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.

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 FAQ; 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 CO₂ 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

\[ \log_{10}P = -2.881 + 0.826\logPP - 0.505\logA - 0.152\logTL + 1.887\logCT + 0.111\logHCT + 0.505\logC + 0.111\logHCT + 0.505\logC + 0.111\logHCT + 0.505\logC \]

where \( P \) is the potential catch (in t·year⁻¹, estimated as the mean of several years with the highest catch); \( PP \) is the annual

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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 1 to 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) might benefit from the large-scale redistribution of fish species, while low-latitude, tropical countries would 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.

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...a few high latitude countries (e.g., Norway, Iceland) might benefit from the large scale redistribution of fish species... while low latitude, tropical countries would suffer declines of 10-30% in their catch potential.

![Change in catch potential](image)

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 ocean oxygen distribution in, and acidification, of the oceans, and hence represent an optimistic scenario (see text).
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.

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.

References
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. 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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While taking a course in marine resource law, I became very intrigued with the concept of an ocean ‘commons’, and the idea that there could still be areas of the sea essentially unowned by people. What happens to the resources in these areas? Who is responsible for them? Comprising about 60% of the ocean’s surface, the high seas are often left out of the global fisheries discussion.

This is what led me to my thesis topic: the effectiveness of global regional fisheries management organizations on the high seas. Regional fisheries management organizations, RFMOs, are currently the only fishery bodies mandated to manage and conserve the fish resources in the high seas (United Nations 1995). Currently, RFMOs cover the majority of the global oceans (Figure 1). Through increased management, RFMOs are touted as being part of the solution to overfishing; thus calls to increase their numbers have been made, and as a result, more are slated to come into existence soon.

Yet while we continue to blanket the seas with RFMOs, the question of whether or not these management bodies are even effective remains unanswered.

I conducted a two-part study. The first part examined the state of RFMOs in theory, i.e., how well they did when compared to guidelines (see Lodge et al., 2007). The second part examined the effectiveness of RFMOs in practice, i.e., how well they scored in relation to the status of the stocks which they manage.

The average score across RFMOs in the first part of the study was 57%: the majority of RFMOs fail to meet the best-practices requirements. Scores were particularly low regarding schemes to promote compliance. The results of the second part of the study were even more shocking: two-thirds of the stocks examined under RFMO management were either depleted or overexploited, which matches with FAO’s current estimate (FAO 2009). These results show that high seas stocks are worse off than those within EEZs, and with a much shorter fishing history, too. The RFMOs scored predictably worse in this half of the study, averaging 49%.

There appeared to be no correlation between how RFMOs scored in the first assessment, and how they scored in the second; in other words, what an RFMO says it’s doing does not necessarily reflect what is actually happening in the sea.

My study concluded that RFMOs face many organizational problems which can account in part for their low scores, but generally, the most pressing concern is our failure to accept...
that the ‘Freedom of the Seas’ exists no longer. “First, the principle of freedom of fishing could be retired from the pantheon of fundamental principles. Indeed, the continued articulation of the principle is both inaccurate and misleading, if not downright disingenuous” (Rayfuse 2007). And because we don’t accept this, we continue to treat the high seas like a global commons. Flags of convenience, IUU, and high rates of bycatch are all rampant on the high seas, illegal acts aided easily by their immensity and unmonitored state.

Until we succeed in giving RFMOs both full responsibility and accountability for managing and conserving fish in the high seas, their state- and that of the fish- can only be expected to get worse.

These findings will soon be submitted to a journal. Yet while valuable, they are overwhelmingly depressing. It’s a strange feeling: part triumphant at finishing one’s degree, part despair upon realizing just how bad it is for the oceans.

Ah, the ups and downs; they definitely get one’s blood flowing.

Thankfully, there were other, more uplifting parts of my time at the Fisheries Centre. Like what it’s like to be at the epicentre of cutting-edge global fisheries research, or to exchange ideas with an incredibly diverse and competent international group of people. Or to have conversations with the leading minds in fisheries science...

and sometimes, even to disagree with them. Or to shrink in one’s seat in a classroom, surrounded by professors, post-docs, and students, all people of imposing analytical capacity. Or to collect an eminent scientist at the airport because she is scheduled to give a lecture at your institution- a scientist who will soon go on to work for the Obama Administration, becoming the first female in history to head NOAA. Or to have your hero write to you because he read an article you wrote in FishBytes. Or, to have the freedom to do science while acting on the responsibility we have as scientists and as citizens.

My time at the Fisheries Centre has been replete with opportunities and intellectual stimulation (and exhaustion). These things have all made my three years here matchless in scope, and very, very full. For all this, I am grateful and proud. Thanks to all who have been part of it.

References


Notes
1 ‘Tiny’ being relative: the topics of theses supervised in the context of the Sea Around Us Project, being global in scope, are notoriously ambitious!
2 For a list of current and future RFMOs, see www.fao.org/fishery/rfb/search.
3 Unlike coastal fisheries, high seas fishing only really began in the 1950s.
4 Dr Jane Lubchenco gave a FISH 500 seminar at the Fisheries Centre as part of the lecture series in March 2008, exactly a year before she became administrator of NOAA.
The Upper Gulf of California (UGC) is Mexico's most important fishing ground (Acosta, 2008). The bulk of the fisheries since the 1930s have targeted shrimp. Two sectors coexist: an artisanal and a commercial shrimp fishery. The latter use trawlers, while the former uses a multitude of small boats or ‘pangas’, with a length of less than 7.5 m and an outboard motor. The gear used to catch shrimp is a gillnet or ‘chinchorro de linea’, forming a curtain in the water column. This generates huge bycatch, including of protected species, for example the giant croaker Totoaba macdonaldi, as well as marine turtles.

Thus, this fishery is viewed as a major cause for the decline of Phocoena sinus, or ‘vaquita’ (literally: ‘little cow’), a small endemic porpoise whose low population (of about 400 individuals) suffers an anthropogenic mortality of 40-80 individuals per year (WWF, 2006).

A number of Mexican and international agencies are attempting to mitigate this problem. Among the former, the Escuela Nacional de Ingeniería Pesquera (Universidad Autónoma de Nayarit) runs, jointly with the Comisión Nacional de Acuacultura y Pesca, a project to evaluate the possibility of converting pangas from using gill nets to using modified trawls equipped with fish-excluding devices, which would reduce or eliminate the vaquita and other bycatch.

Fishing tests performed in the buffer zone of the biosphere reserve that is part of the UGC (including the delta of the Colorado) were encouraging. Consecutive 30-minute hauls were performed in areas selected by fishers, with and without modified gear, and catch samples were obtained which were then separated into the shrimp catch and bycatch species (CONAPESCA, 2009). The main result: the modified gear catch generates less bycatch, and if widely adopted, would reduce the threat to vaquita, totoaba and marine turtles.

References
CONAPESCA. 2009. Realiza CONAPESCA reunión sobre pesca responsable y protección de la vaquita marina [www.conapesca.sagarpa.gob.mx/wb/cona/06_de_julio_de_2009_mazatlan_sin1]

Note
1 In 2009 Ms Bucio, from Universidad Autónoma in Mexico, spent July and August as a volunteer with the Sea Around Us Project.

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Sea Around Us newsletter print version will cease

In 2010, the Sea Around Us and FishBytes newsletters will be going fully electronic. We want to thank all of our readers for their continued support over the years. We request that those readers who are receiving hard copy versions of our Sea Around Us newsletter kindly email the editor, at SeaNotes@fisheries.ubc.ca, with their electronic address, and their preference to receive url or pdf mailing. Having a fully electronic format will help us to be more sustainable by reducing our reliance on paper, and will allow us to use colour for visual aids to communicate with our readers, such as the use of photos and graphs. We appreciate your cooperation and patience as we make this transition. We hope you will continue to read and enjoy our newsletters!