Chapter 4

Dealing with uncertainty – implications for fisheries adaptation

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This chapter discusses uncertainties related to the impacts of climate change on marine social-ecological systems, with a focus on the management and governance challenges in helping fisheries to adapt.

Four types of uncertainty are identified, relating to observations, models, processes, and the development and implementation of policies. Observation uncertainty occurs due to natural variability and difficulties in making accurate observations. Model uncertainty is due to wrong or incomplete processes being included in the model and to a lack of knowledge of model parameter values. Process uncertainty results from a lack of knowledge of how the system is structured and how it functions and, in the case of social-ecological systems, includes uncertainty over human behavioural responses. Policy uncertainty recognises that policies are not applied perfectly, may be inappropriate for the given situation, and includes difficulties in communicating amongst stakeholders and policy makers.

Expected impacts of climate change on marine ecosystems include changes in species' distributions, changes in their abundance and resulting community compositions, and changes in ecosystem productivity. While global-scale projections of these impacts can be made, their details, in particular at regional and local scales, are highly uncertain, yet people interact with marine systems at these regional and local scales. Human fishery systems already have a number of strategies for adapting to variability and uncertainty in marine ecosystems, including intensification of effort, diversification of species, capacity building, restructuring, and community closure.

Climate change is an additional stress on social-ecological systems, one which may push these systems beyond their "normal" range of variability. This chapter provides fisheries policy makers with recommendations for addressing uncertainty in the marine social-ecological systems.

Introduction

Ocean ecosystems and the people who interact with them for their livelihoods form coupled marine social-ecological systems (Berkes and Folke, 1998). These are complex adaptive systems with feed-back relationships between the biophysical subsystem (also called the "natural" ecosystem) and the human social subsystem (including cultural, management, economic, socio-political, and ethical aspects). They embody an integrated humans-in-nature concept in which the delineation between the two subsystems is artificial (Berkes, in press). Such systems have always responded to changes in both subsystems (*e.g.* Perry *et al.*, 2010a), for example due to environmental variability and the more recent impacts of globalisation (*e.g.* Taylor *et al.*, 2007), but now these systems are faced with the additional uncertainties related to climate change (*e.g.* Daw *et al.*, 2009). This paper discusses uncertainties associated with the impacts of climate change on marine social-ecological systems, with a focus on the issues of adaptation by fisheries.

Types of uncertainty

Uncertainty related to environmental variability and climate change predictions can be separated into four main types:

- *Observation uncertainty* implies that the current state of the system is not completely known. This is due to natural variability on a variety of time and space scales, and to difficulties in making accurate observations.
- *Model uncertainty* recognises that the present models, and modelling capacities, are not perfect. Models may contain incomplete, or wrong, systems and components, or they may miss important components entirely. In addition, there is almost always a lack of knowledge of parameter values and their statistical uncertainties.
- *Process uncertainty* represents a lack of knowledge and understanding of how the system is structured and how it functions and, in particular for marine social-ecological systems, includes a lack of understanding of the interacting effects of multiple drivers of change and human behavioural responses.
- *Policy uncertainty*, in which polices are not applied perfectly or may not be appropriate for the current situation. This can include uncertainty over how the current situation and policies are communicated amongst stakeholders and decision makers (R. Peterman, Simon Fraser University, Burnaby, BC, pers. comm.).

There is a large and growing literature on the potential impacts of climate change to coupled marine social-ecological systems (e.g. Cochrane *et al.*, 2009; Perry and Ommer, 2010). In general, these impacts can be summarised under three topics:

- Changes in species' distributions. As ocean conditions change, and in particular as sea temperatures warm, species are expected to shift their distributions so as to maintain their optimal "adapted" thermal range. Such changes have been observed (Perry *et al.*, 2005) which have good physiological explanations (Pörtner and Knust, 2007). One model of potential range shifts on a global basis predicts average relocations of 600 km for pelagic species and 200 km for demersal species, with 83% of these moving poleward (Cheung *et al*., 2009).

- Changes in species' abundances. The abundances of species in any particular location or ecosystem are expected to change due to shifts in their distributions, to environmental conditions exceeding physiological limits, and to changes in recruitment (Barange and Perry, 2009). Due to the multiple and interacting factors which control the recruitment to marine populations, such changes can be difficult to predict, including even the direction (increasing or decreasing recruitment, and therefore whether abundances will go up or down with climate change).
- Changes in the productivity of marine systems. This is one of the most difficult of the potential climate changes to predict, because it depends on a number of poorly understood processes such as controls on vertical stratification, nutrient supply, etc. (Barange and Perry, 2009). In general, the expectation is for marine ecosystem productivity to decrease at low latitudes and to increase at higher latitudes (Sarmiento *et al*., 2004; Polovina *et al*., 2008). The responses of wind-driven upwelling systems, which provide a large fraction of the global commercial fish yield, to climate change is particularly uncertain (Barange and Perry, 2009).

There are several factors which complicate the predictions of climate change impacts on marine systems, inducing large uncertainties. These include the downscaling of predictions made at the global scale to their detailed impacts at regional and local scales, and it is these latter spatial scales at which people interact with marine ecosystems. The uncertainties relating to downscaling include the specific effects of winds and how they interact with coastal topography, which have important influences on vertical stratification, nutrient inputs, and circulation patterns; the effects of non-linearities in the system in which, for example, the positive influences of winds on ocean productivity are maximised at some intermediate wind speed (Cury and Roy, 1989); and the potential for threshold effects, in which an apparently small change can push the system from one state to another (e.g. deYoung *et al*., 2008). As noted above, marine communities will be pulled apart and reformed into new communities as a result of different horizontal range shifts, rather than simply being displaced geographically as intact assemblages (e.g. Mueter and Litzow, 2008). Changes in seasonality are also expected, for example the timing of spawning or the peak in biomass of a key species in the ecosystem, which can create mismatches with the timing of dependent species (e.g. Mackas *et al*., 1998). Significant uncertainties in predicting the responses of marine ecosystems to climate changes are created by human actions such as fishing and habitat loss (Perry *et al*., 2010b). These activities can shorten the life spans of species and can cause the loss of sub-populations and genetic diversity, all of which decreases the adaptive capacities of these ecosystems to climate change (Perry *et al*., 2010b; Schindler *et al*., 2010). The strong implication is that marine ecosystems which are heavily exploited will not respond to climate variability and change as they did in the past (Perry *et al*., 2010b). The results of these factors, cumulatively, are increased model and process uncertainties.

Since these are coupled social-ecological systems, it is important to recognise that human drivers of change can also have significant direct and indirect impacts. Direct human impacts include fishing, habitat degradation, contaminants, introductions of exotic species and mineral extractions. Indirect human impacts can be generated by demographic changes (for example, an increase in retired people who drive an increase in recreational fishing), economic changes (for example where fishing may be considered as a livelihood of last resort), market and trade changes (e.g. marine certification programs, Thrane *et al*., 2009), policy changes, and societal and international agreements (Perry *et al.*, 2010a). The interactions of these factors with "natural" ecosystem drivers of change such as climate create significant uncertainties of how climate change will be manifest at local spatial scales, and how fishing systems will respond.

How do human fishing systems respond to marine ecosystem variability?

Human social systems have developed several mechanisms to deal with variability and uncertainty within their "normal" range of experience, and to adapt to variability beyond their "normal" experience (Smit and Wandel, 2006; Perry *et al.*, 2010a). Coping strategies at shorter time scales and in response to "normal" variability include intensifying effort (*e.g.* to find the few fish that remain); diversifying effort to other gears and species; migrating to follow the distributional changes of the fish; and "hibernation", in which families rely on relatives or the state for support until conditions improve (Perry *et al.*, 2010a). If the change in the marine ecosystem persists or is large (such as a catastrophic collapse of a key stock), then uncertainty is increased because it may represent conditions not previously experienced, which forces the human social system to implement more significant adapting strategies. These include political actions to obtain more support from the state; education and retraining to update skills or for new opportunities; restructuring to reduce reliance on fisheries and marine products; and ultimately, if the collapse continues with no relief or alternative prospects in sight, abandonment of the community (Perry *et al.*, 2010a).

Quinoñes (2010; see also Leal *et al.*, in press) provides an example of the potential consequences of increased scientific uncertainty relating to climate change and fisheries. The jack mackerel (*Trachurus symmetricus murphyi*) stock in the south-east Pacific spawns far offshore of the coast of Chile. In 1997, juveniles dominated the catches, and major uncertainty arose as to whether the signs of stock decline were a result of overfishing or major changes in distribution of the stock due to the strong *El Niño* of 1997-98. In 2001, the Chilean government proposed major cuts in quota, triggering significant social disruption including riots in the streets. The differing scientific views as to the causes of the stock changes contributed to the social unrest (Quinoñes, 2010). This "jack mackerel" crisis, as it became known, was ultimately resolved by formation of a high-level government scientific panel to reach agreement on the abundance versus distribution debate, agreement on the necessary cuts in fishing capacity, and required flexibility in the responses by all sectors (Quinoñes, 2010).

Dealing with uncertainty in marine social-ecological systems

The key point to remember when considering the potential impacts of climate change on coupled marine social-ecological systems is that uncertainty is inherent. Climate change impacts include the current issues of observation, model, process and policy uncertainties, but will go beyond to produce, in many cases, situations for which past ("normal") experience is no longer a guide to future expectations. The question, then, is how are such coupled systems to deal with uncertainty that may go beyond their previous experience? Rather than building a system which is tuned to respond to *predicted* changes, it will be more important, and likely more practical, to enhance the existing capacities of marine social-ecological systems to adjust to variability and uncertainty, regardless of the cause.

This will require enhancing the adaptive capacities of both the human social *and* biophysical subsystems. Much of this existing adaptive capacity, of course, will be based on the conditions which human communities have experienced in the past, and how they have responded. Hamilton (2007) provides an example from Iceland in which one community thrived when fish distributions and abundances changed, because it had developed a broad-based fish catching and processing capability, whereas another community struggled when its primary species declined.

There are several policy options for enhancing the natural adaptive capacities of biophysical subsystems. These include reducing the overall fishing pressure, which would reduce one of the important factors that interact with climate change (Brander, 2008). In addition to reducing fishing pressure overall, an effort should be made to move away from a focus on biomass and to include maintaining the age distribution and life span similar to that of the unfished population as well as maintaining the diversity of sub-populations (Perry *et al.*, 2010b). A better match must be made to adapt fishing and stock rebuilding plans to the productivity conditions, including being alert for new fishing opportunities that may arise from changes in distributions.

There are several policy options for enhancing the adaptive capacities of human social systems to marine ecosystem changes. Many of these will also serve to enhance the capacities to adapt to changes in other sectors of human social systems, since climate change is expected to have multi-sector impacts (*e.g.* to agriculture and forestry). Policies to enhance human social system adaptations to climate change include adopting a livelihoods approach, in which fishing is one of several ways for people to obtain a living (Allison and Ellis, 2001). Such an approach is common among traditional fishing societies (*e.g.* Kalikoski *et al.*, 2010; Cinner *et al.*, 2009) but can also occur in unexpected ways, as for example in Ghana where an increase in the poaching of bushmeat from coastal national parks was observed concurrent with declines in coastal fishing opportunities (Brashares *et al.*, 2004). It is also important to recognise that current policies, for example specific management targets (*e.g.* limit and target reference points), which have been developed from time series during previous conditions, may not be appropriate for the new conditions with climate change. In addition, policies such as subsidies for fishing may retard a fishery from recognising that conditions have changed and from adapting to the changes. Increased uncertainty requires increased monitoring and reporting of environmental conditions (*e.g.* UNEP and IOC-UNESCO, 2009), so as to determine how conditions are changing. Increased uncertainty also requires more active, and more rapid, communications with stakeholders so that discussions about potential changes and how to respond can be worked out in advance, and that observations of new conditions and their implications can be communicated promptly. The U.S. National Weather Service is moving towards a process which explicitly includes uncertainties, and uses these uncertainties in a probabilistic context to assist with decision making (Table 4.1).

Table 4.1. Process proposed for use by the U.S. National Weather Service for explicit consideration of uncertainties in weather forecasts

“Old” paradigm	**“New” paradigm based on explicit consideration of uncertainties**
Focus only on reducing uncertainty	Focus on reducing and quantifying uncertainty
Single value “most likely” forecast	Most likely value and probabilities of other values
Decisions based only on “most likely” scenario	Decisions based on weighing costs and impacts of each possible scenario
Status quo socio-economic losses due to forecast error	Risk mitigation, socio-economic enhancements due to factor forecast errors into decision making

Source: modified from NOAA, 2009

Additional recommendations for dealing with uncertainty due to climate change include:

- *Observation uncertainty*: invest in monitoring, in particular of the critical components of the full social-ecological system. This means identifying appropriate indicators which include human social and natural ecosystem elements. Good progress is being made in the development of indicators for marine ecosystems (Link, 2005), although similar suites of indicators for human social systems within a marine ecosystem context are not as well developed (*e.g.* St. Martin *et al.*, 2007; deYoung *et al.*, 2008). In addition, statistical modelling could focus on forecasting near-future conditions, rather than making long-term projections for which the errors and uncertainties will compound.
- *Model uncertainty*: develop multiple, and fully coupled social-ecological, models for the same system, preferably with different underlying assumptions and structures. This will lead to an ensemble approach to assessing model predictions, which has proven fruitful for example in the Intergovernmental Panel on Climate Change process (Tebaldi and Knutti, 2007).
- *Process uncertainty*: invest in research to improve understanding of critical processes (and which processes are critical), to identify highly sensitive components and connections, and to identify important processes which are not included in the models.
- *Policy uncertainty*: invest in policy planning with stakeholders regarding how to respond to changes when they happen, monitor the implementation of the policies to ascertain if they are working as desired, and conduct periodic reviews as to whether the policy is still appropriate. Institutional changes may be needed to facilitate rapid responses, including increased flexibility regarding locations and species fished and an ability to alter management plans quickly as information is updated. Learning how to make decisions with reduced knowledge and greater uncertainty is a part of this process, but it must be recognised that each sector in fisheries, from fish catching, to processing, management, and investments (*e.g.* banks) will put their own interpretations on uncertainty relating to climate change, which can lead to conflicting goals (*e.g.* Broad, 2003).

Conclusions

Climate change is but one of many drivers of change in marine social-ecological systems. Fisheries systems have capacities to adapt to uncertainties due to environmental and human variability, which can be enhanced or suppressed by management and policy actions. It is important, therefore, to recognise the inherent uncertainties of observations, models, the underlying processes, and the application of policies. This will require a process of decision making under uncertainty. No matter how good the predictions, however, there will always be uncertainties and, consequently, "surprises". What is needed is to build and enhance the capacities of both the "natural" and human social systems which support adaptation to uncertainty and surprises.

Acknowledgments

This paper is derived from the work of the Global Ocean Ecosystem Dynamics (GLOBEC) program, which is a core program of the International Geosphere-Biosphere Program (IGBP), the Scientific Committee on Oceanic Research (SCOR), and the Intergovernmental Oceanographic Commission of the United Nations (IOC). I also wish to thank specifically Rosemary Ommer, Manuel Barange, and Cisco Werner for their close collaborations and discussions on these and related topics over many years. Finally, I thank the OECD Committee for Fisheries for the invitation to present this paper at the workshop on "The Economics of Adapting Fisheries to Climate Change", held in Busan, Korea, 10-11 June 2010.

Bibliography

Allison E. and F. Ellis (2001), “The Livelihoods Approach and Management of Small-Scale Fisheries”, *Marine Policy*, 25, pp. 377-388.

Barange, M. and R.I. Perry (2009), “Physical and Ecological Impacts of Climate Change Relevant to Marine and Inland Capture Fisheries and Aquaculture”, in K. Cochrane, C. De Young, D. Soto and T. Bahri (eds.), *Climate Change Implications for Fisheries and Aquaculture. Overview of Current Scientific Knowledge*. FAO Fisheries and Aquaculture Technical Paper, No. 530, FAO (Food and Agriculture Organization), pp. 7 – 106.

Berkes, F. (in press), “Marine Social-Ecological Systems”, in R.E. Ommer, R.I. Perry, P. Cury and K.. Cochrane (eds.), *World Fisheries: a Social-Ecological Analysis*, Fish and Aquatic Resources Series, Wiley-Blackwells, Oxford.

Berkes, F. and C. Folke, C. (eds.) (1998), *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*, Cambridge University Press, Cambridge, UK.

Brander, K. (2008), “Tackling the Old Familiar Problems of Pollution, Habitat Alteration and Overfishing will Help with Adapting to Climate Change”, *Marine Pollution Bulletin*, 56, pp. 1957–1958.

Brashares, J.S., *et al.* (2004), “Bushmeat Hunting, Wildlife Declines, and Fish Supply in West Africa”, *Science*, 306, pp. 1180-1183.

Broad, K. (2003), “Biological and Societal Impacts of Climate Variability: An Example from Peruvian Fisheries”, in T.D. Thomas and B.R. Colman (eds.), *Handbook of Weather, Climate, and Water: Atmospheric Chemistry, Hydrology, and Societal Impacts*, John Wiley and Sons, pp. 817-832.

Cheung, W.W.L., *et al.* (2009), “Large-Scale Redistribution of Maximum Fisheries Catch Potential in the Global Ocean Under Climate Change”, *Global Change Biology*, 16(1), pp. 24-35, doi: 10.1111/j.1365-2486.2009.01995.x.

Cinner, J., M. Fuentes and H. Randriamahazo (2009), “Exploring Social Resilience in Madagascar’s Marine Protected Areas”, *Ecology and Society,* 14(1): 41, www.ecologyandsociety.org/vol14/iss1/art41/.

Cochrane, K., C. De Young, D. Soto and T. Bahri (eds.) (2009), *Climate Change Implications for Fisheries and Aquaculture. Overview of Current Scientific Knowledge*, FAO Fisheries and Aquaculture Technical Paper, No. 530, FAO, Rome.

Cury, P. and C. Roy (1989), “Optimal Environmental Window and Pelagic Fish Recruitment Success in Upwelling Areas”, *Canadian Journal of Fisheries and Aquatic Sciences*, 46, pp. 670-680.

Daw, T., W.N. Adger, K. Brown and M.-C. Badjeck (2009), “Climate Change and Capture Fisheries: Potential Impacts, Adaptation and Mitigation”, in K, Cochrane, C. De Young, D. Soto and T. Bahri (eds.), *Climate Change Implications for Fisheries and Aquaculture. Overview of Current Scientific Knowledge*, FAO Fisheries and Aquaculture Technical Paper, No. 530, FAO, Rome pp. 107-150.

deYoung, B. *et al.* (2008), "Regime Shifts in Marine Ecosystems: Detection, Prediction and Management", *Trends in Ecology and Evolution*, 23, pp. 402-409.

Hamilton, L.C. (2007), "Climate, Fishery and Society Interactions: Observations from the North Atlantic", *Deep-Sea Research II*, 54, pp. 2958–2969.

Leal, C.P., R.A. Quiñones, R.A and C. Chávez (in press), "What Factors Affect the Decision Making Process When Setting TACs?: The Case of Chilean Fisheries", *Marine Policy*, 34(6),doi: 10.1016/j.marpol.2010.04.002.

Link, J.S. (2005), "Translating Ecosystem Indicators into Decision Criteria", *ICES Journal of Marine Science*, 62, pp. 569-576.

Mackas, D.L., R. Goldblatt and A.G. Lewis (1998), Interdecadal Variation in Developmental Timing of *Neocalanus plumchrus* Populations at OSP in the Subarctic North Pacific", *Canadian Journal of Fisheries and Aquatic Sciences*, 55, pp. 1878–1893.

Mueter, F. J. and M.A. Litzow (2008), "Sea Ice Retreat Alters the Biogeography of the Bering Sea Continental Shelf", *Ecological Applications*, 18, pp. 309-320.

NOAA (National Oceanic and Atmospheric Administration) (2009), *State of the Science Fact Sheet: Weather Forecast Uncertainty,* NOAA, US Department of Commerce, 2pp www.nrc.noaa.gov/plans_docs/2010/ForecastUncertainty_StateofScience_12_22_09_fin.pdf.

Perry, A.L., P.J. Low, J.R. Ellis and J.D. Reynolds (2005), "Climate Change and Distribution Shifts in Marine Species", *Science*, 308, pp. 1912-1915.

Perry, R.I. and R.E. Ommer (2010), "Introduction: Coping with Global Change in Marine Social-Ecological Systems", *Marine Policy*, 34 pp. 739-741.

Perry, R.I., *et al.* (2010a), "Interactions Between Changes in Marine Ecosystems and Human Communities", in M. Barange, J. Field, R. Harris, E. Hofmann, R.I. Perry and C. Werner (eds.), *Marine Ecosystems and Global Change*, Oxford University Press, Oxford, pp. 221-251.

Perry, R.I., *et al.* (2010b), "Sensitivity of Marine Systems to Climate and Fishing: Concepts, Issues and Management Responses", *Journal of Marine Systems*, 79, pp. 427-435.

Polovina, J.J., E.A. Howell and M. Abecassis (2008), "Ocean's Least Productive Waters are Expanding", *Geophysical Research Letters*, 35: L03618.

Pörtner, H.O. and R. Knust (2007), "Climate Change Affects Marine Fishes Through the Oxygen Limitation of Thermal Tolerance", *Science,* 315, pp. 95-97.

Quinoñes, R.A. (2010), "Box 8.3. Social Adaptive Responses: The Case of the Jack Mackerel Fishery off Central-Southern Chile", in M. Barange, J. Field, R. Harris, E. Hofmann, R.I. Perry and C. Werner (eds.), *Marine Ecosystems and Global Change*, Oxford University Press, Oxford, pp. 237-239.

Sarmiento, J.L., *et al.* (2004), "Response of Ocean Ecosystems to Climate Warming", *Global Biogeochemical Cycles,* 18, GB3003, doi: 10.1029/2003GB002134.

Schindler, D.E., *et al.* (2010), "Population Diversity and the Portfolio Effect in an Exploited Species", *Nature*, 465, pp. 609-612.

Smit, B. and J. Wandel (2006), "Adaptation, Adaptive Capacity and Vulnerability", *Global Environmental Change*, 16, pp. 282–292.

St. Martin, K., *et al.* (2007), "Communities, Knowledge, and Fisheries of the Future", *International Journal of Global Environmental Issues*, 7, pp. 221-239.

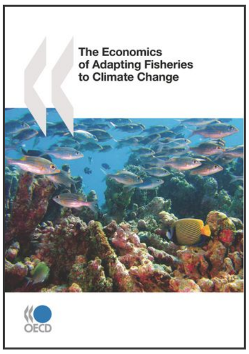
Taylor, W.W., *et al.* (2007), "Globalization: Implications for Fish, Fisheries, and their Management", in W.W. Taylor, M.G. Schechter and L.G. Wolfson (eds.), *Globalization: Effects on Fisheries Resources*, Cambridge University Press, Cambridge, pp. 21-45.

Tebaldi, C. and R. Knutti (2007), "The Use of the Multi-Model Ensemble in Probabilistic Climate Projections", *Philosphical Transactions of the Royal Society A*, 365(1857), pp. 2053-2075.

Thrane, M., F. Ziegler and U. Sonesson (2009), "Eco-Labelling of Wild-Caught Seafood Products", *Journal of Cleaner Production*, 17, pp. 416-423.

UNEP (United Nations Environment Programme) and IOC-UNESCO (Intergovernmental Oceanographic Commission) (2009) *An Assessment of Assessments, Findings of the Group of Experts. Start-Up Phase of a Regular Process for Global Reporting and Assessment of the State of the Marine Environment Including Socio-Economic Aspects*, UNEP, ISBN 978-92-807-2976-4.

Young, C. De, A. Charles and A. Hjort (2008), "Human Dimensions of the Ecosystem Approach to Fisheries: an Overview of Context, Concepts, Tools and Methods", *FAO Fisheries Technical Paper*, No. 489, FAO, Rome, 152pp.



The Economics of Adapting Fisheries to Climate Change

Perry, R. Ian (2011), “Dealing with uncertainty – implications for fisheries adaptation”, in OECD, *The Economics of Adapting Fisheries to Climate Change*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264090415-7-en