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Sea Around Us

Global warming: effects on sea-food security

by Daniel Pauly and William W.L. Cheung

There are various ways that scientists of diverse disciplines can contribute to the debate on global warming. The first, obviously, was to establish the reality of the greenhouse effect, and this was achieved well over a hundred years ago, through the work of Svante Arrhenius (1896). However, it is only in the last three decades that the work of Charles Keeling, James Hansen and others, systematized in successive IPCC assessments, established empirically that humans not only could change the climate, but were indeed engaged in doing so, with potentially catastrophic outcomes.

The mechanisms at work are mainly physical and chemical, and notwithstanding numerous exceptions (see e.g., Wilson *et al.* 2009) and feedback loops, this mainly means that the systems biologists study are at the receiving end of climate change. In other words, we must study how ecosystems and the species therein are going to respond to physical forcing. Terrestrial ecologists have taken a lead on this, not least because they could build on spatial information on natural (forests, savannas, etc.) and agricultural systems, for which numerous global databases exist.

This is different for marine biologists and fisheries scientists, two disciplines whose practitioners are accustomed to working at a local level on one, or a few, species at a time, and to testing narrow hypotheses (Peter 1991). Thus, their main response to the global warming challenge so far

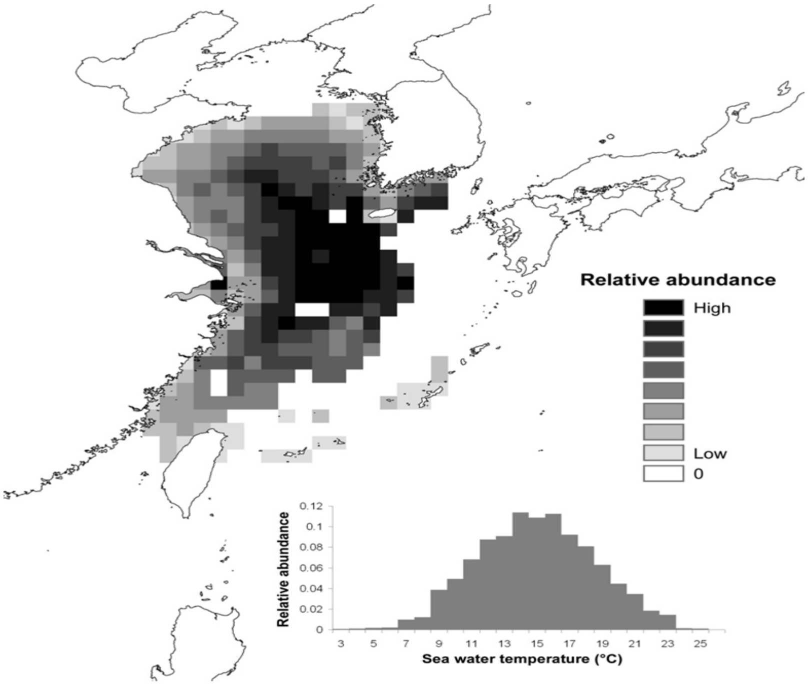

Figure 1. Example of a distribution range map for yellow croaker Larimichthys polyactis *and (as insert), the resulting temperature preference profiles. Similar maps, pertaining to well over 1000 species and higher taxa may be found at www.seaaroundus.org.*

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has been local studies, highlighting, e.g., the poleward movement of selected species (see Perry *et al.* 2005), from which global inferences are then drawn. This approach is fraught with problems, especially considering the representativeness of the species and locales studied.

... insights gathered in the course of this work enable us to tackle global climate change issues.

The *Sea Around Us* Project has a global mandate, however. This is the reason why we have mapped the growth and decline of global catches since 1950 (Pauly 2007; Watson *et al.* 2004), and the data and insights gathered in the course of this work enable us to tackle global climate change issues. The following account briefly discusses steps that we used to produce a number of papers on the impact of global warming on marine biodiversity and fisheries on the world's marine ecosystems, and to lay a strong foundation for future contributions. We proceeded in four steps.

Step 1 was the elaboration of a model for shifting the species distributions (generally poleward, and into deeper water) as temperature increased, building on the over one thousand range maps we constructed, in the course of the *Sea Around Us* Project, for mapping fisheries catches. (We have a map for all 'commercial species', these being defined as fish or invertebrate species for which at least one member country submits catch data to the FAO; Figure 1). From each of these maps, a temperature preference profile was derived (Figure 1, insert), defined by the water preferentially inhabited by that species. (Note that we avoided circularity, because we never used temperature to define species range maps; see Close *et al.* 2006). Then, for each (half degree lat./long.) cell of a species distribution range map, a population dynamics model was set up, featuring the (bi)annual broadcasting of reproductive propagules whose survival is determined largely by the water temperatures they encounter. Given increasing temperatures, this generates amoeboid poleward movement of the species in question, lasting as long as the initial temperature preference profile is not re-established (see contributions in Cheung *et al.* 2008a). The projected temperature data we used for this originates from outputs of the Ocean-Atmosphere coupled general circulation model (GCM) CM 2.1 of NOAA's Geophysical Fluid Dynamics Laboratory and provided by our partners at Princeton University, led by Jorge Sarmiento. These output account not only for temperature changes, but also for changes in currents. We examined the effects of changes in ocean conditions under three greenhouse gas emission scenarios: 720 ppm, 550 ppm, 370 ppm CO_2 concentration by 2100, but we limited our projections to 2050.

Step 2 consisted of establishing a strong predictive relationship between the area of distribution of a species and its productivity, as required to reflect the changed distributions generated in Step 1. Such a strong relationship is documented in Cheung *et al.* (2008b) and has the form $\log C_p = -2.881 + 0.826 \cdot \log PP - 0.505 \cdot \log A - 0.152 \cdot \log TL + 1.887 \cdot \log CT + 0.111 \cdot \log HCT + e$ where C_p is the potential catch (in $t \cdot year^{-1}$, estimated as the mean of several years with the highest catch); PP is the annual

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The *Sea Around Us* website may be found at www.seaaroundus.org and contains up-to-date information on the project.

The *Sea Around Us* project is a scientific collaboration between the University of British Columbia and the Pew Environmental Group. The Group supports nonprofit activities in the areas of culture, education, the environment, health and human services, public policy and religion. Based in Philadelphia, Pew makes strategic investments to help organizations and citizens develop practical solutions to difficult problems. In 2000, with approximately $4.8 billion in assets, the Group committed over $235 million to 302 nonprofit organizations.

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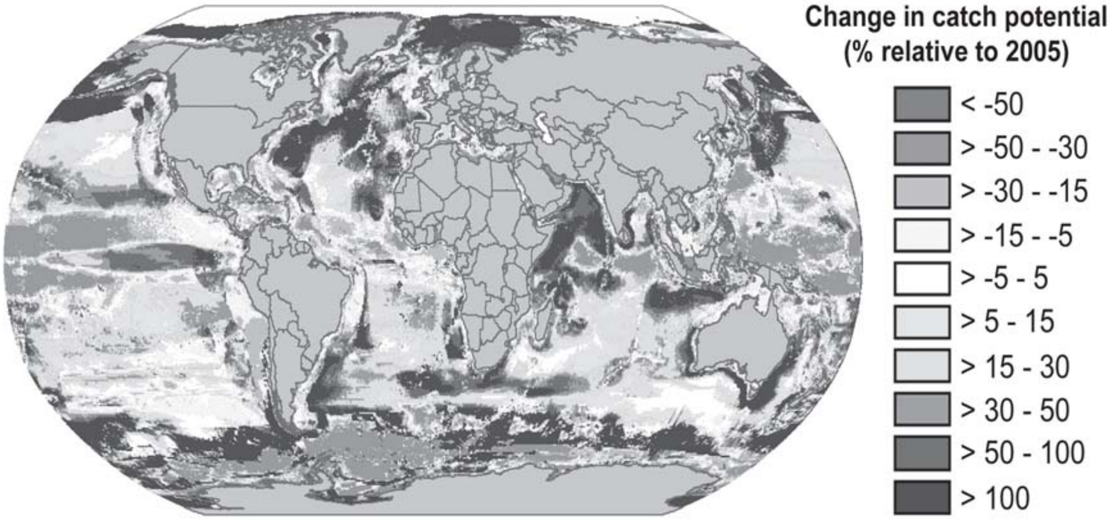

Figure 2. Predicted change in the potential of fisheries, given the distribution range shifts induced by global warming. Some high-latitude countries (e.g., Norway, Iceland) are predicted to see increases (20-40 %) in their catch potential, while tropical countries are predicted to see decreases (10-30 %) from such changes (Cheung et al. 2009b). However, these predictions do not account for change in oxygen distribution in, and acidification, of the oceans, and hence represent an optimistic scenario (see text).

primary production in the area of distribution (g·C); A is the area of distribution (km^2); TL is the trophic level; CT is number of years used from the computation of C_p; HCT is the catch reported in the corresponding genus or family (to account for reporting in taxa other than species) and *e* is the error term of the model, which explains 70% of the variability in a data set comprising 1066 species, covering animals as diverse as Antarctic krill *Euphausia superba* and yellowfin tuna *Thunnus albacares*.

Step 3 then consisted of applying the shift model in Step 1to over 1,000 species as defined above (857 species of finfish and 229 species of invertebrates).This led to global maps showing areas dominated by species extirpations (near the poles, and in the inter-tropical belt), areas dominated by invasions (Arctic and Southern Ocean), and areas with high turnover (extirpation + invasions). They represent the first global maps of threats to marine biodiversity (see Cheung *et al.* 2009a). Moreover, because they were based on a large sample size and on species with a large biomass, we believe that the pattern they identify is representative and thus can guide future work about the impact of global warming on marine biodiversity.

Step 4, by combining the catch potential in Step 2 with the species shifts in Step 3, generated maps of change in catch potential for the world oceans (Figure 2). When these were overlaid with the outlines of countries' Exclusive Economic Zones, the main result was that a few high-latitude countries (e.g., Norway, Iceland) may benefit from the large scale redistribution of fish species, i.e., see increases of their catch potential of up to 40%, while low-latitude, tropical countries may suffer declines of 10-30% in their catch potential (Cheung *et al.* 2009b). In countries covering a large latitudinal range, such as the USA and Australia, the positive changes in high latitude areas would offset negative changes in low latitude areas, as revealed by soon-to-be submitted national-scale studies for the US and Australia. Here again, we anticipate that our result will inspire international research on this topic because our inferences are based on huge datasets and do not represent solely local conditions.

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This work also allowed identification of limitations in our coverage of the world's biodiversity, as there are numerous countries which, in their reports to FAO, omit the catch of artisanal fisheries (i.e., coastal species), important as they usually are (see contribution in Zeller and Pauly 2007). In the future, we will remedy this by ensuring that every EEZ in the world is represented by at least several

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coastal species. However, the major limitation of our study probably is the non-consideration of four important factors, which we assess will be critical to future research.

The Sea Around Us Project is positioning itself to be a major player on the scientific study of the effect of global warming on ocean biodiversity and fisheries.

One factor so far neglected is dissolved oxygen, which generally will be reduced in future oceans because stronger temperature gradients with regards to depth will reduce mixing. We will account for this potentially strong effect on fish productivity by explicitly taking account of the impact of oxygen on fish growth (Pauly 1981).

The second neglected factor is acidification. Lower pH is generally perceived as affecting only organisms with calcium carbonate shells, but in reality it is likely to affect all water-breathing organisms, by reducing the gradient which allows them to get rid of carbon dioxide as they exhale. Empirical evidence exists that a reduction of this gradient will impact performance of water-breathers, and hence the productivity of fish (e.g., Munday *et al.* 2009).

The third factor we must consider is that, while primary production is generally predicted to remain similar in the next decades, it may actually consist of smaller cells (picoplankton; various flagellates) and less of the larger phytoplankton (especially diatoms), which fuel productive marine food webs. We plan to account for this by inserting a trophic level between the small phytoplankton and the zooplankton, which will account for the microbial food web (where much of the small phytoplankton ends up), and reduce the primary production supporting fisheries yields.

Finally, the current version of coupled GCM does not represent well the dynamics along the coast and on the continental shelf, where many exploited species are found, which adds considerable uncertainty to our finer-scale projection in some regions. Thus, we are undertaking regional case studies (e.g, in Western Australia) in which higher-resolution physical outputs from regional oceanographic models are used to drive our biological models. The results so far suggest that the general patterns of range shift that we showed in the global analysis remain robust at the regional scale. Nevertheless, we will, in the future, use outputs from GCMs with finer resolution and better coastal representation.

A paper outlining these four steps is in progress and we expect that it will generate estimates of potential catch devoid of 'winners': the world fisheries will lose out, and the effect will be strongest in the tropics.

Overall, this global modelling exercise will gradually include much of what we know about important physiological and trophic mechanisms. Also, it will be enriched when the work of Villy Christensen, working with Ecopath with Ecosim and the *Sea Around Us* databases, adds a food web perspective to this (see Christensen *et al.* 2009). Overall, with this work, the *Sea Around Us* Project is positioning itself to be a major player in the scientific study of the effect of global warming on ocean biodiversity and fisheries. This will often make us the bearer of bad news, as it appears that the more we build into our model the worse the predictions become.

On the other hand, our work – already now - indicates that the faster the root cause of global warming is addressed, the better it will be for the millions of people who depend directly or indirectly on seafood for their subsistence or their enjoyment.

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High times, high seas, high blood pressure: completing an MSc at the Fisheries Centre has it all

by Sarika Cullis-Suzuki

This fall 2009, I closed the door on part of my life: I finished my three-year MSc at the Fisheries Centre at UBC. Unfortunately, what was not put to an end: all the ocean's problems.

Certainly one of the most overwhelming things I dealt with early in my studies was becoming aware of the global crisis of fisheries, and the resultant feeling of being so small as to be completely ineffectual in the face of it. I definitely remember my early days at the Fisheries Centre, rushing over to my supervisor's office, plunking myself into a chair and asking: how do the oceans even stand a chance? And how do you maintain your composure?? I suppose Dr Daniel Pauly has witnessed (or been the victim of) such a reaction before. He calmly explained to me how you do what you can: you put the parts back, tiny piece by tiny piece[1]. And so that's what I tried. As we all do, as members of the *Sea Around Us* Project.

Initially for my research, I began working on global Marine Protected Areas (MPAs), continuing on with the work of Dr Louisa Wood, who graduated from UBC in 2006. While this did lead to some interesting results (see Alder *et al.* 2009; Cullis-Suzuki and Pauly *in press*), after a year it was time to move on to something new.

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