., Matear, R., Mikolajewicz, U., Monfray, P., Soldatov, V., Spall, S.A., Stouffer, R., 2004. Response of ocean ecosystems to climate warming. *Global Biogeochemical Cycles* 18(3), GB3003.1-GB3004.23.

Wilson, S.K., Fisher, R., Pratchett, M.S., Graham, N.A.J., Dulvy, N.K., Turner, R.A., Cakacaka, A., Polunin, N.V.C., Rushton, S.P., 2008. Exploitation and habitat degradation as agents of change within coral reef fish communities. *Global Change Biology*, 14, 2796-2809.