Chapter 6

Is the current fisheries management toolbox sufficient to address climate change?

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This report is presented in response to the request by the Fisheries Committee of the OECD as a submission to the international workshop on "The Economics of Adapting Fisheries to Climate Change" to be hosted the OECD Committee for Fisheries and the Fisheries Policies Division and held on June 10-11, 2010 in Busan, Korea. The workshop addresses what fisheries policy makers should do in order to develop adaptive and flexible fisheries management regimes to the changing climate and help the transition of fishing industries and communities.

This paper examines current fisheries and aquaculture management methods and their strengths and weaknesses, successes and failures with dealing with the potential risks and pressures posed by climate change. The paper also addresses how fisheries management deals with uncertainty in planning fisheries management strategies and examines management responses to climate change threats and impacts. Finally, the paper discusses fisheries management methods alignment to adapt to pending climate change.

The paper concludes that what is required is an evolving, responsible, and resilient fisheries management system that establishes a contextual and participatory governance framework characterised by flexible, and adaptive operational and strategic decision making. Decision support tools featuring operational targets and decision rules are presented to illustrate adaptive fisheries management.

Introduction

Signs of the changing climate are increasingly visible and the trends are undeniable. Rising temperatures are melting polar ice and together with thermal expansion of water are contributing to sea level rise, changing precipitation patterns, more frequent intense weather events, storm surges and flooding, coastal erosion, increased sedimentation of coastal waters, and pollution from flooded or destroyed infrastructure and storm runoff (IPCC 2007a, 2007b; IISD, n.d.; FAO, 2007; UNEP, 2008).

In capture fisheries and aquaculture, climate change impacts are evident by changes in the aquatic ecosystem, including swings in primary productivity, species interactions and predator-prey relationships, spatial and abundance shifts in stock distribution through changes in recruitment, growth rate and natural mortality rates. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change States that with "high confidence" changes will occur in marine biological systems due to rising water temperatures affecting shifts in pelagic algae and other plankton, and fish abundance in high latitudes (IPCC, 2007a). Migratory patterns of stocks are expected to alter due to modified seasonality of marine and freshwater systems. Traditional fisheries and fisheries management in this shifting system need to be similarly adjusted thereby incurring increasing costs for administration, science, monitoring and observation systems as well as rising uncertainty and input costs to the commercial fisheries. These aggregate changes as a result of the changing climate are expected to increase in intensity in the coming decades of the 21st century (Grafton, 2009; FAO, 2008a, 2008b, 2007b).

As is noted in the *State of Fisheries and Aquaculture* report for 2008, increasing energy and food prices as well as the threat from climate change mean that

The conditions for capture fisheries and aquaculture are changing. That said, the combined effects of rising prices and climate change are complex, and they affect a very large number of fisheries and aquaculture operations in a mosaic of natural, social and economic contexts. Hence, it is too early to have a clear understanding of the cumulative impact worldwide on fisheries and aquaculture. (FAO, 2009, foreword)

Considerable analysis had been done to analyse the potential impacts on fisheries and aquaculture systems due to pending climate change. Studies include:

- PICES International Symposium on Climate Change Effects on Fish and Fisheries*:* Forecasting Impacts, Assessing Ecosystem Responses, and Evaluating Management Strategies, April 25-29, 2010, Sendai, Japan.
- U.S. National Research Council of the National Academies of Sciences Report on *America's Climate Choices* (May 19, 2010 release), Washington DC.
- Special Issue of the *Journal of Marine Systems* on the Impact of climate variability on marine ecosystems: A comparative approach, February 2010, Volume 79.
- Royal Swedish Academy of Agriculture and Forestry Report on *Fisheries, Sustainability, and Development*, October 13, 2009.
- North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) program, Bering Sea Ecosystem Study (BEST), Northeast Pacific Program (NEP), June 2009 involving PICES, USA, Korea.

- The Institute of Public Works Engineering Australia (IPWEA) National Conference on Climate Change: *Responding to Sea Level Rise*, IPWEA (2008), Coffs Harbour, New South Wales, 3-5th August 2008.

- U.S. Global Ocean Ecosystem Dynamics Program (GLOBEC) and GLOBEC International, Integrating Climate and Ecosystem Dynamics in the Southern Ocean, July 2008.

- High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy at FAO headquarters in Rome from 3 to 5 June 2008 and the Expert Panel 7-9 April 2008.

- PICES 2008 Workshop, Forecasting Climate Impacts on Future Production of Commercially Exploited Fish and Shellfish on July 19–20, 2007, in Seattle, USA.

- The Fourth Assessment of the Intergovernmental Panel on Climate Change, AR4, (IPCC, 2007a, 2007b); AR5 pending release (IPCC, 2013).

Despite this extensive body of mainly scientific work, uncertainties persist and implications have not been made yet at the local, operational level for managing fisheries. Coastal communities, for example, have not developed effective means to mobilise people, institutions, and commercial enterprises – notably the fisheries and aquaculture sector – to prepare for warming, increased storm frequency and sea level rise in order to adapt to the pending changes and impacts to the coastal zone and production.

Fisheries management plays a crucial role in adapting fisheries and aquaculture to the changing climate of coastal communities. Effective fisheries management systems are characterised as being adaptive, flexible, and participatory. Effective fisheries management decision making under uncertainty is based on precautionary and whole ecosystem approaches to problem solving taking into account multiple stakeholders and the multiple criteria of ecosystem, social, economic and administrative consequences. The challenge of developing and assessing policy options and operationalising strategies represents the real challenge for adaptive fisheries and aquaculture management at the local community, regional, and national levels.

Against this background, the OECD Committee for Fisheries and the Fisheries Policies Division presented the international workshop on "The Economics of Adapting Fisheries to Climate Change" to address what fisheries policy makers should do in order to develop adaptive and flexible fisheries management regimes and help the transition of fishing and aquaculture industries and coastal communities.

This paper addresses the question of whether the current fisheries management toolbox is sufficient to address climate change. The paper discusses the elements and the strengths and weaknesses of the current fisheries management toolbox in terms of dealing with potential additional risks and pressures posed by climate change. This discussion is followed by a consideration of the impacts on fisheries and aquaculture that are expected from the suite of changes to the climate including increased frequency of severe events in the short-term, and reduced longer-term productivity of aquatic ecosystems (FAO, 2008). The responsiveness of the current management systems to the climate change impacts is examined.

While the paper confirms the more theoretical capabilities of the fisheries management toolbox to respond to climate change, it also notes its operational deficiencies in adapting to change in practice. Finally, the paper offers some thoughts on the transition to adaptive fisheries management including ways and means of dealing with uncertainty in planning fisheries management strategies through evoking intuitive solutions, developing our ecosystem observation and learning processes, clarifying ecosystem objectives, and engaging local communities and stakeholders more directly in the decision making process.

The current fisheries management toolbox

The current fisheries management toolbox includes a range of output and input controls often combined with technical measures in dealing with the different scales of the fishery including commercial, artisanal, and recreational fisheries and aquaculture sectors and the additional risks associated with uncertainty in management. This section presents a summary of the fisheries management toolbox generally used worldwide to apply fisheries management administration and discusses its strengths and weaknesses and its responsiveness to the uncertainty of the pending impacts of climate change.

Characterising the current fisheries management toolbox

The fisheries management system or "toolbox" is characterised by several key elements that define it, including:

1. general objectives of the fisheries management system;
2. management measures (input controls, output controls and technical measures);
3. institutional arrangements, support structures for scale of management and user participation.

Each of these elements is described briefly below.

General objectives of the fisheries management system

Countries' mandates and policy directions for fisheries management systems have typically evolved from a focus on resource development and conservation, expanding over time with varying levels of emphasis on socio-economic dependence and community benefits from fishing and aquaculture operations. The Code of Conduct for Responsible Fisheries (FAO, 1995) highlighted the common theme in its call for responsible and sustainable management of fisheries. Recently, fisheries management objectives are under criticism in regimes experiencing declining fish stocks, falling catches, and the anticipated negative impacts of climate change on the status of our oceans and waters.

Some countries' major legislation and guidelines have attempted to create lasting policy ties between resource conservation, sustainability and wealth generation associated with exploitation by the country's commercial fishery and aquaculture sectors all the while recognising the reality of the inherent conflict between conservation and exploitation. For example, the government of Canada recently embarked on a policy of "Fisheries Renewal" with renewed objectives for the fisheries management system. The renewed statement of the fisheries management objectives is:

- Long term sustainability - By enabling resource users to achieve strong conservation outcomes through risk management frameworks incorporating the ecosystem considerations and precaution.

- Economic prosperity - By aligning fisheries policies and decision-making processes to aim to achieve economic prosperity working with stakeholders throughout the seafood value chain through an Ocean to Plate Approach.

- Improved governance - By increasing stability, transparency and accountability and by promoting shared stewardship with resource users and others with an interest in the resource. (source: DFO website: www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/index-eng.htm. Accessed May 19, 2010).

These objectives are aligned with that of most developed and developing countries. In the European Union, the objective of the Common Fisheries Policy (CFP) is "to provide for sustainable exploitation of living aquatic resources and of aquaculture in the context of sustainable development, taking account of the environmental, economic and social aspects in a balanced manner" (Holden, 1994). As in Canada, recent reform of the CFP also seeks to improve fisheries governance – a common lament given unrealised objectives – through enhanced stakeholder engagement. As stated in the CFP Green paper:

Pollution from industrial and other human activities, and climate change have also contributed to stock decline or lack of fish in some areas. Measures to counteract the effects of these factors on stocks are urgently needed otherwise conservation and management policy for the fishery resources will be constantly undermined. (Commission of the European Communities, 2001, p.10)

In summary, countries' fisheries management systems objectives may be characterised by:

- Ecological sustainability and ecosystem conservation: as expressed in biodiversity goals

- Economic viability and social stability: objectives related to sustainable development and socio-economic support

- Responsibility: shared stewardship and partnership with fisheries system stakeholders

Clearly stated objectives and their realisation in policy have important implications for an effective fisheries management system adapted to climate change.

Management measures

Sutinen's work on the 1994-96 OECD Fisheries Committee work program was presented under the title of "economic aspects of the management of living marine resources" (OECD, 1997). In that work, management instruments are reviewed and assessed with the objective of facilitating appropriate economic analysis useful for fisheries management decision making. Tables 6.1 to 6.4 below summarise the management measures of the fisheries management toolbox in effect for today's commercial marine fisheries and aquaculture systems. Table 6.1 summarises the output, input, and technical measures, while Tables 6.2 through 6.4 focus on controls and measures and their expected and practical consequences.

Input control systems limit access to fisheries and restrict the use of capture devices (gear) in order to conserve exploited resources while attempting to equalise fleet activity through overall or individual vessel fishing effort control. Prior to the 1970s, input controls were prevalent in commercial fisheries, and were applicable nationally and internationally. Fishing effort restrictions began with aggregate measures to limit fleet and vessel numbers through limited licensing programs. Gradually, these measures became more restrictive and more directly applicable to individual fishermen with respect to a limit quota on total fishing effort (*e.g.* days fishing), and on individual vessel's size, weight, configuration, and gear, *e.g.* net size and shape (diamond or square mesh, soak time limits for passive net gear, limit numbers of hooks used).

Output controls restrict the controlled delivery of exploited marine resources on the aggregate capture of whole fleets (*e.g.* total annual or seasonal catches, TACs), on the designated subset of fishing fleets assigned quotas to be shared among themselves (*e.g.* catch shares or community quotas), or on individually licensed vessels or operators (*e.g.* individual quotas either transferable or not transferable among fishing units). Historically, output controls were established globally (only since the 1970s) in response to the apparent ineffectiveness of combined input controls and technical measures that had been in place to this point to sustain exploited fish populations. The popular trend in output controls is away from purely aggregate fleet output controls (*e.g.* TACs) and toward more specifically applied output controls to individual vessel operators (*e.g.* individual transferrable quotas [ITQs], or individual vessel quotas [IVQs]). This transition has been identified with enhancing fisheries access and allocation as a property right, and is applied as a consequence of the difficulties and ineffectiveness of controlling only aggregate outputs.

Technical measures define the acceptable limits of captured marine resources both in terms of units captured and their spatial and temporal characteristics. Technical capture regulations may be applicable to the allowable size, sex, space, and time for stock exploitation. In recent years, the definition of spatial-temporal Marine Protected Areas (MPAs) have become a popular technical measure. MPAs often designate "no take" areas, although some MPAs are designed as multi-use zones with defined time-area uses.

Table 6.1. Management measures toolbox

Application target	Input controls	Output controls	Technical measures
Aggregate fleet	1.Total allowable fishing effort limits/limited licences	1. Total allowable (seasonal) catch limits (TACs)	1. No take zones (strict MPAs)
Individual vessel /operator	2. Individual fishing effort quota restrictions	2. Individual operator quotas (IQs), Individual transferable quotas (ITQs), catch shares	2. Time-area closures (multi-use MPAs)
Combined fleet and operator	3. Vessel and gear restrictions	3. Vessel catch limits	3. Output selectivity restrictions (for size and sex)

Source: Adapted from OECD (1997), Table 1, p.13.

Most modern fisheries management systems utilise all of these management measures identified in Table 6.1 as part of their overall application of the modern toolbox for achieving the fisheries and aquaculture system objectives. Table 6.2 below presents details on the input control measures of the toolbox along with the expected and actual (critical) consequences of these controls.

Input controls provided managers with direct fishing effort reduction on vulnerable stock components, particularly juvenile fish. Effort controls promised resource recovery and improved sustainability for the exploited stocks. Individual vessel effort controls were designed to mitigate the fleet's tendency to "race for fish" under a limited global quota regime such as TACs.

In practice input controls were initially effective for limiting licences and the number of vessels and fishermen by restricting direct access to the commercial fisheries. However input controls expressed as operational conditions (*e.g.* the restricted use of gear) proved to be difficult to monitor and enforce in practice. As well, the difficulties of establishing measures and effectiveness of fishing effort became onerous such that the application of input restrictions were easily circumvented and less effective than anticipated. All effort restrictive approaches increase operating costs and reduce efficiencies of production and lower profitability.

Table 6.2. Input controls

Input control	Expected consequences	Practical consequences
1.Total allowable fishing effort limits/limited licences	Direct effort reduction; Resource recovery and improved resource conservation.	• Established licence/vessel number limits while excluding fishermen, and defining barriers to entry and the need for buy-back programs; • Economic inefficiencies, higher costs of production; • Capital stuffing from new and uncontrolled other inputs; • Initial trend in total effort decreases then increase among limited fleet/licence holders; • Difficulty in monitoring and enforcing in operational (real) time conditions and neglected reporting of outputs; • Evidence of discarding and highgrading to assign effort limits to most valuable outputs.
2. Individual fishing effort quota restrictions (transferable or non-transferable)	Direct effort reduction; Resource recovery and improved resource conservation; Mitigates the “race for fish”.	• Problematic setting of effort units and individual limits; • Exclusive fishermen, barriers to entry; buy-back costs; • Economic inefficiencies, higher costs of production; • Improved technology and capital stuffing from new and uncontrolled and combined other inputs; • Difficulty in monitoring and enforcing in (real) time conditions and poor reporting of outputs; • Evidence of discarding and highgrading to assign effort limits to most valuable outputs.
3. Vessel and gear restrictions	Effective effort and catchability reduction; Resource recovery and improved resource conservation and reduced fishing mortality on targeted stocks components.	• Problematic setting of effort units and limit levels; • exclusive fishermen, barriers to entry; buy-back costs; • economic inefficiencies, higher costs of production; • improved technology and capital stuffing from new and uncontrolled and combined other inputs; • difficulty in monitoring and enforcing in operational (real) time conditions poor reporting of outputs; • evidence of discarding and highgrading to assign effort limits to most valuable outputs.

Source: Adapted from OECD (1997), pp.88-100.

In general terms, the input controls of Table 6.2, by themselves, are not sufficient to reduce exploitation and improve stock conservation. Moreover, the absence of focus on output creates an unknown for stock management and assessment. In practice, the expected success of input controls is reduced in isolation with other management measures (output controls and technical measures). As noted previously, to be effective, input controls need to be combined with other measures (output controls, and technical measures).

Table 6.3 below presents details on the output control measures of the toolbox along with the expected and actual (critical) consequences of these controls.

Table 6.3. Output controls

Output control	Expected consequences	Practical consequences
1. Total allowable (seasonal) catch limits (TACs)	Direct limit on aggregate output and fishing mortality; Resource recovery and improved resource conservation.	• Problematic setting of aggregate total; • Difficult to enforce aggregate due to data recording delays; • Unintended season shortening – "race for fish" with over-investment in fishing capital ("capital stuffing"), higher operating costs; • Rent dissipation with free entry and exit; • Safety concerns re "race for fish"; • Market gluts at peak output, unstable supply; • Evidence of highgrading problems.
2. Individual operator quotas (IQs), Individual Transferable quotas (ITQs), catch shares	Direct limit on individual output and fishing mortality; Resource recovery and improved resource conservation; Eliminate "race to fish"; Generates resource rents by removing inefficient input controls.	• Problematic setting of vessel quota allocations (absolute share versus proportion of TAC); • Difficult to enforce individual quota to data recording delays; • Rent dissipation with free entry and exit; • Evidence of highgrading problems; • IQ as property – issues of duration, flexibility, transferability, divisibility; in-season transfers; initial allocation problems; • Difficulties in enforcement and compliance.
3. Vessel catch limits	Direct control on landings /vessel per trip; reduced landings, total fishing effort; smooth landings, effort distribution; eliminate "race to fish"; Control exploitation	• Increased discards and underreporting; • increased enforcement costs due to increased control; • highgrading problems and incentives; • difficulties in enforcement and compliance.

Source: Adapted from OECD (1997), pp.72-88.

In general terms, output controls, by themselves required enhanced monitoring and enforcement. In practice, where these enhanced services were not in place, then the expected success of output controls was reduced. As noted previously, output controls were often used in conjunction with other measures (input controls and technical measures).

Table 6.4 below presents details on the technical measures of the toolbox along with the expected and practical consequences of these controls.

Technical measures were designed to protect sensitive areas from fisheries exploitation by imposing direct closures entirely or in part. Designating whole areas as marine parks or protected areas does not prevent "leakage" of resource units into contiguous grounds. MPAs deflect fishing effort, and do not necessarily eliminate it. Increases in effort outside the MPA may have unforeseen impacts on other parts of the marine space. Similarly, a deflection of selectivity to protect vulnerable segments of the population may create related problems of how the unused effort is misdirected or misreported.

Table 6.4. Technical measures

Input control	Expected consequences	Practical consequences
1. No take zones (strict MPAs)	Eliminate fishing mortality in an area; protect designated marine ecosystem and vulnerable (spawning, juvenile) stock units.	– Fishing effort shifted to adjacent (spill over) areas; – Does not account for transboundary/trans-ecosystem movement; – Increases costs of fishing effort due to space-time restrictions; – Increased misreporting; – increased enforcement costs.
2. Time-area closures (multi-use MPAs)	Protect vulnerable (spawning, juvenile) stock units.	– Increases costs of fishing effort due to space-time restrictions; – Increased misreporting; – Increased enforcement costs.
3. Output selectivity restrictions (for size and sex)	Protect vulnerable (spawning, juvenile) stock units by controlling exploitation.	– Increases costs of fishing effort; – Increased misreporting; – Increased enforcement costs; – Highgrading problems and incentives.

Source: Adapted from OECD (1997), pp.100-111.

In general terms, technical measures taken by themselves do not necessarily achieve their expected consequences. In practice, it is difficult to determine the effectiveness of closed areas, especially considering the impact of displaced fishing effort. However, as with the other management measures, the combination of output controls, input controls, and technical measures can be effective in delivering management objectives and sustainable fisheries and aquaculture.

Institutional arrangements, support structures for scale of management, and user participation

The institutional arrangements in place in the fisheries management system are fundamental to the effective delivery of the toolbox. Ostrom defines an institution as: "simply the set of rules actually used (the working rules or rules-in-use) by a set of individuals to organize repetitive activities that produce outcomes affecting those individuals and potentially affecting others" (Ostrom, 1992). Ostrom's rules are formalised as institutional arrangements. Nielsen and Vedsmand (1995) define specific sets of organisational and institutional arrangements which define government-citizen co-operation and are influenced by:

- scale of management, *e.g.* local (artisanal, recreational), regional (sectors), national, and international participation and characterisation of fisheries
- management measures and the structure of property rights
- user group involvement in decision making

Jentoft and McCay (1995) characterise user participation within the implementation of fisheries management on a spectrum related to the role of governments and the increasing contribution and power of stakeholders. The highest level of government control or top-down hierarchy with minimal user responsibility is denoted as "informational". A "consultative" arrangement formalises user input but does not necessarily commit the responsible government authority to act accordingly. Consultation is seen as a means of demonstrating transparency in government decision making. Finally, the bottom-up approach is designated as "co-management" whereby the government devolves authority for decision making and responsibility to users who are then able to apply traditional and communal rights systems.

Table 6.5 below characterises fisheries management by virtue of the scale of operations, associated management measures and the degree of user participation.

Table 6.5. Management scale, measures and participation

Scale	Measures	User participation	Characterisation
Local (small)	Limited restrictions; few barriers to entry; open access.	User-based but with little management; limited government involvement; minimal government lobbying.	• Manual, simple technology (passive gear), fishing • Limited to local waters; • Low capital requirements (many small boats, artisanal, recreational); • Low cost access (minimal licensing); low returns; • practised mostly by developing countries; • Near-shore marine and inland waters; • Generalist, flexible fleet, many species; • Full and part time, often poor, subsistence income; • Fishing communities remote from government, limited or no scientific information available.
Regional	Limited licences.	Mainly consultative, shared management with fishermen, communities, regional government	• Limited barriers to entry; • Near-shore marine and inland waters; • Generalist, flexible fleet, multiple gear types (fixed and mobile); • Fishing communities linked to regional governments, some but limited scientific capacity.
National	Limited licences; TACs; Effort limits; Individual quotas.	Consultative and informational; national government priority; formalised engagement of stakeholders (ENGOs, industry); organised lobbying.	• Larger vessel, specialised (mobile) fleets, few species; • Industrial, organised sector; • Domestic enforcement; • Mostly marine (often oceanic) waters; • Practised mostly by developed countries; • Mechanised, advanced technology, possess distant water, mobile gear fleet not limited to local waters; • National, government supported scientific capacity.
Inter-national (large)	Limited licences; TACs; effort limits; IQs; Restrictive measures on gear and vessels.	Informational, consultative, formalised engagement of industry toward co-management; professional government lobbying.	• High capital cost; barriers to entry; oligopolistic; • Shared international enforcement (coastal state); • International agreements, e.g. ICAAT, RMFOs (NAFO); • Mostly marine waters; • Practised mostly by developed countries; • Mechanised, advanced technology, possess distant water, mobile gear fleet not limited to local waters; • Homogeneous, specialised fleet, few species; • Full-time, professional fishermen; • Large management bureaucracies, extensive scientific attention and capacity.

Sources: after Berkes *et al.*, 2001; Pauly, 2006; and Baelde, 2007

In general, the smaller the scale of the fisheries or aquaculture operations, the less organised the sector, with little government intervention. Globally, it is estimated that small scale operations use one-tenth less carbon-based fuel than industrialised fisheries. This is combined with low relative catches per unit effort of fishing. The catches are mainly for food as in artisanal fisheries. Globally, small scale fisheries involve tens of millions of people, mainly in developing coastal regions of the world.

At the other end of the scale, fully industrialised international fishing fleets use high levels of fuel in catching approximately ten times the catch volume with 1% of the labour of the small scale fisheries. In comparison with small scale operations, catches per unit fuel use is approximately equal (2-5 tonnes per tonne of fuel). Industrialised fisheries produce for higher valued international markets for food, and bulk quantities for reduction to fishmeal for aquaculture operations (Berkes *et al.*, 2001; Pauly, 2006; Baelde, 2007).

Finally, Table 6.6 identifies the basic (scale independent) set of operational tasks of the fisheries management system and the associated engagement and user participation in these tasks.

Table 6.6. Fisheries management operational tasks and user participation

Fisheries Management Tasks	Discipline	Responsible	User Participation
Stock assessment	Fisheries science	Fisheries scientists	Informational
Fishing access	Fisheries management	Fisheries managers	Consultative
Fishing allocation	Fisheries economics/policy	Fisheries managers	Consultative
Monitoring & enforcement	Fisheries officers	Fisheries managers	Informational
Fisheries policy/ decision making	All	Government leader	Consultative

The history of the fisheries management toolbox has been driven by the apparent inability to maintain resource sustainability over time amid improved fishing technologies and capacity. Over time, management measures have needed to "ratchet up" control by applying further restrictions to fishing inputs in the aggregate, and later to individual fleets sectors and vessels. Input inefficiencies and continued resource problems led to aggregate output controls followed in turn by fleet sector and individual output restrictions, leading finally to specific management measures denoting ultimate restrictions via closed and protected areas. Arguably, to date, the fisheries management toolbox has experimented with the full spectrum of management controls. It is noted that the modern toolbox represents a diversity of management approaches that are most effective when operated jointly and designed specifically and uniquely for the context and fishery in question.

The responsiveness of the modern fisheries management toolbox to address climate change is linked to the basic characteristics of the toolbox, and the ability of governments and users to manipulate these tasks in developing adaptation strategies. The fisheries management toolbox exhibits strengths and weaknesses with regard to dynamic changes in the complex environments in which it operates. These are discussed below.

Strengths

The ability of the fisheries management toolbox to adapt to change in the marine and freshwater systems environment is a function of its informational gathering capabilities, innovation and responsiveness, and its command and control of its user base.

Local knowledge and governance

Regional, national, and international fisheries generally provide clear provision in government-controlled legislation for formal governance mechanisms. The EU RACs, the US Regional Fisheries Management Committees (RFMCs), the Australian Management Advisory Committees (MACs), and the Canadian Fisheries Resource Conservation Council (FRCC) in the Atlantic and Pacific are formal, legitimised structures established as intermediaries to acquire local knowledge. These groups have precipitated well-organised fisheries associations and stakeholder and community groups with platforms to present options to government representatives in the critical issues of accessibility to the fishery and allocations of the resources. These mechanisms, typical of modern fisheries management systems, provide a direct connection from the local community to governments and give the impression of transparency and democracy through consultation. Accordingly, they are meant to provide the means for government decision makers to respond and adapt to the changing environment.

The adoption of the precautionary approach

Since the mid-1990s, fisheries management systems have struggled with dealing with uncertainty in the complex marine and freshwater environments. The FAO has been instrumental in promoting countries to adopt the precautionary approach (PA) as the effective response to uncertainty (FAO, 1995). The PA mantra that "the lack of information is not justification for taking action" is clear and motivating. With regard to climate change, the potential is for the PA to define conservative, risk-averse decision making in the face of potential negative implications of change.

Fisheries and aquaculture carbon footprint

The fisheries management toolbox can be used to improve carbon-based fuel efficiency for the sector as a whole by using management measures to reduce overcapacity and excess effort thereby improving fuel efficiency by promoting specific gears. Support programs for reducing greenhouse gases (GHGs) for new technologies and innovation for fisheries operations and the transport, processing and storage of fish can be developed under suitable management measures from the existing toolbox.

International associations and agreements

Fisheries management is a globally recognised field of study supported in large part by governments and disciplinary associations such as the International Council for the Exploration of the Sea (ICES), the international Code of Conduct for Responsible Fisheries and special studies, notably the OECD work programs of 1994-96 and 1997-2000 (OECD, 1997, 2000). The Code of Conduct for Responsible Fisheries was adopted by the FAO in 1995 (FAO, 1995). Under Section 12 of the code, "Future Research", the code specifically identifies the changing climate as a priority:

> *States should be able to monitor and assess the state of the stocks under their jurisdiction, including the impacts of ecosystem changes resulting from fishing pressure, pollution or habitat alteration. They should also establish the research capacity necessary to assess the effects of climate or environment change on fish stocks and aquatic ecosystems. (Article 12.5, p.32)*

The OECD studies highlighted the objectives of responsible and sustainable management of fisheries in the face of overexploited stocks and noted the need to harmonise efforts with the environment:

> *The main issue in fisheries management is how to restore fish stocks to environmentally, economically and socially sustainable levels. Some countries consider that fisheries management can be improved, under the responsibility of the administration, by the active participation of management bodies and by the use of management instruments that enhance fisher's sense of shared involvement in solutions. For some other countries, co-management frameworks that provide for input from fishers are considered to be valuable by providing improved user right and stewardship over the resource, in addition to being a valuable source of information. However, all aspects of fisheries – from harvesting to marketing to consumers – should be considered in a comprehensive way for a successful transition process to responsible fisheries. In this regard, it would seem that more effort is needed on consulting a broader set of fishing industry stakeholders. (OECD, 1997, p.7)*

In theory, the fisheries management toolbox has been conceived as a flexible and adaptive system to respond to the complex setting of the natural marine and freshwater environments. However, whether the toolbox is capable of meeting its objectives (see above) in practice is an open question. In this regard, weaknesses of the toolbox are itemised below.

Weaknesses

The ongoing national and international fora on improving fisheries management toward achieving sustainability and injecting responsibility and stewardship in the fishery provide evidence of the need to address the weaknesses in fisheries management toolbox. A list of these weaknesses is presented below.

Consultative governance systems and governmental command and control

As noted in Tables 6.5 and 6.6 above, user participation in fisheries management has tended toward government controlled consultative arrangements. Government controlled systems reflect the "tragedy of the commons" (Hardin, 1968) that provides the impetus behind the modern role of governments in command and control of the fisheries and aquaculture sector. However, as Ostrom *et al*. (2007) note, appropriate governance of all fisheries systems requires a range of context-driven applications and options. They argue that there is no panacea, "one-size-fits-all" approach for application of the fisheries management toolbox. When there is no authority for local knowledge to act, it diminishes the responsibility and opportunities to engage the local community and stakeholders. Most country management regimes, *e.g.* the EU, and Canada, instill power in the government responsible minister and are known as fisheries that are "run from Brussels" in the case of the EU with "European Competency", and for Canada fisheries as "Ottawa run". These government based paternal systems are typically based on operational disciplinary tasks, *e.g.* fisheries science, management, and policy, from government developed and funded expertise. Stakeholders, industries, communities are typically provided merely a consultative role. This is seen as a weakness in instilling responsibility to users in the command and control system.

Data deficiencies in ecosystem observations and monitoring

Consistent with the major government role, ecosystem observations tend to be controlled and processed by the government agencies to support command and control. Local, regional, national, and international fishermen are often mandated to provide information and observations as part of their licensing agreements. However, the information flow is such that governments tend to use data for their own planning purposes and without a clear and directed communication to users about how the information is compiled and analysed. It is a weakness that resource users' additional observations that may not conform to standard data and model requirements and often gets labelled as "anecdotal information" and are accordingly minimalised or ignored.

Undefined objectives, targets and space in multicriteria decision making

The complexity of the fisheries management toolbox and the myriad of resources require a similar long task list for assigning access and allocation to fishery units in marine space. This requires extensive ecosystem and stock assessment estimates for the resources and associated target and objective setting in the marine space including socio-economic considerations. Government-led initiatives are generally not effective in declaring the full suite of objectives and accountable targets for socio-economic as well as resource status in defined marine areas. It is a weakness that government decisions, while based on the objectives of resource sustainability and socio-economic prosperity, are not clearly defined with respect to how they apply in the marine space and with respect to the multiple and conflicting criteria of fisheries and aquaculture resource systems.

Problems operationalising the PA

Despite well-known and principled approaches to ongoing stock declines, and risk-averse responses to uncertainty, the PA has not resulted in an improved sustainability performance primarily due to the unclear and wide interpretation of how to operationalise the PA in access and allocation decisions. The wide range of PA actions, consistent with environmental variability, invites a range of actions that overall do not reduce downside effects of uncertainty. Moreover, actions taken in the name of the PA do not necessarily translate into improved ecosystem performance due to the complexity of the system and the multiple and conflicting criteria of decisions. Despite the acknowledgement that science cannot fully inform decision makers, it is a weakness of fisheries management that there are significant difficulties with the application and operationalisation of the precautionary approach.

Government lobbying

Large scale international fisheries typically involve a small number of commercial entities (Table 6.5 above). Collectively, these entities may exert a significant force on government lobbying, bilateral agreements, and political interference. Under the current management toolbox characterised by government control systems, the incentives for big business are to maintain productivity, reduce costs, and increase profitability. These incentives tend to promote continued exploitation, the advancement of socio-economic considerations at the expense of resource sustainability, and may undermine potential ecosystem sustainability concerns.

Fisheries and aquaculture carbon footprint

Fisheries and aquaculture activities contribute to greenhouse gas emissions during production operations and the transport, processing and storage of fish and differentially by species and regions. Overcapacity and excess effort lead to lower fuel efficiency. Protein, energy consumption, and peripheral effects consumed in producing fish food from aquaculture varies significantly. Estimates of the ratio of edible protein energy output to industrial energy inputs varies considerably to the point of questioning the sustainability of aquaculture. Post-harvest activities entail stocking, packaging, transport and post-consumption waste are also linked to increased GHG emissions. International trade in fresh fish products by air freight produce high emissions that are estimated to be nearly 4 times higher than sea freight, and almost 100 times that from local transportation of fish consumed locally. As the global commercial fishery trade seeks higher value, continuing internationalization is important to developing nations that depend on valuable export earnings. Consequently, GHG emissions are expected to increase. The recent FAO State of the Fisheries and Aquaculture report for 2009 noted the weakness of the trade-offs between developing-country export benefits and air transport mitigation efforts (FAO 2009, p.87ff).

Fisheries management in practice

A fundamental weakness of the fisheries management toolbox is its inability, in practice, to realise its objectives of ecological sustainability and ecosystem conservation, economic viability and social stability, and responsibility. These objectives remain largely unfulfilled as evidenced by the global response to persistent overexploitation by national and international fishing fleets, and the persistent policy of states' subsidisation of fisheries and aquaculture operations in the guise of social stability and economic viability.

In light of this description of the modern fisheries management system, the following section examines the pending impacts on the system from climate change and the response of the system to these impacts.

Climate change impacts and response of the fisheries management toolbox

This section discusses the requirements of adaptation strategies within the contexts and spatial specifics of the fisheries management toolbox summarised above. It also examines anticipated climate change impacts on the fisheries and aquaculture sectors. Finally, responses to climate change impacts of the fisheries management system in place are examined.

Environmental impacts

The High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy at FAO headquarters in Rome (FAO, 2008a) concluded that in terms of physical and biological impacts, climate change is modifying the distribution of marine and freshwater species. Warm-water species are being displaced towards the poles with changes in fish size and stock productivity, ecosystem productivity is reduced in tropical and subtropical oceans, in the seas and lakes, and increased in higher latitudes. Temperature increases are also affecting fish physiological processes resulting in both positive and negative effects on fisheries and aquaculture systems depending again on the region and latitude.

Differential warming between land and oceans and between polar and tropical regions affect the intensity, frequency and seasonality of climate patterns (*e.g. El Niño*) and extreme weather events (*e.g.* floods, droughts and storms). These events impact the stability of related marine and freshwater resources and have unpredictable consequences for fish production due to changes in the seasonality of marine and freshwater food webs and resource biological processes. Species invasions and spreading of vector-borne diseases increase the unpredictable risks of expected changes.

Sea level rise and land subsidence, glacier melting, ocean acidification, and changes in precipitation affecting groundwater and river flows significantly impact the productivity of coral reefs, wetlands, rivers, lakes and estuaries.

The conference also reported that extreme events impact coastal infrastructure, ranging from port landing and fish farm sites to post-harvest facilities and transportation routes. Safety at sea and coastal settlements and communities living in low-lying areas are at increased risk. Water stress and competition for water resources affect aquaculture operations and inland fisheries production, and increase conflicts among water-dependent activities.

A number of recent studies have been undertaken to detail climate changes and their impacts on fisheries and aquaculture. Notably, the work of Brander (2007, 2010) including his work in the collection of studies appearing in the recent special issue of the *Journal of Marine Systems* (Drinkwater *et al.*, 2010; Emeis *et al.*, 2010; Jennings and Brander, 2010; Ottersen *et al.*, 2010; Overland *et al*., 2010; Perry *et al.*, 2010; Planque *et al.*, 2010; Schwing *et al.*, 2010) discuss the impacts of climate change on global and regional fisheries. Cheung *et al.* (2009) project impacts on global marine biodiversity under climate change. Turner's (2000) work examines the socio-economic impacts of change in the coastal zone.

Table 6.7 summaries the effects of anticipated climate change from this literature with acknowledgement to the work of Cochrane *et al.*, (2009), Sherman *et al.*, (2000), O'Reilly and Hyde (2009), Allison *et al.*, (2009), FAO (2007), and Gallardo and Yakupitiyage (2009). As noted, this work is considerable and Table 6.7 fashions a summary with focus on fisheries and aquaculture impacts in order to address the toolbox response.

Table 6.7. Direct and indirect effects of climate change on fisheries and aquaculture

Description	Physical impacts	Observed impacts on fisheries and aquaculture
Warming – increasing heat content and rising temperatures	Increased oxygen demand, decreased pH; warming surface waters and deep warming (Atlantic Ocean). Moderate to strong warming in freshwater lakes, decreasing levels. Increased river run-off at higher latitudes; decreases in West Africa, southern Europe and southern Latin America; decreasing rainfall and evaporation in African lakes. Contraction of marginal sea ice biome and seasonally stratified subtropical gyre. Reduced ice cover in high-latitude, high-altitude lakes, longer growing season, increased algal abundance and algal blooms, increased invasive species, and diseases. Anthropocentric concentration of GHG emissions by fisheries and aquaculture sectors.	Oxygen demands cause stress in fish stocks interrupting reproductive success. Delayed diatom spring bloom and peak biomass reduced; changes in the dominant phytoplankton; deep tropical lakes experiencing reduced algal abundance, declines in productivity from reduced resupply of nutrients; changes in freshwater and marine species planktons. Rapid changes in fish (pelagic) communities, vertical movements to counteract surface warming. Species (terrestrial and marine) ranges driven toward the poles, expanding the range of warmer-water species, contracting colder-water species; reduced species diversity in tropical waters; populations at the poleward extents of their ranges tend to increase in abundance with warmer temperatures (achieved when food supply is adequate); populations near the equators decline in abundance as temperatures warm. Marine and freshwater trophodynamics altered by ocean warming through predator-prey mismatch and reduced production and biodiversity and increased variability in yield.
Changing ocean salinity, water column stratification; mixing of water in lakes and oceans	Increased salinity in surface ocean waters, decreasing in high latitudes. Combined temperature and salinity changes reduce density of the surface ocean, increase vertical stratification, and change surface mixing with some geographical differences. Decrease nutrient supply to surface waters due to increased stratification.	Increased vertical stratification and water column stability in oceans and lakes reduce nutrient availability to the euphotic zone affecting primary and secondary production; distribution shifts due to tight trophic coupling adversely affects fisheries, reduction in prey and in primary productivity. In high latitudes the residence time of particles in the euphotic zone will increase, extending the growing season and small global increase in primary production with large regional differences.
Changing ocean circulation and coastal upwelling changes in timing and latitude	Reductions in the ocean currents expected from freshwater input in the Arctic and subarctic, increased stability of the surface mixed layer, reduction in salt flux, reduced ocean convection and less deepwater formation. Upwelling seasonality affected. Changes in lake water levels and dry water flows in rivers.	Intensification of hydrological cycles influence limnological processes, increased run-off, discharge rates, flooding area and dry season water levels boost productivity at all levels (plankton to fish); changes in timing of floods may trigger production at the wrong time and flush biological production out of its habitat with important food web consequences. Nutrient supply in surface waters altered, primary productivity reduced; changes in open sea fish and pelagic fish distribution and reduced coral-reef fisheries productivity.

Table 6.7. Direct and indirect effects of climate change on fisheries and aquaculture (*cont.*)

Description	Physical impacts	Observed impacts on fisheries and aquaculture
Sea level rise, land subsidence	Rise in global average sea level rates accelerating since 1993 to about 3.1 mm per year. Losses expected in Atlantic, Gulf of Mexico, coasts of the Americas, Mediterranean, Baltic and small-islands; intertidal and coastal wetland habitats substantially reduced. Coastal profile changes, loss of harbours, homes; increased exposure of coastal areas to storm damage; increased vulnerability of coastal communities and infrastructure to storm surges and sea level.	Reduced production and yield of coastal and related fisheries due to loss of coastal fish breeding and nursery habitats, *e.g.* mangroves, coral reefs, and reduced area available for land-based aquaculture. Increased risks associated with fishing, higher insurance, more days at sea lost to storms, higher risks of accidents and damage to gear and aquaculture installations, less viable livelihood options for the poor, higher costs, reduced profitability. Salt water intrusion damage to land-based water systems, wells, and aquifers. Reduced freshwater availability for aquaculture.
Ocean acidification, increased CO_2	Decreased surface seawater pH. Impacts of ocean acidification uncertain, severe for shell-borne organisms, tropical coral reefs, and cold-water corals in the Southern Ocean.	Reduced production for calciferous marine resources, *e.g.* molluscs, crustaceans, corals, echinoderms, phytoplankton, calciferous marine resource species; coral bleaching and mortality; reduced coral calcification and enhanced reef erosion. Changes in surface water availability threat to fisheries production.
Atmosphere-ocean, land-ocean exchanges	Hydrological impacts of land-use change with consequences for ecosystem production, changes in sediment loads, damned water flows, and physico-chemical consequences (hypoxia, stratification and salinity changes)	Ecosystem community composition impacts, production seasonality shifts in plankton and fish. Pressure on inland fish and land-based, water intensive, food production systems (*e.g.* rice), particularly in developing countries; reduced diversity of rural livelihoods, less predictable rain/dry seasons and decreased ability to plan.
Low frequency climate variability patterns	Increase in the intensity and frequency of atmospheric patterns: North Atlantic Oscillation (NAO), El Nino-Southern Oscillation (ENSO) events. Warming trend throughout the ocean basins. Reduced water flows and increased droughts	Changes in species sex ratios associated with event timing and altered times of spawning, migrations, peak abundance of juvenile fish leading to reduced productivity overall. Changes in lake water levels, dry water flows in rivers leading to reduced productivity freshwater systems; increased invasive species, diseases and algal blooms and parasites; changes in fisheries and aquaculture infrastructure and operating costs from infestations of fouling organisms, pests, nuisance species, predators.
Increased frequency of extreme weather	Large waves and storm surges. Inland flooding from intense precipitation.	Salinity changes; introduction of disease or predator; loss of fishing gear, damage/loss of aquaculture facilities and aquaculture stock; increased costs needed to construct and secure wharvage, cages.
Combined climate changes leading to “regime shifts” with increasing	Amplification of combined climatic signals provoke short term, unpredictable biological responses as ecosystems shift from state to state. Large-scale changes related to	Regime shifts in the North Atlantic, North Pacific oceans affecting productivity. “Rapid” time scales (years): changes in distributions of both freshwater and marine species, changes in abundance from recruitment failure; changes in the timing of life history, rapid turnover species, *e.g.* plankton, squid

regional climate variability	temperature, winds, freshwater availability, and acidification, longer growing seasons, decreased ice cover, changing levels of precipitation (more droughts or floods), changes in sea level, and increased frequencies of extreme events (such as flooding and storm surges).	and small pelagic. Intermediate time scales (decades): temperature-mediated physiological stresses and phenology changes impact recruitment success and abundances. Long time scales (multidecadal): decreasing primary production with regional variability; reduced ecosystem resilience to climate variability as a result of changes caused by fishing. Increased intensity and duration of floods, shifts to freshwater fish species adapted to migration, spawning and transport of spawning products; lower water quality and increased production costs as freshwater aquaculture compete with changes in availability of freshwater due to agricultural, industrial, domestic and riverine requirements.

Table 6.7 summarises the anticipated climate changes and the potential impacts on the fisheries and aquaculture sector. It is recognised that the cause-effect of these climate changes in the complex marine and freshwater systems have direct and indirect cumulative impacts on these sensitive ecosystems. As such, these impacts are taken from observations. No functional response or predictable impacts can effectively be determined for the climate change impacts on fisheries and aquaculture. Nevertheless, it is instructive to postulate how the current fisheries management toolbox may respond to the pending changes. The following section examines the response of the fisheries management system for the anticipated impacts of Table 6.7 above.

Fisheries management toolbox response

By virtue of the recognised historically weak performance of the current fisheries management toolbox amid declining stocks, falling catches and catch rates, the evidence is that the response to change is lacking in practice (FAO, 2009; OECD, 1997, 2000). In this section, the climate change impacts summarised in Table 6.7 provide the focus for how the fisheries management toolbox may be expected to respond to the pending changes due to climate shifts. This exercise identifies the gaps in the applications and practical consequences of the fisheries management toolbox. The results direct us toward a more adaptive fisheries management system that is designed to deal with the complexities of climate change.

Table 6.8 below associates the key elements of the current fisheries management toolbox with the anticipated climate changes presented in Table 6.7 above. The "response" suggests how management measures, operational tasks, and governance approaches within the capacity of the current system can be called on, at least theoretically to address the pending impacts. Columns 1 and 2 of Table 6.8 are taken from the Table 6.7 description and impacts of anticipated climate changes, respectively. The last column of Table 6.8 applies relevant management measures and operational tasks of the fisheries management toolbox to the identified changes and their impacts.

Table 6.8. Fishery management toolbox response to climate change impacts

Description	Impacts on fisheries and aquaculture	Fishery management toolbox response
Warming – increasing heat content and rising temperatures	Stress in fish stocks interrupting reproductive success.	Protection of spawning grounds using technical measures, MPAs, time and area closures, improved fisheries science on the migration and timing of species' life cycles.
	Delayed algae blooms and changes in abundance and timing.	Enhanced systems for observation, monitoring, improved science of the migration and timing of species life cycle.
	Changes in fish (pelagic) communities, and behaviour; changes in species ranges.	Fishery behaviour tracking and ecosystem observation; catch statistics review including location of capture and analysis.
	Fisheries and aquaculture industry anthropogenic contribution minimal.	Shift to fixed or passive gear, versus mobile gear, new technology for reducing emissions.
Changing ocean salinity and water column stratification	Increased vertical stratification and water column stability reduced nutrient availability	Longitudinal observation system from surveys, timing of fish runs, more science on behaviour of fish from deputised fisheries observations.
	Reduction in prey and reductions in primary productivity	Improved and direct science surveys on ecosystem monitoring.
Changing ocean circulation and coastal upwelling changes in timing and latitude	Increased run-off, discharge rate; changes in the timing of floods.	Observations, ecosystem monitoring systems, comparative analyses.
	Nutrient supply altered, primary productivity reduced.	Improved and direct science surveys on the ecosystem monitoring.
	Changes in open sea fish and pelagic fish distribution and reduced coral-reef fisheries productivity.	Science tracking systems; assistance of fisheries observations with Science-aided information gathering.
Sea level rise, land subsidence	Loss of coastal fish breeding, nursery habitats, reduced area for aquaculture.	Ecosystem observations, shore and fisheries based.
	Increased risks; more days at sea lost to storms, higher risks of accidents and damage, reduced profitability.	Analysis and tracking evidence: information gathering; financial information analysis.
	Salt water intrusion damage to land-based water systems.	Integrated tracking of coastal water systems.
	Reduced freshwater availability for aquaculture.	Policy adjustment from evidence to shift to brackish water species.
Ocean acidification, increased CO2	Reduced production for calciferous marine resources.	Science and enhanced stock assessment of affected resources; ecosystem observation.
	Reduced coral calcification and enhanced reef erosion.	Development and maintenance of longitudinal records, trends.
Atmosphere-ocean, land-ocean exchanges	Changes in surface water availability.	Improved science information and monitoring.
	Shifts in production and seasonality processes in plankton and fish	Enhanced information and ecosystem monitoring observation systems.
	Pressure on water use	Development of integrated overall water use.
	Reduced diversity of rural livelihoods	Establish measures of local, regional dependence on fisheries and aquaculture.

	Altered times of spawning, migrations, and peak abundance of juvenile fish.	Improved analysis of catch observations, timing, life history and spatial range; technical measures applied to spawning and juvenile rearing areas.
Low frequency climate variability patterns	Reduced freshwater productivity.	Integrated analysis of water use and flows.
	Increased invasive species, diseases and algal blooms and parasites.	Enhanced ecosystem monitoring and observations.
	Increased costs from pests, fouling organisms, nuisance species, predators.	Observations and access and allocation management to remove organisms, reduce pests.
Increased frequency of extreme weather	Salinity changes, disease, predators	Improved ecosystem monitoring and observations.
	Loss and damage to gear, loss of aquaculture stock	Improved science and engineering for advanced technology and innovation on materials and gear.
Regime shifts	Regime shifts affecting productivity, pelagic, demersal species dominance.	Enhanced science and ecosystem modelling, observation, and systems analysis.

Table 6.8 suggests how the existing fisheries management toolbox can be expected to respond to the anticipated climate changes impacts. The table identifies those functions, measures and activities that are part of the toolbox and that need to be generally enhanced in the existing system in order to address the designated impacts. From Table 6.8 the following management toolbox responses are noted:

- **Enhanced ecosystem observation systems**: the most prevalent requirement to respond to the suite of climate change impacts is to establish enhanced systems for ecosystem modelling, observation, and analysis of species' status. This also requires enhanced science of the understanding of species' life cycle (migration and timing and fish behaviour), spatial and temporal analysis of the fishery, review and analysis of spatial-temporal catch statistics, and ongoing predator-prey relationships.

- **Protection of vulnerable species components**: species productivity and timing impacts require the protection of vulnerable spawning stocks and spawning events, and juvenile rearing areas to relieve stress and toward improving recruitment success using technical measures, *e.g.* MPAs, time and area closures.

- **Integrated tracking of coastal water systems**: integrated analysis of water use and flows in freshwater and marine systems including all sources and uses in a regular accounting and tracking of water use.

- **Gear shifts:** shift to fixed or passive gear versus overly efficient mobile gear using management measures gear restrictions in order reduce the sector's carbon footprint and to associate fishing effort and output more closely with the natural variation of the marine system.

- **Policy shifts**: shift fisheries and aquaculture effort to alternative species based on evidence from ongoing observations and based on preset targets for decision making.

- **Sector dependence analysis**: establish measures of local and regional dependence on fisheries and aquaculture through integrated social and financial information analysis with feedback to the access, allocation and governance processes.

- **Technological innovation**: improved science and engineering for advanced technology and innovation on materials and gear to decrease the carbon footprint, improve safety and reduce the risks of damage.

These responses are presented with respect to the potential impacts of climate changes and without critical analysis of their applicability or practicality in different contexts, regions, and scales of operation. Suffice it to say that technically, resource restrictions and practical issues of implementation notwithstanding, the current fisheries management toolbox can theoretically be responsive to the needs of the changing climate. However, it is noted that successful response requires a timely and practical application of the toolbox measures that arguably has not been attained to date.

The State of the Fisheries and Aquaculture report (FAO, 2009) points out that despite considerable scientific analyses, the future impacts of climate change on fisheries and aquaculture are nevertheless poorly understood. Further, FAO (2009) states clearly that the key issue lies less with our scientific knowledge than with our ability to respond practically and effectively:

> *The key to minimizing negative impacts and maximizing opportunities will be understanding and promoting of a wide range of creative adaptive strategies – implemented by public institutions or the private sector – and their interactions with existing policy, legal and management frameworks. Addressing the potential complexities of climate change interactions and their possible scales of impact requires the mainstreaming of cross-sectoral responses into governance frameworks. Responses are likely to be more timely, relevant and effective where they are brought into the normal processes of development and engage people and agencies at all levels. This requires not only the recognition of climate-related vectors and processes, and their interaction with others, but also the availability of sufficient information for effective decision-making and approaches that engage the public and private sectors. (FAO, 2009, p.90)*

The above statement underlies the real challenge for adapting the fisheries and aquaculture sector to the dynamics of our changing climate. The following section examines how an adaptive fisheries management toolbox can address effectively the complexity and uncertainty of climate change with a revised governance system.

Adaptive fisheries management

This section presents a blueprint for the evolution of a participative fisheries management system that is designed to adapt to sources of uncertainty including the pending impacts of climate change to coastal communities and our marine and freshwater resources. The characteristics of the governance system for an adaptive fisheries management program is described as the fundamental basis about which effective decision making can take place. Secondly, we describe the operationalisation of the precautionary approach as the means to managing uncertainty in the complex fisheries system. Finally, the ways and means and characterisations of moving toward an effective "best practices" adaptive fisheries management system is discussed.

Effective fisheries management systems are adaptive, flexible, and participatory. They embrace decision making under uncertainty based on precautionary and whole ecosystem approaches to problem solving and taking into account the multiple criteria of ecosystem, social, economic and administrative consequences.

The following describes a renewed adaptive fisheries management system that seeks to redress these weaknesses identified above towards realising the required responses to climate change impacts through renewed governance arrangements and evolved decision-making structures.

Governance needs

Top-down command and control approaches do not offer the flexibility to ensure resilient fisheries systems and communities under climate change. Adaptive fisheries management is designed to address uncertainty and incorporate the knowledge and engagement of integrated resource users (Armitage *et al.*, 2008). Adaptive governance systems focus on continual learning from observations under ongoing experimentation and performance (FAO, 2007b). Thus, the most important adjustment of the current fisheries management toolbox is the shift from paternalistic government control of fisheries to a devolved process that embeds roles and responsibilities into all resource users.

Ostrom *et al.*, (2007) caution against the tendency, under uncertainty, to believe that linked social-ecological systems can provide general solutions to resource overuse. Rather, they note that since the preferences and perceptions of different resource users are not the same, then a diagnostic approach is required for initiating effective governance and monitoring. Thus, effective systems require the full engagement and participation of resource users and community members in this process, and a renewal of the heretofore prevalent roles of government in the fisheries management system.

The need for a governance shift and user engagement is acknowledged in the FAO's *State of the Fisheries and Aquaculture* report for 2008:

> *Policy-making and action planning in response to climate change will require cooperation and coordination across a range of government line agencies and departments as well as community or political representatives at subnational and national levels. It will also be necessary to build and strengthen partnerships among public, private, civil society and non-governmental sectors. In addition: Nationally, information gaps and capacity-building requirements need to be identified and addressed through networks of research, training and academic agencies. Internationally, networks should be created or developed that encourage and enable regional or global exchanges of information and experiences, linking fisheries issues with those of other sectors such as water management, community development, trade and food security. Existing management plans for the fisheries and aquaculture sector, coastal zones and watersheds need to be reviewed and, where appropriate, further developed to ensure they cover potential climate change impacts, mitigations and adaptation responses. (FAO 2009, p.90)*

Therefore, what is required is the establishment of real co-management regimes defined through the necessary policy, legal and implementation frameworks that recognise shared decision making authority and responsibility of resource users and all stakeholders. This also implies a renewal of the role of government as auditor and decision support to stakeholder decision makers in their delivery of access, allocation rights, and operational regulations for the fisheries and aquaculture sector. This governance shift will require strengthening existing local and regional structures and processes with a focus on the changing environment, and explicit recognition of the multiple objectives and targets of the sector.

Further, the proposed co-management regime needs to be defined in an integrated fashion so that in the coastal zone, all agencies and stakeholders involved in ecosystem planning are contributors to policy that integrates the joint activities of commercial fisheries and aquaculture users, coastal zone managers, coastal developers, recreational users, other resource users (*e.g.* extractors of oil and gas), as well as non-governmental agencies. As noted in FAO (2009), this requires community capacity building and the realignment of scientific, management and technical services including links to "interior affairs, science, and education, but also those for national development planning and finance". The objective is to integrate fisheries and aquaculture management around integrated coastal zone management. This also requires an explicit identification of the coastal zone fishing areas and clarification of land-sea spatial planning and management jurisdictions. In marine areas, countries' spatial management can be encapsulated within coastal nation's exclusive economic zones as defined in the UNCLOS and UNFA limits, trans-boundary resources notwithstanding.

In Canada, for example, Fisheries Renewal includes improved governance mechanisms to support the participation of all relevant stakeholders in transparent, consistent, and inclusive decision-making processes that can bring about shared stewardship. The establishment of a National Advisory Body for short-term and more immediate consultation with stakeholders on developing policies including the consideration of climate change is proposed. However, a long-time barrier to this renewal in the Canadian system is the required devolution of the ultimate authority of the Minister of Fisheries and Oceans under the *Fisheries Act*, and the reluctance of the dominant players in the commercial fisheries to take on the responsibility now in the hands of the benevolent Minister of Fisheries and Oceans responsible for ecological sustainability, social stability and economic viability. This effectively implies the government's ongoing regional and public commitment to the sector to mitigate outcomes contrary to its mandated responsibilities.

Finally, associated with co-operative and devolved management is the need for enabling financial mechanisms currently under the auspices of governments to carry out their legally assigned command and control operations. The full potential of existing financial mechanisms, including insurance, will more than ever need to include the issue of climate change impacts and related food security concerns.

Accounting for risk and uncertainty in fisheries' adaptive decision making

The consideration of policy options and activities to minimise the negative impacts of climate change, to improve on mitigation and prevention strategies, and to maintain and build adaptive capacity in the face of an uncertain future was a topic of The High Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy (FAO, 2008a). The list below identifies related approaches and decision support mechanisms with respect to the impacts of climate change (Table 6.7) and the toolbox response (Table 6.8) to account for risk and uncertainty in adaptive decision making in fisheries and aquaculture.

Enhanced ecosystem observation systems

The FAO Workshop noted the importance in planning for uncertainty of "developing the knowledge base" to take into account the greater possibility of unforeseen climate events. The knowledge base defines the enhanced systems required for ecosystem modelling, observation, and analysis. This includes ecosystem assessment of species' status (condition and abundance) including key supporting species in the food web, *e.g.* plankton production, prey species and predators, in a balanced perspective of ecosystem resources (FAO, 2008a).

This database is a collection of ecosystem data from all sources including scientists, fishermen, and occasional observers of the system. The knowledge base also includes a description of stock dynamics and species' life cycles (migration and timing and fish behaviour and ongoing predator-prey relationships and dynamics) and their interaction with the fisheries systems (the spatial and temporal analysis of the fishery and catches). The knowledge base provides key information for the planning and evaluation of future policy options for review by decision makers.

Issues of climate variability are well-known to the participants in the fisheries and aquaculture sector. They experience climate variability directly as part of their ongoing observations of the ecosystem. Consequently, the experience gained from observations by fishermen, processors, fish farmers and operational managers are extremely useful in documenting the changing climate and directing the simulated analyses, and trend models used for future planning. These parties need to be identified as data owners and important contributors to the overall knowledge base including the declared use and impact of their information.

Clarifying ecosystem objectives

Effective problem solving requires the clear, quantitative statement of the short-term targets and longer-term performance objectives associated with the delivery of the adaptive system. Moreover, these quantitative measures need to be subject to audit and accountability that is used as evidence for the performance of operational management decision making.

Further, the adaptive management approach recognises that different ecosystem objectives have different priorities for stakeholders in a responsible decision making framework. The multi-criteria objectives and the multi-participant context of fisheries management problem solving requires the application of group decision making methods for multicriteria decision making (Lane, 2007, 2008). The methods are well-known in the domain of decision theory and can be readily applied in fisheries and aquaculture settings to address risk and uncertainty. However, application of these approaches in support of fisheries management decisions is minimal.

Incorporating risk in precautionary measures

Adaptive fisheries management must embrace the inherent uncertainty of the ecological system. To do so, a description of the multi-faceted risk profile and trade-offs of the decision makers is required. This information is critical in evaluating and assessing alternative policy options. Risk profiles establish the perspective of the different decision makers with respect to the actual versus the target objectives of the policy evaluation problem. These profiles are combined to establish policy priorities and ranked policy options in support of improved decision making (Lane and Stephenson, 1998b).

Building resilience in communities

Resilience refers to the coping ability or adaptation capacity of the fisheries and aquaculture sector to recover from negative external climate impacts. Mechanisms developed to assess community capacity to adapt to changing climate conditions are important for recognising and prioritising policy options (Sale *et al.*, 2008). Adaptation is constrained by the resilience of the natural systems in the evolution with human systems by their respective ability to cope with external climate shocks (Gunderson and Holling, 2002; Adger *et al.*, 2001). Adaptive fisheries systems build resilience in the coastal communities by advancing economic, environmental and social opportunities in the face of anticipated change.

Establishing flexible and timely seasonal management decision making

Adaptive decision making is applicable at the practical operating level and with minimal lag time for ongoing seasonal implementation. Specification of the well-defined problem situation, information sources, identification of the multiple objectives with targets, participants' risk profiles, and development of alternatives, permit the formulation of the in-season problem in a structured framework. This framework utilises spatial mapping and visualisation to simulate and animate hypothetical situations for participant analysis and discussion including exploring the impacts and response of adaptation and mitigation strategies to perceived and real threats.

Systems Dynamics (SD) techniques are useful for describing and linking environmental, economic and social baselines (Forrester, 1973). Spatial analyses are used to produce hypothetical cases of ecosystem shifts in local community ecosystems. SD projection models complement the delivery of participant-based discussion to identify areas of agreement in which to investigate future community environmental scenarios. Local adaptation planning and decision frameworks result from the group evaluation of the policy options leading to consensus on action planning for mitigation of fisheries and aquaculture problems.

Best practices and areas of further research

Building resilience to climate change and deriving sustainable benefits, requires that fisheries and aquaculture managers re-think the adoption and adherence of best practices in fisheries management response. Practical applications include those described in the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) designed to reduce overfishing and rebuild fish stocks. These practices need to be integrated effectively with the management of the coastal zone, river basins, and watersheds. Applied policies for best practices are conceived from the indicated fisheries management toolbox responses (Table 6.8) and are provided below in this context.

Herbivore and multi-trophic aquaculture

Land-based aquaculture of herbivorous species provides nutritious food with a small relative carbon footprint in comparison with larger scale, international wild capture fisheries. Integrated multi-trophic aquaculture in marine sites involving finfish, filter feeders, and seaweed production in close proximity offer mutually dependent systems that are self-regulating and mutually productive and provide an example of best practices in aquaculture. Farming of shellfish, such as oysters and mussels, helps clean coastal waters, while culturing aquatic plants and assisting waste removal from low water quality sites.

Shifts in fishing gear

Adaptive fisheries management seeks to reduce uncertainty and reduce GHG emissions. Mobile fishing gear obviates the inherent fluctuation of natural inter-seasonal variability by actively hunting migrating adult fish stocks while incurring significant GHG emissions. Alternative best practices point to shifts from mobile to passive or fixed gear approaches to wild capture fisheries. Mobile gear efficiencies reveal significant capability at hunting and capturing directed fish stocks to such an extent that species may be pushed to overexploitation. Passive gear configurations, by their nature, would reduce GHG emissions comparatively and could be configured to target capture of non-vulnerable stock components. Passive gear also encourages environmentally friendly and fuel-efficient fishing best practices attuned to natural fluctuations of species abundance.

Identification and protection of vulnerable species components

The historical mantra in fisheries science and management has been that of “spawn at least once” before recruitment to capture fisheries. The unfortunate consequence of this historical policy in efficient capture fisheries has been the systematic removal of the most productive spawners in the population and the eventual elimination of larger, older ages inevitably leading to stock decline and, in some case, collapse. The corollary of this mantra is the implicit protection of juvenile fish in the population. Alternatively, it may be more appropriate to designate productive spawners (“big fish”) as worthy of protection as vulnerable population components, especially as regards reducing the risk of spawning event failures. Protection of spawners and the spawning event would appear to be a logical hedge against population decline and the negative impacts of reduced productivity from climate change impacts. Research into a switch using passive gear (see above) to exploit limits on more abundant juvenile stocks that are typically subject to high natural mortality may suggest significant returns to resource sustainability. The best practice example from the American lobster (*Homarus amercianus*) fishery in Atlantic Canada reveal that over 80% of juvenile lobsters have been regularly captured annually while spawning lobsters are protected. It is noted that this policy has resulted in burgeoning stocks and increasing landings.

Natural solutions

Mitigation solutions reducing the carbon footprint of fisheries and aquaculture require further innovative approaches found in nature itself. A natural example is inclusion of mangrove conservation as eligible for Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) funding, which demonstrates the potential for catchment forest protection (Pilkney and Young, 2009).

Technological innovation

Innovative technologies and more responsible practices can generate increased and sustainable benefits for fisheries and aquaculture. New technologies to encourage sustainable, environmentally friendly production, *e.g.* the use of biofuels produced from algae and seaweed are a promising and efficient innovation for fishing and aquaculture operations. Another promising innovation is new science used to identify options for carbon sequestration by aquatic ecosystems.

Climate change education

Climate change education in schools and in university cross-disciplinary programs in science, social science, and management create greater awareness within the community and among all stakeholders about the pending shifts in regional and local shifts in our environment. Enhanced education and public awareness sensitises the public to the need for change in adapting locally to climate impacts.

Examples of best practices provide the basis for future study and research. These items are therefore areas of recommended research into ways and means of responding to the impacts of climate change in fisheries and aquaculture and the development of adaptive policy setting.

Conclusions

This paper examines the strengths and weaknesses of modern fisheries management methods and its inability to deal with the risks and impacts presented by pending climate change. The paper also addresses management responses to climate change threats and impacts. Finally, the paper presents aspects of adaptive fisheries management methods as an effective means of re-alignment to adapt to climate change uncertainties. Adaptive fisheries management is characterised by a decentralised and devolved governance system with participation by responsible resource users working within an operational decision making framework that accounts for multicriteria trade-offs among multiple participants in the evaluation of fisheries and aquaculture policy options. Fisheries policy makers should develop strategies to adapt to climate change under uncertainty, taking into account ecological sustainability, social stability, economic viability, and administrative efficiency.

The conclusion to the rhetorical question of whether or not the fisheries management toolbox is sufficient to address climate change is answered by declaring that: (i) the toolbox is replete with historically developed measures that theoretically exert sufficient control of commercial fleets and operators for a myriad of situations including anticipated climate shifts; and (ii) in practice however, the toolbox has failed in delivering the declared objectives of fisheries management and is therefore not sufficient to address climate changes. Consequently, the findings of this paper with regard to the question are duly qualified.

The real question rests not so much with the toolbox and fisheries management measures, but who wields the tools. The evidence and criticism of the fisheries management toolbox indicate that government use of the tools in a command and control setting reduces the effectiveness and acceptance of the tools, and reduces the practicality of achieving stated objectives. An alternative role for governments would be to devolve management authority to users and act instead in an auditing and decision support role rather than assuming the task of ensuring prosperity and sustainability. Local, spatial control on a scale compatible with local and regional climate observations, and associated property rights to communities and industry would enhance users' responsibilities and strategic perspective conducive to sustainability and viability.

In closing, policy makers need to address the following challenges in delivering adaptive fisheries management:

- Identify fishery and aquaculture sector partners

Adaptive fisheries management is focused on the inclusion of multiple groups including the government, the general public, as well as identified dependent subgroups (coastal communities, fishermen, aboriginal peoples), and amorphous "stakeholders" in the decision making framework. There is a clear need to identify partners as well as their respective roles and responsibilities in the management process, including observation and data collection, monitoring and enforcement, analysis and operational decision making in evidence-based decision-making.

- Renewed role of governments in adaptive fisheries management

Under adaptive management, government command and control in fisheries and aquaculture is devolved to sector partners. The idea is therefore that it is more effective for governments to "get out of the way" by adopting a more market-based orientation and assuming a supportive, public information, and fisheries and aquaculture auditing role. The difficulty with this change is that governments begin from a position of authority and are required to devolve this position. The challenge is to make governments see the net benefits of this response. The recent announcement by the New Zealand government has taken up this challenge by moving positively to provide the New Zealand Seafood Industry Council (SeaFIC) with increased authority to manage selected fisheries.

- Determining community dependence and adaptive capacity of fisheries and aquaculture

The evolution of adaptive management is dependent on the reliance, vulnerability, and adaptive capacity of the community. Better understanding is required about how the livelihood security of fishermen and farmers may be threatened by climate change combined with other social and environmental stressors. The challenge is to identify the potential and needs for livelihood transitions such as skills upgrading and education, and as well as individuals' future in fisheries and aquaculture faced with the uncertainty of the changing climate (Adger, 2006). It is likewise challenging to determine the mechanisms to strengthen fishermen's adaptive capacities pending climate change impacts including research on sustainable fisheries production systems, tenure security and equitable access.

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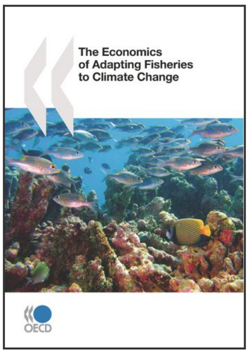

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