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DECISION-MAKING AND ECONOMICS OF ADAPTATION TO CLIMATE CHANGE IN THE FISHERIES AND AQUACULTURE SECTOR

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Decision-making and economics of adaptation to climate change in the fisheries and aquaculture sector

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Preparation of this document

This document provides an introduction to a range of different approaches and methods to assess the costs and benefits of adaptation options in the fisheries and aquaculture sector with the overall aim to help adaptation planners and practitioners identify the most appropriate interventions. It builds upon FAO Fisheries and Aquaculture Technical Paper No. 627, *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge adaptation and mitigation options*. Chapter 5 was further developed as part of the project Supporting Member Countries Implement Climate Change Adaptation Measures in Fisheries and Aquaculture (GCP/GLO/959/NOR), executed by FAO with funding from the Norwegian Agency for Development Cooperation (Norad).

Abstract

With increased international finance for climate change adaptation, and the emergence of national adaptation plans and adaptation projects, there is a greater focus on the economic appraisal of adaptation. Economic appraisal is standard practice in public-sector investment decisions in many countries, as well as in international development finance and overseas development assistance. It provides support to decision makers to help ensure the appropriate use of available resources, and to assess the options available for meeting objectives, by assessing costs, benefits and performance against other decision criteria. This publication reviews available information on the costs and benefits of climate change adaptation in the fisheries and aquaculture sector. It highlights the challenges in applying conventional appraisal and decision-support tools to adaptation, and then reviews emerging frameworks (including no- and low-regret actions, addressing potential lock-in, and early planning for long-term adaptation) as well as economic tools to appraise adaptation options. It identifies that the available evidence is low, and that a key priority is to advance the application of economic analysis to adaptation case studies in order to provide a better understanding of the merits of assessment approaches and their applicability to the sector. This publication can also be used to provide good practice examples and supplementary guidance for application of the adaptation toolbox developed by FAO in 2018 to help guide communities, countries and other key stakeholders in their adaptation efforts.

Contents

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Abbreviations and acronyms

CBA	cost–benefit analysis
CEA	cost-effectiveness analysis
CGE	computable general equilibrium
DMUU	decision-making under uncertainty
EAA	ecosystem approach to aquaculture
EACC	economics of adaptation to climate change
EAF	ecosystem approach to fisheries
ENSO	El Niño–Southern Oscillation
FAD	fish aggregating device
GHG	greenhouse gas
IFF	investment and financial flow (analysis)
IPCC	Intergovernmental Panel on Climate Change
MCA	multicriteria analysis
MPA	marine protected area
NAP	national adaptation plan
NDC	nationally determined contribution
Norad	Norwegian agency for development cooperation
ROA	real options analysis
SDR	social discount rate
SSB	spawning stock biomass
UNFCCC	United Nations Framework Convention on Climate Change
WTA	willingness to accept
WTP	willingness to pay

1. Introduction

Climate change will have potentially large impacts on the fisheries and aquaculture sector (Porter *et al.*, 2014; OECD, 2016; Barange *et al.*, 2018). These impacts are expected to be the result of a number of changes in the abiotic (i.e. sea temperature, oxygen levels, salinity and acidity) and biotic (i.e. primary production and food webs) conditions of the sea, affecting reproductive success, growth and size, disease resistance, as well as the distributional patterns and composition, of species. There are also potential impacts from climate change on critical habitats for fisheries (e.g. corals) and on fishers and fishing operations (vessels, cages and infrastructure), as well as from changes in the intensity and frequency of storms (including tropical storms) and extreme weather events. Finally, there are potential impacts of sea-level rise and storm surges, as well as other extremes, on the infrastructure and value chains associated with the fishing industry. However, all of these changes need to be seen against the background of existing human activities, which affect the abundance and distribution of many marine organisms and fish stocks. In other words, climate change is an additional threat multiplier to fisheries and aquaculture sustainability.

A number of methods have been used to assess the vulnerability and impacts of climate change on fisheries and aquaculture (Barsley, De Young and Brugère, 2013; Brugère and De Young, 2015). These include qualitative and quantitative methods, although the latter are more relevant for subsequent economic analysis, and include ecological trophic modelling, statistical analysis, statistical forecasting, time-series analysis, GIS-based analysis and coupled modelling approaches, including hydrodynamic and ecosystem coupled modelling and coupled physical–biogeochemical modelling (Tröltzsch *et al.*, 2018). The main focus of economic analysis has been on the impact of the distribution of fish biomass and changes in fishery productivity, although there are also studies of the impacts of the loss of critical habitats, the effects of sea-level rise, and emerging studies on acidification.

Several global and regional studies have used these modelling approaches to look at the potential changes in annual catch (including in monetary terms) and the redistribution of stocks or catch potential with climate change (Cheung *et al.*, 2009; Cheung *et al.*, 2010; Cheung *et al.*, 2013; Blanchard *et al.*, 2012; Merino *et al.*, 2012; Barange *et al.*, 2014; Lotze *et al.*, 2019). In summary, these studies generally project that fisheries productivity will increase in high latitudes and decrease in mid- to low latitudes (Porter *et al.*, 2014), primarily due to species shift. This has important implications for developing countries, which are generally located in the tropics.

In response to these projected impacts, a range of potential adaptation options are possible. Recent review studies, notably the recent FAO publication on *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge adaptation and mitigation options* (Barange *et al.*, 2018), have identified options for the fisheries and aquaculture sector. This publication builds on that work and provides an introduction to a range of different approaches and methods to assess the costs and benefits of adaptation options in the fisheries and aquaculture sector, and to help adaptation planners and practitioners identify the most appropriate interventions using economic analysis. In particular, Chapter 2 summarizes the approaches used for assessing the costs and benefits of adaptation in the fisheries and aquaculture sector over time. Chapter 3 overviews some of the methodological issues and assumptions to be applied. Chapter 4 identifies some of the emerging frameworks and methods for early adaptation and decision-making under uncertainty. Finally, Chapter 5 provides

some insights on the application of economics for fisheries and aquaculture adaptation planning.

The analysis here considers fisheries and aquaculture from the broad perspective of value chains. Thus, it includes adaptation responses to address the impacts of climate change on production, management, fishers / fish farmers (occupational risks), infrastructure (e.g. landing and processing) and value chains.

2. Available information on economic analysis of adaptation in the fisheries and aquaculture sector

While there has been a much greater focus on the analysis of adaptation options and increasing levels of early implementation in recent years, the evidence base on the economics of this adaptation remains low. A recent international review of the costs and benefits of adaptation (ECONADAPT, 2015, 2017) found fewer than a thousand published studies (academic and grey literature). Of these, only a handful were on the fisheries and aquaculture sector.

This section updates this earlier review, focusing on the fisheries and aquaculture sector. While it has found more information, the evidence base remains very small compared with adaptation information in other sectors. The review has also found that the existing adaptation studies in the sector use different methods to assess adaptation, and have different objectives, timescales, aggregation levels and applicability for practical adaptation. Therefore, in order to assess the evidence base from the literature, it is important to outline these methods. They are set out below.

Methods and example publications on the economics of adapting fisheries to climate

Some of the earliest economic studies on fisheries and aquaculture estimated near-term adaptation costs using **investment and financial flow (IFF) analysis**. These include studies on fisheries at the global and national scale. The IFF studies assess existing sector flows (i.e. current investment in the public and private sectors), and project them forward in time (generally out by 20 years or so). They then re-analyse these future flows with the additional uplift (the additional costs) needed to address climate change, i.e. for adaptation. In many cases, this does not use detailed fisheries analysis, but instead applies a general percentage "mark-up" on current investment/finance levels to reflect the extra adaptation investment needed. These studies have the advantage of grounding the analysis in current policy and plans, but they tend to have less analysis of future climate change. Importantly, they rarely quantify adaptation benefits.

At the global level, an analysis by the United Nations Framework Convention on Climate Change (UNFCCC, 2007) estimated the additional costs of adaptation for the fisheries sector at about USD 300 million/year by 2030 (McCarl, 2007) [USD 2005].[1] Following this global study, there was a programme of national IFF studies (UNDP, 2011), although only one country included fisheries (Peru). This study estimated the cumulative total cost of adapting the national fisheries sector at USD 0.5 billion from 2012 to 2030 [USD 2005]. This included adaptation for human consumption (focusing on anchovy) and aquaculture (shellfish and trout). The capture fisheries subsector was estimated to require an additional investment of USD 280 million (cumulative

[1] The estimates reported in this chapter are presented in terms of United States dollars, unless otherwise stated, and are presented as the original values with the relevant price year.

2012–2030) to implement identified measures, while the aquaculture sector was estimated to require an additional USD 174 million (cumulative 2012–2030). For capture fisheries, the identified options consisted of: infrastructure, machinery and equipment for production and extraction; training, outreach and awareness; research; conservation and environmental management; and institutional capacity building in public administration. Importantly, it identified that many of these costs would fall on fishing companies, although there would also have to be a significant government budget increase (which could be funded by fishing rights). For aquaculture, the investments were near-shore, primarily by the private sector, but required the introduction of new standards or regulations, as well as research, training, awareness and supervision.

Subsequent studies have focused more on the **economic analysis of adaptation costs and benefits** (OECD, 2015a). These generally use scenario-based impact assessment (see Metroeconomica, 2004; UNFCCC, 2009). These studies first assess the change in future climate change (using climate model projections) and then assess the physical impacts and economic costs of climate change that are projected to occur. They further assess the potential benefits of adaptation in reducing these impacts, as well as the potential costs. This framework can be used to assess the costs and benefits of individual options or combinations of interventions, and even the optimal level of adaptation – the latter being the balance between the costs of adaptation, the benefits of adaptation, and residual impacts after adaptation (OECD, 2015a).

This approach was adopted in a World Bank study of the economics of adaptation to climate change (EACC). However, while fisheries were included, the full analysis of costs and benefits was limited. The global EACC study published a discussion paper on the Cost of Adapting Fisheries to Climate Change (World Bank, 2010a). This estimated the future impact (using a projected climate change and fisheries model) of climate change at USD 80 billion per year (2050) from the loss of fisheries gross revenues [USD 2005]. The study then investigated four aspects to estimate the costs of adapting fisheries to these impacts: potential loss in gross revenues or landed values due to climate change; potential loss in household incomes from fisheries as a result of climate change; the capital required as an endowment to replace the projected loss in gross revenues through time; and the estimated cost of adjusting fisheries to catch declines as a result of climate change. The resulting total estimate of the annual direct adaptation cost was between USD 7 billion and USD 30 billion over time to 2050 [USD 2005]. The impacts of climate change, and the adaptation costs, were predominantly in developing countries.

The EACC study also undertook some country studies. In Viet Nam, the analysis looked at aquaculture, considering the impacts of climate change from increased flooding and salinity due to sea-level rise (World Bank, 2010b) and potential adaptation responses. This examined the direct costs, and the (autonomous/spontaneous) adaptation costs and benefits over the following decade and out to 2050. Focusing on catfish, it reported that successful adaptation would require a combination of better feed conversion and improvements in marketing, together with investments in upgrading dykes to reduce flooding and salinity intrusion. For semi-intensive and intensive shrimp producers, the analysis found additional estimated costs of water pumping to maintain water and salinity levels. It identified that these costs would be borne by operators, rather than by government, and estimated the total cost of adaptation at an average of USD 130 million per year over the period 2010–2050 (equivalent to 2.4 percent of total costs) [USD 2005].

However, these future-oriented studies – and the resulting adaptation options and costs and benefits they identify – use a science-first, impact assessment methodology. They tend to focus on the medium term (e.g. 2050 and even 2100). While the information they produce is important to understand future risks and future options, they do not provide the information for informing early and practical adaptation decisions (UNFCCC, 2009), i.e. the costs and benefits of near-term adaptation policy and plans,

as might inform national adaptation plans (NAPs), sector adaptation plans, or specific projects or investments. Moreover, they are stylized and rarely consider wider (non-climatic) drivers and existing policy, and they often focus on technical adaptation. This means they often omit important opportunity, transaction and implementation costs associated with practical adaptation (OECD, 2015a).

More-recent studies have addressed these issues by moving to a policy or decision-first led approach (see Ranger, Reeder and Lowe, 2013) and focusing on early adaptation that might be undertaken within the next five or ten years (see Warren *et al.*, 2018).

More recently, there has been a greater focus on the use of decision-making under uncertainty (DMUU) approaches, which also include economic analysis (Watkiss *et al.*, 2014). These approaches (discussed in more detail in Chapter 4) are becoming more widely used (ECONADAPT, 2017), although there has been very little application of these DMUU approaches in the fisheries and aquaculture sector to date.

Available evidence across various adaptation options

In order to advance the analysis of adaptation, it is useful to consider the various current and recommended adaptation options in the fisheries and aquaculture sector, and collate information on their costs and benefits. To do this, it is necessary to have a typology of adaptation options. Several generic typologies have been developed (in the third and fourth assessment reports of the Intergovernmental Panel on Climate Change [IPCC]) as well in other literature. These often include the categorization of options by type, for example:

- Technical options. These primarily include technical or engineered design, but can include green and ecosystem-based adaptation.
- Non-technical options, including:
  - institutional and capacity building;
  - information, research and behavioural change;
  - non-technical options or measures;
  - financial and market-based options (including insurance);
  - policy and legislative.

They also include typologies that split adaptation by approach, for example, options that:

- reduce risks;
- reduce exposure;
- reduce vulnerability;
- spread risks;
- live with the risks.

Specific typologies have also emerged for adaptation in the fisheries sector. The OECD (2010) distinguished three fundamental strategies to reduce the actual impacts of climate change on fisheries: (i) promoting resilience in order to reduce system sensitivities; (ii) increasing adaptation capacity and effectiveness of adaptation responses; and (iii) improving the adaptation–planning processes.

Poulain, Himes-Cornell and Shelton (2018) used a further categorization as part of a suggested FAO fisheries and aquaculture adaptation toolbox (Tables 1 and 2), which split adaptation into three non-mutually exclusive areas as follows:

1. Institutional adaptation: Interventions, mainly on the part of public bodies, that address legal, policy, management and institutional issues including public investments and incentives; they include the planning, development and management of fisheries and aquaculture in a manner that addresses the dynamic nature of natural systems and societal needs in the face of climate change,

following the principles of the ecosystem approach to fisheries (EAF) or the ecosystem approach to aquaculture (EAA).

2. Livelihood adaptation: Interventions that include a mix of public and private activities, within or among sectors, most commonly through diversification strategies within or outside the sector to reduce vulnerability.
3. Risk reduction and management for resilience: Interventions that include a mix of public and private activities to promote early warning and information systems, improve risk reduction (prevention and preparedness) strategies and enhance response to shocks.

The three categories have been used as the framing for this publication. Tables 1 and 2 provide selected examples of adaptations.

TABLE 1

Types and selected examples of adaptation tools and approaches in capture fisheries

INSTITUTIONS
Public policies
Public investments (e.g. research, capacity building, sharing best practices and trials, communication)
Climate change adaptation policies and plans address fisheries
Providing incentives for fish product enhancement and market development
Removing harmful incentives (e.g. for the expansion of fishing capacity)
Addressing poverty and food insecurity, which systemically limit adaptation effectiveness
Laws and regulations
Flexible access rights to fisheries resources in a changing climate
Dispute settlement
Adaptive legal rules
Regulatory tools (e.g. move away from time-dependent effort control)
Institutional frameworks
Effective arrangements for stakeholder engagement
Awareness raising and capacity building to integrate climate change into research/management/policy/rules
Enhanced cooperation mechanisms including between countries to enhance the capacity of fleets to move between and across national boundaries in response to change in species distribution
Management and planning
Inclusion of climate change in management practices, e.g. ecosystem approach to fisheries, adaptive fisheries management, co-management
Inclusion of climate change in integrated coastal zone management
Improved water management to sustain fisheries services (particularly inland)
"Adjustable" territorial use rights
Flexible seasonal rights
Temporal and spatial planning to permit stock recovery during periods when climate is favourable
Transboundary stock management to take into account changes in distribution
Enhanced resilience by reducing other non-climate stressors (e.g. habitat destruction, pollution)
Incorporate traditional knowledge in management planning and advice for decision-making
Management/protection of critical habitats for biodiversity and recruitment

LIVELIHOODS
Within sector
Diversification of markets/fish products, access high-value markets, support diversification of citizens' demands and preferences
Improvement or change in post-harvest techniques/practices and storage
Improvement of product quality: eco-labelling, reduction of post-harvest losses, value addition
Flexibility to enable seasonal migration (e.g. following stock migration)
Diversification of patterns of fishing activities with respect to the species fished, location of fishing grounds and gear used to enable greater flexibility
Private investment in adapting fishing operations, and private research and development and investments in technologies, e.g. to predict migration routes and availability of commercial fish stocks
Adaptation-oriented microfinance
Between sectors
Livelihood diversification (e.g. switching among rice farming, tree crop farming and fishing in response to seasonal and inter-annual variations in fish availability)
Exit strategies for fishers to leave fishing
RISK REDUCTION AND RESILIENCE RESPONSE
Risk pooling and transfer
Risk insurance
Personal savings
Social protection and safety nets
Improvement in financial security
Early warning
Extreme weather and flow forecasting
Early warning communication and response systems (e.g. food safety, approaching storms)
Monitoring of climate change trends, threats and opportunities (e.g. monitoring of new and more abundant species)
Risk reduction
Risk assessment to identify risk points
Safety at sea and vessel stability
Reinforced barriers to provide a natural first line of protection from storm surges and flooding
Climate-resilient infrastructure (e.g. protecting harbours and landing sites)
Addressing underlying poverty and food insecurity problems
Preparedness and response
Building back better and post-disaster recovery
Rehabilitation of ecosystems
Compensation (e.g. gear replacement schemes)

Source: Poulain Himes-Cornell and Shelton, 2018.

Table 2
Types and selected examples of adaptation tools in aquaculture

INSTITUTIONS	SPATIAL SCALE
Public policies	
Mainstreaming of aquaculture into national and regional adaptation and development plans	National/regional
More effective sharing of and access to water and coastal space	National/watershed
Investments in R&D on aquaculture adaptation technologies; new species, breeding for species tolerant to specific, or a combination of, stressors (disease, temperature, salinity, acidification, etc.)	National, regional, international
Investments to facilitate the movement and marketing of farm products and supply inputs	National, regional, international
Appropriate incentives for sustainable and resilient aquaculture, including taxes and subsidies	National, international,
Attention to poverty and food insecurity within aquaculture systems	
Legal frameworks	
Property rights, land tenure and access to water	National
Standards and certification for production and for resistant facilities	National
Institutional frameworks	
Strengthening cross-sectoral and inter-institutional cooperation and coordination	Zone/national/regional
Mainstreaming of adaptation in food safety assurance and control	National
Management and planning	
Climate change mainstreamed into integrated coastal zone management	National/watershed/regional
Community based adaptation	Site and community levels
Aquatic protected areas (marine and freshwater) and/or green infrastructure (see ecosystem approach [EAA] to aquaculture guidelines)[1]	National/regional
Mainstreaming of climate change into aquaculture area management under the EAA	Zone/watershed/national
Better management practices including adaptation and mitigation, i.e. better feed and feed management, water quality maintenance, use of higher-quality seed	Site level/zone/management area
Mainstreaming of climate change into spatial planning and management for risk-based zoning and siting	Site level/zone/management area
Integration of climate change in carrying capacity considerations (production, environmental and social)	Site level/zone/management area
LIVELIHOODS RESPONSE	
Within sector	
Development and promotion of new, more-resilient farming systems and technologies	Site level/national
Genetic diversification and protection of biodiversity	National
Integration of climate change in microfinance	National

Aquaculture diversification	All
More resistant strains	Site level
More resistant and/or resilient hatcheries and hatchery-produced seed	Zone/national
Value addition	National, regional, international
Better market access; new markets for new species and products	Zone, national regional
Shift to non-carnivore species	Site level
Fishmeal and fish oil replacement	Site level/national
Empowering farmers and women's organizations	Management area/national
Integrated farming systems and circular economy	Site level/management area
Between sectors	
Diversification of livelihoods	Site level/national
RISK REDUCTION AND RESILIENCE RESPONSE	
Risk pooling and transfer	
Social safety nets	National
Social protection	National
Aquaculture insurance	National
Early warning	
Integrated monitoring (relevant aquaculture area), information analysis, communication and early warning	Farm, watershed, zone
Development of national and local vulnerability maps and raising awareness of risks	Subnational/national
Scientific and local knowledge synthesized; logistics to disseminate information	All
A national risk communication system that provides reliable early warning to hazards	National
Meteorological infrastructure and system that can effectively support crop and farm assets insurance (particularly weather-indexed or parametric insurance)	National
Risk reduction	
Stronger farming structures (e.g. net pens) and more-resilient designs (e.g. deeper ponds)	Site level/national
Enabling adaptive movement between mariculture and inland aquaculture (recirculation aquaculture systems, aquaponics)	Site level/national
Better management and biosecurity frameworks	Site level/zone/farm clusters
Preparedness and response	
Contingency for emergency management, early harvest and/or relocation	National
Rehabilitation and building back better plans	National/international
Relief programmes, such as work-for-food and "work in reconstruction and rehabilitation projects", that offer temporary jobs for famers and farm workers	International/national
Emergency assistance to avoid additional damage and loss from climate-related disasters – could include fish feed to avoid massive mortality of stocks	National

[1] FA0, 2010.

Source: Poulain Himes-Cornell and Shelton, 2018.

Institutional adaptation

There is some economic literature on institutional and management options (OECD, 2010). There are also studies that have assessed the costs and benefits of management options for adaptation to future climate change. They includes the global EACC study (World Bank, 2010a) as well as the studies highlighted earlier for Peru (UNDP, 2011) and Viet Nam (World Bank, 2010b).

Other studies have considered similar options. Dey *et al.* (2016) assessed the economics of natural resource management and aquaculture as climate adaptations in Fiji. They showed that the net economic gain per year for aquaculture would be USD 802 701 by 2035 and USD 2.6 million by 2050 [USD 2009]. They found that natural resource management (plus fish aggregating devices [FADs]) would generate annual gains of USD 11 million by 2035 and USD 14.5 million by 2050. Together, both options could generate annual gains of USD 16 million by 2050 compared with no adaptation. Dey *et al.* (2016) estimated the economic implications of adapting fisheries in Solomon Islands, looking at FADs, aquaculture and natural resource management. They also found annual net economic gains for each of these options, reaching USD 370 000 by 2050 for aquaculture, USD 10 million for FADs, and USD 2.5 million for natural resource management [USD 2009]. Rosegrant *et al.* (2016) undertook a similar study for Timor-Leste and Vanuatu, again looking at aquaculture development, natural resource management (marine protected areas [MPAs]) and deployment of low-cost, inshore FADs, and assessing the increase in national economic gain with these measures under a future changing climate.

Gaines *et al.* (2018) undertook analysis of future climate change. They found that improvements in fisheries management could offset the negative consequences of climate change (enhancing biomass, catch and profit, compared with "business as usual") if current reforms to fisheries were implemented to address current inefficiencies, adapt to fisheries productivity changes, and proactively create effective transboundary institutions.

However, other studies have found that the standard tools for fisheries management may not be sufficient to build resilience for future climate change (Grafton, 2010; Lane, 2010), as such tools focus on maintaining spawning stock biomass (SSB) above predetermined thresholds and regulate fishing mortality to achieve these SSBs. It is also noted that historical climatic variability does seem to have some correlations with past fisheries collapses (Hannesson, 2011), suggesting at least some role in addition to human influence, and highlighting the potential for threshold effects that might exceed the limits of some of these options.

Some studies have found that **spatial controls** could be important adaptation options, especially options that focus on conservation and protection. These include the introduction of MPAs and locally managed marine areas, as well as the conservation and restoration of near-shore ecosystems that are important for fisheries or play an important role in breeding or ecosystems (notably corals and mangroves). There have been economic studies valuing MPAs, and estimating their potential costs and benefits for fisheries, although there are fewer examples of the benefits under future climate change. For example, economic valuation studies of MPAs have been undertaken in the Mediterranean Sea (Mangos and Claudot., 2013) and in the United Kingdom of Great Britain and Northern Ireland (Kenter *et al.*, 2013; Eftec, 2014), including for specific value chains on shellfish and cod (Eftec, 2015) and studies of MPAs for coral reefs (Emerton, Baig and Saleem, 2009; Londono-Diaz *et al.*, 2015).

Institutional options, including strengthening and capacity building, are also key factors for successful adaptation. These can include technical assistance to support implementation of climate adaptation options and investments in climate-sensitive

sectors, which have been identified as a good low-regret option[2] (LSE, 2016). There is general evidence on the benefits of capacity building and training in climate-sensitive sectors, which report high benefit-to-cost ratios for technical assistance (Mullen, Gray and de Meyer, 2015), although there is no specific evidence for fisheries in the climate domain.

An important set of management options relates to **monitoring and awareness raising**. There is a set of options to take advantage of the threats and opportunities of climate change (Frontier Economics, Ibaris and Ecofys, 2013). There can also be management choices to try and ensure opportunities for small vessel operators. For example, it would be possible to look at prioritizing new opportunities for smaller boats that operate on shorter distances, as opposed to larger deep-water vessels.

A key issue is the need to address information barriers. Thus a priority is to assess, monitor and raise awareness of threats and opportunities for fishers and fish workers along the value chain. This requires the monitoring of new as well as existing species, and planning for both in fisheries management frameworks.

There is also a need to raise awareness for markets and demand for new species. What is clear is that, given evolving risks over time, there is a need for fisheries management options to bring on board the concepts of adaptive management (see Chapter 4), that is, to have an iterative cycle of monitoring, review and learning. This reflects a growing literature on the role for adaptive and dynamic management approaches in fisheries (e.g. Holsman *et al.*, 2018). This includes, for example, the use of a monitoring and learning cycle to inform fisheries policy over time, as well as raising awareness on these changes with fishers. This is likely to be particularly important for species abundance and distribution, and emerging threats such as marine heatwaves and acidification. This information can be subsequently fed back into fisheries policy (e.g. to change catch limits, including between species) and to raise awareness on changes to fishers, to provide information to help them adapt. Early economic analysis of adopting such a method (Watkiss and Cimato, 2019), drawing on the potential benefits outlined by Costello *et al.* (2010), indicates potential positive benefit-to-cost ratios.

In the climate change context, an early option will therefore include the need to enhance monitoring of biophysical parameters of relevance to climate change, e.g. temperature and salinity, as well as of current and new fish species.

Livelihood adaptation

A further set of adaptation options are centred on livelihood adaptation, within the sector and to other sectors.

There are market and livelihood adaptation strategies that respond to climate-induced changes, i.e. anticipatory and/or reactive responses, including autonomous adaptation.[3] Under future climate change, the fishing industry will adjust reactively to address losses, and will take advantage of the opportunities that may occur from changes in fish stocks and the distribution of species and/or changes in species composition. In developed countries, many of these changes will be driven by the existing private sector automatically, although they could be facilitated with information, awareness, etc. from the public sector. Indeed, such changes are already happening (Young *et al.*, 2019).

The costs and benefits of these reactive changes will depend on the localized losses or opportunities faced, and thus have strong distributional patterns. Temperature defines the geographical distribution of many species and their responses to climate change (Pörtner *et al.*, 2014), and this will lead to changes in abundance, geographical distribution, migration patterns, and timing of seasonal activities of species. This means

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[2] Low-regret options have the potential to offer benefits now and lay the foundation for addressing projected changes (IPCC, 2012).

[3] "Adaptation in response to experienced climate and its effects, without planning explicitly or consciously focused on addressing climate change. Also referred to as spontaneous adaptation." Glossary II in IPCC, 2015.

that some areas will experience improvements in catch potential or value, while others will lose. Where there are opportunities (Frontier Economics, Ibaris and Ecofys, 2013), these reactive adaptation options may include increasing vessel capacity and changing equipment to fish for different species, if new or more profitable opportunities arise. Where there are losses, fishers may also adapt reactively to try and address these falling catches, for example, by taking longer trips or by making additional investments such as with FADs. However, these measures will involve additional costs from longer distances travelled, or the need to change equipment or to deeper-water vessels. An early adaptation option is to increase awareness and communicate these changes to fishers, which in turn involves enhanced monitoring of new species (Frontier Economics, Ibaris and Ecofys, 2013), although this falls to the public sector.

There can also be market (autonomous) adaptation from changes in aggregate production, prices and trade. This may lead to changes in supply chains (longer supply chains or alternatives), or it could lead to changes in demand. As an example, these types of changes have been modelled using computable general equilibrium (CGE) models. These show that reactive adaptation costs may be low because economic welfare impacts are compensated by the counteracting effect of trade (although this depends on the substitutability for trade flows and domestic production). For example, the CIRCLE modelling analysis of future climate change (OECD, 2015b) modelled changes in global fisheries catch potential (linking to analysis from Cheung *et al.*, 2010). CGE models can also look at the autonomous effects of enhanced trade in reducing impacts, although they tend to overlook some of the additional transaction costs (and friction) as well as additional transport (and cold storage) costs from longer-supply chains. Again, in some cases, these autonomous changes can be encouraged by governments, for example, by stimulating domestic demand for a broader range of species, or through joined-up retailer and media campaigns (Frontier Economics, Ibaris and Ecofys, 2013). Government is also likely to have a role if increased international trade is used to compensate for local falls.

Alongside this, there is a set of **livelihood diversification options within the sector** that will be important for developing countries, where impacts will be larger (notably in the tropics, and small island developing States). As these may impact particularly on subsistence or small fishers, the reactive responses mentioned/listed above may be difficult to implement due to financing and information barriers, i.e. there is a need for planned support to encourage such changes. These impacts are likely to be most acute for shallow and near-shore fisheries, including fish and shellfish, especially where these are combined with impacts on key habitats (corals, seagrass, mangroves, etc.). This leads to a set of livelihood adaptations, either within the sector or between sectors.

One set of options centres on fisheries value chain development (for example, support to supply chain infrastructure, access to markets, support to diversification or high-value markets), but also extends to reducing post-harvest losses. However, these are not specifically targeted at climate risks. Several studies have identified aquaculture as one of these options. As an example, small-scale aquaculture has been identified as a viable adaptive strategy by fishers living around Lake Chad, where severe droughts have reduced the size of the lake (Ovie and Belal, 2012). Several studies have included aquaculture as part of a portfolio of marine adaptation options in the economic analysis of fisheries adaptation (Dey *et al.*, 2016; Rosegrant *et al.*, 2016). However, aquaculture is often costly and often involves support (training, management, and finance for infrastructure). Moreover, aquaculture is itself affected by climate change and thus may need to adapt (i.e. to be climate-smart). Porter *et al.* (2014) highlight that invertebrate fisheries and aquaculture are vulnerable to the impacts of ocean acidification, as well as to climate-induced changes in critical habitats. They find that this may require improved feeds, selective breeding for higher-temperature-tolerant strains, shifting to more tolerant species (whether for temperature or acidification), better site locations,

and the use of integrated water resource management, as well as improved weather and climate services (for floods and weather extremes).

There are also options for **diversifying livelihoods between sectors**, notably for local fishing and port communities. Tourism is sometimes suggested as an alternative income source for fishing communities, but this can create its own challenges and exacerbate the climate change risk.

Risk reduction and management for resilience

There are a number of options that are focused on reducing and managing risks. There are studies on the benefits of **weather and climate services** for fisheries, including **early warning systems**, which are often classified as low-regret options. These have been found to have good benefit-to-cost ratios, across a range of sectors (ECONADAPT, 2015). Benefits arise from the use of information to improve decisions (the value of information), which reduces losses/enhances gains. However, to deliver benefits, there needs to be investment along the whole weather chain (i.e. including forecast accuracy, communication and end-user response) not just in meteorological infrastructure.

In the commercial fishing industry, weather forecasts (daily to weekly) including early warning systems are important for fishers' safety. As extreme weather events have the potential to increase under climate change, these can also be considered as adaptation options. The benefits of early warning systems are high, especially when avoided fatalities are included.[4] There is also the potential to use longer-term climate services, such as seasonal forecasts, to look at enhanced fisheries management.

An earlier review (Clements and Anderson, 2013) identified six studies that had looked at the benefits of weather and climate services for the fisheries sector, although several of these were for recreational fisheries and all were based on the United States of America. These normally value the increased number of fishing days (commercial or recreational) or enhanced value of catch. Costello, Adams and Polasky (1998) estimated the value of perfect and imperfect forecasts for El Niño–Southern Oscillation (ENSO) forecasts for the coho salmon fishery in the Pacific. They estimated that perfect ENSO forecasts would produce annual welfare gains of about USD 1 million in consumer and producer surplus (e.g. profits for producers, and consumer surplus for recreational fishing). Some studies have looked at short-term forecasts, with studies of coho salmon fisheries in the State of Washington, the United States of America. Kaje and Huppert (2007) looked at the benefits of short-term climate information and estimated an improvement in the total value of 2–24 percent, with USD 90 million in welfare benefits, for boat-based recreational anglers in the Gulf of Mexico and Wieand (2008) estimated the value of forecast information (including improved ocean observation systems and ENSO forecasts) for recreational fishing. Clements and Anderson (2013) also report on one other study, by Jin and Hoagland (2008), who estimate the benefits of forecasts of harmful algal blooms at from USD 1 million to USD 50 million to near-shore commercial shellfish fisheries in New England, the United States of America (benefits varying with the frequency of blooms, prediction accuracy and response). The National Oceanic and Atmospheric Administration (NOAA, 2002) estimated values associated with improvements to the geostationary operational environmental satellites system, including for ocean fishing, as such satellites allow for better monitoring of storm development and movement. However, Orlove, Broad and Pettyl (2004) studied the response of fishers to ENSO forecasts in Peru, and Broad, Pfaff and Glantz (2001) studied misinterpretation of forecasts for forecast users within the Peruvian fisheries

[4] These include the valuation of prevented fatalities, more specifically the change in the risk of a fatality. There is extensive literature on such valuation, although it is often still considered controversial. Recent World Bank documentation (Narain and Sall, 2016) suggests that, while the human capital approach is appropriate for financial analysis and accounting, an alternative approach – based on individuals' willingness to pay to avoid or reduce the risk of premature mortality – is more appropriate for economic analysis. The appropriateness of the willingness-to-pay approach is discussed in more depth in Chapter 3.

sector during the 1997–98 El Niño season. Both these studies highlight the challenges in producing good forecast information, accurate and timely communication, and the uptake and use of these forecasts to improve decisions.

There is ongoing cost–benefit analysis (CBA) of new early warning systems for fishers, including off the coast of the United Republic of Tanzania (multi-hazard early warning service [WISER, 2017]) and in Lake Victoria (Highway [WISER, 2018]). The latter is particularly important as the lake has some of the highest fatality rates for fishers anywhere in the world.

These weather and climate services also have potential for aquaculture, but there is less documented evidence of the development of targeted services.

There are also opportunities for **insurance, risk pooling and risk transfer**. Insurance is a potential low-regret option (IPCC, 2012), and has potential application to the fisheries sector for extreme events. This is a complementary tool to planned adaptation as it shares and transfers the financial risks of large-impact, low-probability extreme events across many different locations.[5] However, it should not be seen as an answer to address slow-onset change (trends) – or very frequent extreme events – because premiums become unaffordable (DFID, 2014). Insurance has potential benefits in helping to spread the risk of wind storms (and damage to fishing vessels and equipment) but not to changes in fish distribution or catches (trends). While climate change will alter the frequency, intensity, extent, duration and timing of extreme weather and climate events, and is likely to result in unprecedented extremes (IPCC, 2012), the impact on wind storms (especially tropical storms) is uncertain with respect to frequency, intensity and location (storm tracts). There is more evidence that human-induced global warming has increased the frequency and intensity of heavy precipitation events, and increasing extreme heat (IPCC, 2018), which are relevant for aquaculture.

There are existing insurance schemes for such risks, and their uptake is therefore a form of adaptation. There is also an emerging focus on insurance for aquaculture and existing pilots (FAO, 2016, 2017) – although these highlight some challenges (premium levels, and moral hazard) – which includes new insurance offerings such as index-based insurance. When these target small-scale fishers, there is often a need for some level of government support.

There is also a greater focus on national risk-pooling facilities (CCRIF, 2010; ARC, 2014) that provide macro and regional risk pooling, for example, to cover extreme tropical storm risk. Development cooperation providers have also pioneered the use of prearranged credit lines and disaster contingency funding (credit) to provide rapid access to funding following an extreme event (Campillo, Mullan and Vallejo, 2017; ADB, 2019).

For the most vulnerable people, there is the potential for targeted support, i.e. social protection and shock contingency response funds. These have been found to have high benefit-to-cost ratios in general (DFID, 2011; Cabot Venton and Coulter, 2013; Cabot Venton and Majmuder, 2013; Cabot Venton, Coulter and Schmuck, 2013), and there are some examples of the application to small-scale fisheries communities (FAO, 2015).

There is a wider range of **risk reduction** measures. One set of these relate to equipment and infrastructure, undertaken by fishers themselves. These can include specific targeted adaptation measures, for example, vessel type, safety and stability to address changing storm risks, stronger structure, or more resilient design for aquaculture.

In terms of coastal marine and coastal aquaculture, there are more obvious risk reductions to address rising sea-level rise and storm surges. Construction of sea walls or dykes has been highlighted as an adaptation for coastal aquaculture. As an example,

[5] However, this should be treated with caution as an extreme event can bring about the collapse of an entire system. In the literature, this issue is referred to as systematic risk problem. Chapter 3 discusses risks in more depth.

Danh and Khai (2014) conducted a CBA of dykes, including the benefit/value of aquaculture by comparing the value of salinity-free production with salinity-affected production of giant river prawns.

Moving to coastal infrastructure, i.e. landing, port facilities and storage facilities, there is a large literature on the costs and benefits of coastal protection (for a review, see ECONADAPT, 2015). This literature shows high benefit-to-cost ratios when applied for densely populated coastal areas. However, in lower-density areas, the benefit to cost ratios of these larger-scale protection measures fall.

There are also studies that consider the use of alternative ecosystem-based adaptation for coastal protection, particularly in tropical countries. Some of these (corals and mangroves) are also promoted as an alternative to hard protection (sea walls), and studies show potentially high benefits – with enhanced fisheries as an important co-benefit of the primary focus on shoreline protection. Examples include high benefits from coral (Jones, Hole and Zavaleta, 2012) and high benefits from mangroves (CWF, 2009; CCRFI, 2010) as alternatives to hard coastal protection. There are also benefits found for sand dunes and offshore sand banks, which offer greater flexibility and lower capital costs than hard alternatives, but have higher maintenance costs – thus, the discount rate will affect the benefit-to-cost ratio (de Bruin, 2012). However, ecosystem-based adaptation usually has modest benefit-to-cost ratios due to fact that these systems take time to establish (benefits arise in the future), and they often have opportunity or transaction costs.

One particular area of focus is on the design of new infrastructure, including ports, jetties, etc. A key priority here is for enhanced climate risk screening. This is a low-cost step to assess the potential current and future risks, and to identify potential changes in design. The results of climate risk assessments can support the decision of whether to climate-proof infrastructure from the outset, make the project climate-ready, or wait for further information (ADB, 2015). This is being integrated as part of multilateral developments banks' due diligence and investment appraisal project cycles, and has been applied to port and coastal investments (see for example, ADB, 2014). It can help to avoid decisions that are expensive or impossible to reverse later. Most multilateral development banks have now introduced climate risk screening. The benefits of these systems are informally captured through the identification of climate risks, and thus impacts prevented. This can be seen through the economic appraisal of options (ex ante) as compared to baseline (do nothing).

There is a further set of risk reduction measures along supply chains, i.e. processing, storage, transport, marketing (wholesale and retail) and final consumer retail. Identification of key elements along supply chains may be important in developing adaptation strategies. Plagányi *et al.* (2014) developed a quantitative metric to identify critical elements in a fisheries supply chain, and to understand the relative stability of different supply chain structures.

In general terms, disaster and emergency **preparedness and response** has very large benefits, as identified in reviews of the early adaptation literature (Shreve and Kelman, 2014, ECONADAPT, 2015). Although these reviews focus primarily on terrestrial disasters, they have high relevance for tropical storms and potential damage to the fishing industry.

Conclusion

This chapter has summarized the methods used to assess the economics of adaptation to climate change in the fisheries and aquaculture sector. It shows that the approaches used for assessing the costs and benefits of adaptation have changed over time. Earlier studies focused on the costs of adapting to long-term changes. Over time, more emphasis has been placed on the costs and benefits of adaptation to inform near-term on-the-ground adaptation. Alongside this, there is a recognition that there are different types of adaptation, and to address this a number of adaptation typologies

have emerged. They include typologies that align more strongly to the fisheries and aquaculture sector, with institutional adaptation, livelihood adaptation and risk reduction and management. Finally, while more standardized methods and option typologies are now emerging for adaptation in the fisheries and aquaculture sector, the evidence base on the costs and benefits of adaptation remains low. This highlights the need to develop more evidence in this area.

3. Methodological challenges concerning the costs and benefits of adaptation

With the uplift in international climate finance[6] and flows for adaptation (UNEP, 2018), and the emergence of NAPs through to local projects, there is now a greater focus on the economic appraisal of adaptation. Economic appraisal is standard practice in public-sector investment decisions in many countries (e.g. HMT, 2018), as well as in international development finance and overseas development assistance. It provides support to decision makers to help ensure the appropriate use of public finances, and to assess alternative options available for meeting objectives, by assessing costs, benefits and performance against other decision criteria.

These appraisal methods are also used in fisheries and aquaculture management. For example, as set out in the FAO Ecosystem Approach to Fisheries (EAF) toolbox (FAO, 2009), once the set of operational objectives, indicators and performance measures for a fishery have been identified, the next action is to produce an agreed set of management measures to generate acceptable levels of performance. This involves the identification of potential management options and some level of appraisal to determine which of these will be the most practical and appropriate given the fishery's value and location, and the level of resources available (human, financial and information). This analysis can include quantitative as well as qualitative analyses.

However, there are additional challenges in applying these conventional appraisal and decision-support tools to adaptation, especially for economic analysis (OECD, 2015a). They include the challenges involved in the quantification and valuation of benefits, but also issues relating to uncertainty and to discounting. This chapter summarizes these challenges.

Risk and uncertainty: a conceptual difference

Adaptation aims to prevent or minimize damage, or to take advantage of opportunities, that may arise from climate change. To estimate the costs and benefits of adaptation options relative to a baseline scenario, the projected climate change impacts and the costs of different options must be examined. In this regard, it is important to clarify on what basis the assessment can be made, and more specifically, to keep in mind the difference between the concepts of **risk** and **uncertainty**.

The economics literature generally uses the two terms in a very distinct way (see Box 1). The economic definition of risk is the likelihood, measured by its probability, that a particular event will occur (see for example, HMT, 2011). It is partially reflected in the climate change literature, with risk defined (IPCC, 2014) as "The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as **probability or likelihood** of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur." However, the IPCC (2014) also uses the term "risk" as an overarching term in its core concepts, whereby risk is the combination of hazard,

[6] The term climate finance is defined by the United Nations Framework Convention on Climate Change (UNFCCC) Standing Committee on Finance (UNFCCC, 2014): "Climate finance aims at reducing emissions, and enhancing sinks of greenhouse gases and aims at reducing vulnerability of, and maintaining and increasing the resilience of, human and ecological systems to negative climate change impacts."

exposure and vulnerability. For example, "risk is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure" (IPCC, 2014).

BOX 1

Distinction between risk and uncertainty

In economics, the distinction between risk and uncertainty can be traced back to Frank Knight and John Maynard Keynes. The latter wrote that: "By 'uncertain' knowledge, let me explain, I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject, in this sense, to uncertainty; nor is the prospect of a Victory bond being drawn. Or, again, the expectation of life is only slightly uncertain. Even the weather is only moderately uncertain. The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention, or the position of wealth owners in the social system in 1970. About these matters there is no scientific basis on which to form any calculable probability whatever."[1] Keynes considered uncertainty as closely related to the development of the economy and society. In particular, economic activities take place in a context where the future is uncertain and cannot be handled by probabilities. For Keynes, this explains the advent of crises and the instability of the economy. One reason for the fragility of the financial system that led to the financial crisis of 2008 was the confidence that uncertainty could be transformed into calculable risk. In the words of Alan Greenspan: "A Nobel Prize was awarded for discovery of the pricing model that underpins much of the advance in derivatives markets. This modern risk management paradigm held sway for decades. The whole intellectual edifice, however, collapsed in the summer of last year."[2]

[1] Keynes, J.M. 1973. The General Theory and after. *The Collected Writings of John Maynard Keynes*, Vol. XIV, pp. 113-114. Macmillan, London.

[2] House of Representatives. 2010. *The Financial Crisis and the Role of Federal Regulations, Hearing Before the Committee on Oversight and Government Reform, Second Session, October 23, 2008*. Washington, DC, Government Printing Office.

On the other hand, uncertainty generally relates to a case where it is impossible to attach probabilities to outcomes (see for example, HMT, 2011). It has been defined as: "A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior." (see Moss and Schneider, 2000; Mastrandrea *et al*., 2010).

This publication uses the term risk when it is possible to estimate the probability of certain events or outcomes, based on existing data, and therefore to consider economic analysis. Insurance companies calculate premiums based on risk estimates. This is because they can estimate the probability and costs of an event by referring to time series and statistical data (for example, number of car accidents, probability of death or illness for each age, or number of extreme weather events recorded in the past and their economic effects).

This publication uses the term uncertainty when there is no scientific/factual basis for deriving a risk estimate, i.e. where it is impossible to attach objective probabilities. Making decisions under uncertainty is therefore more difficult and involves the use of principles or criteria that will vary with the decision (for example, these may relate to the minimization of reasonably foreseeable damages, or the use of estimates that may

resemble risk assessments). Interestingly, in fisheries and aquaculture, the concept of uncertainty prefigures the precautionary principle (Code of Conduct For Responsible Fisheries, article 7.5 [FAO, 2011]).[7]

Therefore, although decisions can be made under uncertain conditions, the basis is quite different than when making decision under risk. There is in fact no factual basis against which to measure the probability that a particular event will occur. On the other hand, in the case of risk, predictions can be quantitatively substantiated.

Turning to the **nature** of the events subject to risk or to uncertainty, several considerations need to be made. First, there is a profound difference between projecting natural phenomena (such as flood probabilities) and forecasting economic or social processes. For the former, probabilistic modelling can be used, for example, looking at the probability of defined events and building up an overall probability-loss analysis. For the latter, as seen in Box 1, uncertainty is at the heart of these social and economic processes, which are by their nature unpredictable, especially in their long-term evolution. In summary, when considering history and society in the long term, deterministic or stochastic methods need to be used with caution. A key issue here is that climate change is determined by future social and economic change, with different futures leading to alternative future emission pathways, such as low- or high-warming pathways. This means that while it is possible to use climate models to assess the changes from any one specified emission trajectory and its associated radiative forcing (as captured in the alternative representative concentration pathways [see IPCC, 2013]), there is uncertainty over which emission pathway future will occur, which is determined by the socio-economic future. Shared socio-economic pathways (O'Neill *et al.*, 2014) provide socio-economic data for alternative future pathways and include differing estimates of future population and human resources, economic development, human development, technology, lifestyles, environmental and natural resources, policies and institutions, which in turn affect exposure, vulnerability and risk.

As a consequence, it is very difficult to evaluate localized impacts of future climate change in probabilistic terms. There are several reasons for this, starting with the underlying uncertainty around socio-economic futures (which determine emissions) and the difficulty of assigning a statistical probability to future scenarios (due to the complexity of the variables and feedbacks involved in the construction of the models at the local level). There have been examples where probabilistic projections have been derived, but these are only for individual emission pathways (or representative commission pathways) (see for example, Murphy *et al.*, 2009), not for all possible emission pathways as one single composite probability. In other words, uncertainty is the consequence not so much of the nature of the phenomenon itself, but of insufficient knowledge of the dynamics connected to the phenomenon. The difficulties in assessing future climate impacts are due to (National Research Council, 2010):

- The natural internal variability of the climate system: The climate system naturally varies, as a result of the internal dynamics of the coupled atmosphere–ocean system, regardless of external radiative forcing due, for example, to increased concentration of greenhouse gases (GHGs), aerosols from volcanic eruptions or change in land use (Cubasch *et al.*, 2013). This internal variability includes natural fluctuations in large scale phenomena such as the ENSO, often known as climate variability.
- The trajectories of future GHG emissions: Uncertainty also derives from an imprecise understanding of future emissions and concentrations of GHGs and aerosols as a result of: population growth, economic and social development, the development and utilization of carbon-free energy sources and technology,

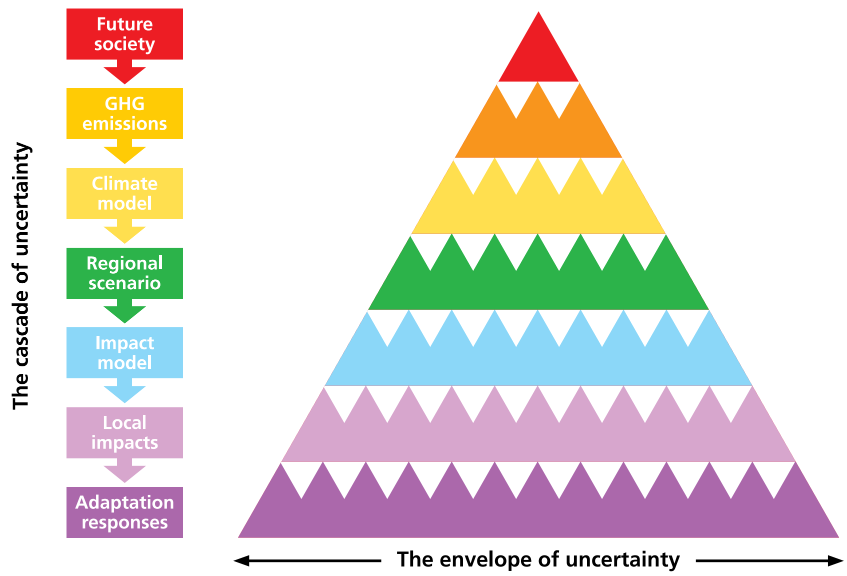
[7] In cases of high uncertainty (or lack of adequate scientific information), the Code of Conduct For Responsible Fisheries recommends adoption of the precautionary principle in order to avoid irreversible damage and high costs to the aquatic resources and to society.

and changes to agricultural practices and land use (Nakicenovic *et al.*, 2000; O'Neill *et al.*, 2014). There are alternative scenarios that project changes in these determinants. However, in order to estimate future emissions levels, or all combinations with future emission pathways, there is future uncertainty over which of these scenarios will occur, and how socio-economic factors will change. This makes the prediction of emissions in the future uncertain (Pielke, 2007; Hallegatte, Przyluski and Vogt-Schilb, 2011).

- The response of the global climate system (as well as of the natural systems and sectors) to any given set of future emissions (and radiative forcing): Responses of the climate system to the GHG emissions are normally analysed using climate models (National Research Council, 2010). Because different models represent the functioning of the climate system differently, model outcomes will be different even for the same radiative forcing scenario – even sometimes with differences in the sign of change, for example, whether there are increases or decreases in rainfall. A further dimension of uncertainty in climate projections arises from downscaling. Current models are not sensitive enough to project all complex climate variables at a local scale (Watkiss, Hunt and Savage, 2014). The lack of local geographical knowledge and the inability to model on a local level are further sources of uncertainty (Refsgaard *et al.*, 2013; Foley, 2010).

In the context of climate change adaptation, the issue is particularly complex, as uncertainty (relating to these factors) expands and proliferates at each stage of analysis (Figure 1). Thus, it is actually more accurate to speak of a "cascade of uncertainty" (Wilby and Dessai, 2010) whereby: "A cascade of uncertainty proceeds from different socio-economic and demographic pathways, their translation into concentrations of atmospheric greenhouse gas (GHG) concentrations, expressed climate outcomes in global and regional models, translation into local impacts on human and natural systems, and implied adaptation responses. The increasing number of triangles at each level symbolize the growing number of permutations and hence expanding envelope of uncertainty."

FIGURE 1
The cascade of uncertainty



Source: Wilby and Dessai (2010).

This means that it is difficult to predict and optimize adaptation. Uncertainty has long been recognized as an issue in the adaptation literature. However, it has also become a major focus of the economics of adaptation in recent years (Watkiss *et al.*, 2014). The following section sets out some of these issues and how they can be addressed.

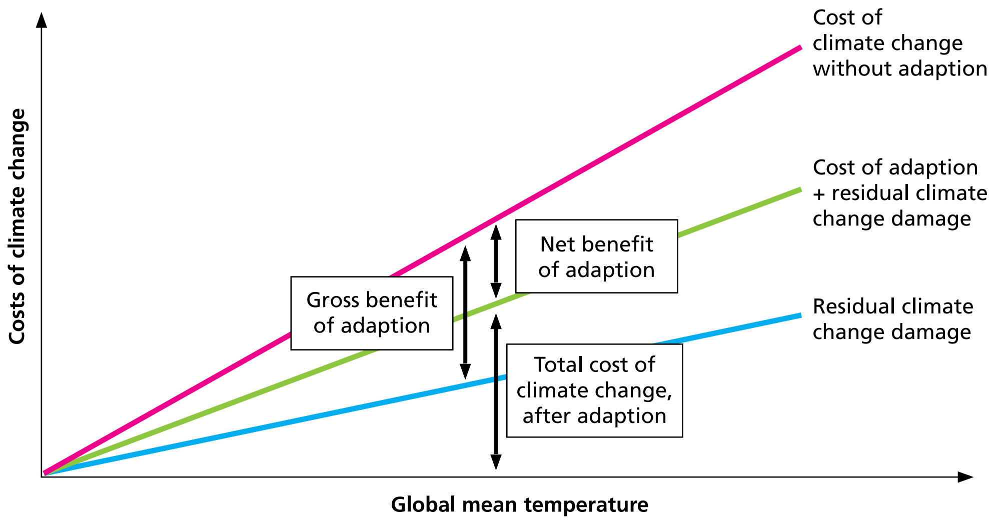
Monetary and non-monetary costs: measurement problems

From an economic perspective, the benefits of investing in a specific adaptation action equal the reduction in the economic damage caused by climate change. Figure 2 shows how these costs and benefits can be represented theoretically (Stern, 2006). However, as highlighted above, it is often not possible to characterize a quantitative approach to implement this due to uncertainty.

Future climate change will lead to economic costs (damage) that increase over time, shown by the red line in Figure 2. Adaptation can reduce these costs downwards, but it is unlikely to remove impacts completely. Therefore, there is residual economic damage even after adaptation (shown by the dark blue line). The reduction achieved by adaptation (to the level of residual damage) reflects the gross benefit of adaptation, i.e. the avoided damage. However, adaptation has a cost, which needs to be added to the residual damage (shown by the green line) to estimate the total cost of climate change with adaptation.

While the net benefit of adaptation is the damage avoided minus the cost of adaptation, there is an important trade-off involved in deciding how much adaptation to do. This trade-off arises because adaptation costs will increase (often disproportionately) as climate impacts are reduced. Thus, there is a balance to be found relating to whether to increase adaptation and bear higher costs, or undertake less adaptation (with lower adaptation costs) and bear higher residual impacts. However, the choice of the level of adaptation (the trade-off between adaptation costs and residual damages) is an ethical and political one, not just an economic optimization, as it involves moral perspectives (UNEP, 2014), for example, relating to the number of fatalities that occur. Views on the objective and criteria for adaptation will therefore vary between actors, notably between those that are financing adaptation versus those that bear the residual impacts.

FIGURE 2
Costs of climate change



Source: Stern (2006).

Using these types of frameworks, the analysis of the costs and benefits of adaptation can be considered in the broader context of economic appraisal. The analysis of adaptation options, as part of the development of policies, plans and projects, is often subject to a process of appraisal, which aims to identify the best way to deliver the objectives.

For public policy, this includes the economic justification for intervention, as well as an economic appraisal of alternative ways of delivering the objective. As highlighted above, this includes the identification of options that could meet the objectives, and an appraisal of their costs and benefits (from a societal perspective). This allows resources to be allocated efficiently against other priorities and allows prioritization from alternative options. This type of economic analysis is carried out from the perspective of the entire economy, and it assesses the impact of a plan or project on the welfare of all of society. The analysis includes the economic valuation of non-market areas, such as environmental costs and benefits, and it considers economic rather than market prices (noting that because of this, it differs from a financial appraisal). This differs from a purely financial appraisal, which considers options from an individual perspective, and excludes non-market prices.

The need to consider both market and non-market aspects is critical for the economic appraisal of fisheries, especially given that fisheries involve natural resources. However, the analysis of these two aspects calls for different approaches.

Where markets exist, there are often prices available that can be used in appraisal. However, it is important to consider whether these are appropriate. To expand, when reference prices are available, economic theory recognizes that these prices are not necessarily a measure of economic well-being. For example, the benefits of an antibiotic or the access to drinking-water, may not be represented by their price. In economics, benefits are measured by the "consumer surplus", that is, the difference between what consumers are willing to pay and what they are actually paying.

The second issue is what to do when no market prices exist, i.e. for non-market sectors. This can be particularly relevant when considering fisheries ecosystems. In such cases, there are economic approaches that can be used to derive costs and benefits, for use in an economic analysis. For adaptation, these methods (Metroeconomica, 2004) include:

- Substitute and replacement cost methods. These measure the value of resources in terms of the costs of the replacing the ecosystem or its goods and services. These costs are then used as a proxy for benefits. These methods have been used for terrestrial ecosystem adaptation, with analysis of the costs of restoration of habitats (e.g. Hunt, 2008). However, this approach does not fully capture ecosystem service benefits, and is therefore only appropriate when other approaches are not possible.
- Methods based on "revealed preferences". These methods use surrogate prices and market values to reveal preferences of non-market prices, for example, measuring how property values differ according to changes in environmental conditions. A further application of this approach is the travel cost approach, which uses the expenditure and time people spend for a recreational trip to reveal the value of a natural resource (i.e. using information on visitors' total expenditure to visit a site to derive their demand curve for the services provided by the site).
- Contingent valuation methods. A set of further approaches asks people directly what value they place on a good or service – they are known as contingent valuation methods. They often use survey questionnaires to describe a hypothetical situation in order to elicit how much the respondent would be willing to pay either to obtain or to avoid the described situation (willingness to pay [WTP], or willingness to accept [WTA]). They therefore ask how much individuals are **willing to pay** for a certain asset or public intervention, or how much they are **willing to receive** to abandon an asset or accept a negative consequence.

These methods have been described in the environmental economics literature for many years, but their application to adaptation is at an early stage. There are also some major challenges in applying them to the climate change context. A key problem is that even if there are estimates of the value of an ecosystem, there is often a lack of quantified information on the impact of climate change on this system (i.e. the attribution of climate change to the impact) and even less information on the exact benefits (in reducing these impacts) that adaptation will deliver.

The revealed and stated preference methods refer to the payment capacities of the individuals involved. Their scientific and theoretical basis is much discussed, both on the level of accountability of the techniques used, and on the level of equity and ethical and distributional issues (see Box 2).

BOX 2

Benefits and efficient allocation in economics

In economics the concept of efficiency, as provided by Pareto, says that a given allocation is efficient if, and only if, it is not possible to change it without causing a loss to somebody. Moreover, in reallocating resources, only those changes that could improve the welfare of somebody without losses to anybody else could be considered welfare improvement. Changes that would create benefits to some and losses to others cannot be assessed against scientific grounds, as this would require an interpersonal comparison of utility. This conception of efficiency sets aside ethical and distributive issues. Against this background, welfare economics has discussed whether to consider the interventions where those advantaged can compensate those damaged while maintaining a profit margin, as Paretian improvements. In the presence of groups or individuals who have suffered a loss in terms of well-being, ethical and distributive issues are decisive. (For a critique of the Pareto efficiency concept, see Ventura, Cafiero and Montibeller, 2016).[1]

[1] Ventura, A., Cafiero, C. & Montibeller, M. 2016. Pareto efficiency, the Coase theorem and externalities. a critical view. *Journal of Economic Issues*, 50(3): 872–895.

It is possible to briefly illustrate the issue by discussing a problem related to the difference between WTP and WTA. Researchers find that the two estimates do not match.[8] The problem is prominent because the efficient choice changes when one or the other of the two references is followed.

As an example, following the WTP measure, one would ask a fishing community how much they are willing to pay in order not to be deprived of the ecosystem on which their subsistence depends (including their social life). The amount/price provided is defined/limited by their financial resources. Following the WTA measure, the same stakeholders/group/individuals are asked how much they are willing to receive in order to consent to the destruction of the same ecosystem. The amount/price put forward could be very large, and the community unwilling to compromise.

The value of the resource can vary considerably, depending on whether, to arrive at a monetary estimate, the WTP or the WTA is used. A way to summarize the problem is to observe that the divergence between the results lies in the different starting points. The WTP method starts from the **subtraction of a right** and asks how much the group/individuals are willing to pay to regain it. This deprivation makes the group poor – the latter can pay little to maintain the right itself. In the WTA case, the starting

[8] "… in principle, either WTP measure or WTA measure could be used interchangeably to elicit individuals' preferences for change in the level of environmental goods and services. Yet, one of the issues that is supposed to affect the validity of the CV [contingent valuation] results is the disparity that arises between the WTP value and WTA value for the same good under consideration." Venkatachalam (2004), Kim, Kling and Zhao, (2015).

point is the **assignment of a right** and the question is at what price they are willing to sell it. This makes stakeholders wealthier and free to choose. It is expected that they will not be willing to sell their right for the same amount as in the previous case. The outcomes from the WTP and WTA methods cannot therefore coincide.[9]

The example helps detail the difficulties encountered in defining the economic efficiency of a policy or an investment regardless of non-economic considerations, such as equity issues or problems related to the allocations of rights (Ventura, Cafiero and Montibeller, 2016). In general, due to differences in the ability to pay, monetary estimates of this nature (particularly those used in CBA) attribute little value to the natural environment in poor areas and more value in the rich ones. Thus, from a strictly economic point of view, the same damaging effect (e.g. destruction of an ecosystem) can be efficient (in the sense that it is not worth investing to avoid it) or inefficient (i.e. it is worth investing to avoid it), depending on the wealth of damaged stakeholders. Similarly, investing in "adaptation" may be efficient or not, depending on whether it benefits high- or low-income populations. To address these difficulties, a common practice is to correct monetary estimates by using equity weights, which recognize that USD 1 lost or gained to a poor person is worth more than USD 1 lost or gained to a rich person (Adler, 2016).[10] However, the application of such rates is rarely undertaken in economic appraisal, and more typically, different options or policies are assessed qualitatively in terms of their distributional consequences.

Time horizons and discount rates

Another challenge concerning the costs and benefits of adaptation relates to the profile of adaptation costs and benefits over time (OECD, 2015a). In many cases, the impacts of climate change only occur (significantly) in the future, notably beyond the 2040s. The full benefits of adapting to these future impacts therefore arise in the longer term as well, although costs may be incurred earlier.

In economic appraisal, the timing of costs and benefits matters. This reflects the principle that, generally, people prefer to receive goods and services now rather than later. This time preference is captured by discounting – a technique used to compare costs and benefits that occur in different periods. This applies discount rates to convert future costs or benefits to present values. As shown in Table 3, the choice of the discount rate is important:

Table 3
Present value of USD 100 in "n" years

	Discount rate			
Years	**1%**	**2%**	**5%**	**10%**
n = 5	95	91	78	62
n = 20	82	67	38	15
n = 100	37	14	0.8	0.007

Table 3 shows that, with a discount rate of 1 percent, USD 100 in five years' time is equivalent to a present value of USD 95, but at a discount rate of 10 percent, this falls to USD 62. Using the standard social discount rates (or economic internal rate of return thresholds) that are typically used in economic appraisal, especially in developing countries, the economic benefits of future adaptation are therefore small in present value terms when a high discount rate is used. This makes it difficult to justify high

[9] The difference can be explained by the income effect, defined as the effect on the demand for an increase or decrease in income. If the goods can be replaced by goods that can be bought on the market and the asset itself is not very relevant for the group/individual, then WTP and WTA can have similar outcomes.

[10] Note that equity weights apply more generally to the issue of economic appraisal – they are not just confined to WTP issues

upfront adaptation costs today for benefits that occur in the future. These issues are amplified for year 20 and especially for periods longer than this.

When lower discount rates are used, higher weight is given to benefits in the future. Conversely, the higher the discount rate, the less the future will count in today's choices. This is important. Developing countries (and overseas development assistance and international finance institutions undertaking economic appraisal in these countries) use social discount rates that are high, e.g. 10 percent or higher (OECD, 2015a).[11] This significantly affects the economic benefits of longer-term adaptation. There are different ways that social discount rates, i.e. ones that are used in economic appraisal, are derived (see Box 3).

Basically, the discount rate operates like the lens of a reversed telescope. It deforms the temporal perspective and alters the consideration of the long-term effects of today's choices. The effect is very marked if the discount rate is high and the period is long. Therefore, when a social planner has to invest resources in the perspective of future benefits (or harm reduction), the choice of the social discount rate (SDR) is decisive.

Nevertheless, discounting is used in all economic appraisals, and a high discount rate means that future benefits are given less weight in today's choices. The problem has particular importance for those environmental choices that have irreversible effects. To correct for these effects, some authors suggest considering a lower discount rate to evaluate benefits that are more distant in time (Arrow *et al.*, 2014; Arrow *et al*., 2013).

BOX 3

Deriving social discount rates

The social discount rates (SDRs) used in economic appraisal are derived in different ways. The classical approach is to use the Ramsey formula, which considers three fundamental parameters:

$$\mathrm{SDR} = P + \mu\, g$$

Where: P is the rate at which individuals discount future consumption over present consumption; μ is the elasticity of marginal utility of consumption; and g is the annual growth per capita consumption. Sometimes a fourth parameter is considered, of a negative sign, which accounts for the uncertainty or the possibility that catastrophic events may occur, factors that induce taking greater consideration of the future by lowering the SDR.

The use of the Ramsey formula is much debated. The debate focuses on the fragility of the hypotheses on which it is based, the difficulty in estimating or observing the parameters, and divergences in the choice of parameters.[1] Moreover, it does not explicitly consider the costs of obtaining capital, the problems of intergenerational equity, or the possibility that, also for the current climate changes, future generations may not be more affluent than the current ones.[2]

A different approach, to avoid the problems of calculating the Ramsey formula, is the use of the social opportunity cost (SOC) of capital. The foundation of this approach is that, in competitive and efficient markets, the interest rate expresses the intertemporal preferences of individuals. The discount rate must then be consistent with the rate of return of funds in the private sector. Here, the question is whether the thesis on market efficiency is valid (Spackman, 2018).

[1] Dasgupta, P. 2008. Discounting climate change. *Journal of Risk and Uncertainty*, 37: 141–169; Drupp, M.A., Freeman, M., Groom, B. & Nesje, F. 2015. *Discounting disentangled: an expert survey on the determinants of the long-term social discount rate*. Centre for Climate Change Economics and Policy Working Paper No. 195, Grantham Research Institute on Climate Change and the Environment Working Paper No. 172.

[2] Freeman, M., Groom, B. & Spackman, M. 2018. *Social discount rates for cost-benefit analysis: a report for HM Treasury*. A summary report from two workshops on recent advances in social discounting practice and theory.

[11] In contrast, discount rates conventionally used in OECD countries are typically being between 3.5 percent and 7 percent.

Considerations on ethical and distributive problems

The issues above pose ethical and social problems. Both risk-related issues and the choice of the discount rate are important from the point of view of intergenerational equity, as it can imply little or no consideration for the well-being of future generations. As Table 3 shows, the choice of the discount rate is very significant, even for a time horizon of 20 years. This issue has become a key issue in the climate mitigation literature (Kolstad *et al*., 2014), where the time dimensions are very long and there are non-marginal effects on future generations. These issues are less relevant for adaptation, where decisions are often similar in nature to conventional policy decisions and thus conventional fisheries economic appraisal. However, it is potentially relevant when the choices made today (or the lack of action) produce irreversible impacts.

There is also a set of issues around intra-generational equity, i.e. between those in society. In the monetary evaluation of the costs and benefits of interventions, issues concerning the rights of individuals and populations are involved. As noted, the attempt to translate these costs and benefits into monetary terms assumes that the welfare measurement of the subjects involved is their WTP. This assumption must be carefully considered. In fact, it can be acceptable when making choices that involve subjects who have comparable financial means. However, caution must be used when this homogeneity is not present and the interests of groups with unbalanced economic power are compared. This is the case, for example, of relations between developed countries and developing countries, and between users of a natural resource for tourism or for the subsistence of low-income populations. In the latter cases, the comparison of payment capacities neglects the needs of the poorest sections of the population, to the advantage of the wealthiest.

Conclusion

This chapter has provided an overview of the additional methodological challenges for assessing the costs and benefits of adaptation. Sometimes, economic theory and appraisal applications try to avoid the above-mentioned problems, bringing them back into a conventional context. However, such issues (e.g. uncertainty, discount rates, equity weights and non-monetary measures) have a major influence on adaptation results. Therefore, it is important to be clear about these issues (and any assumptions) in order to ensure a balanced and reliable comparison between the different options (Poulain, Himes-Cornell and Shelton, 2018).

4. Economic appraisal of fisheries and aquaculture adaptation

The methods for adaptation appraisal have been evolving to address the methodological challenges raised in Chapter 3. Frameworks and approaches for identifying and prioritizing early adaptation, i.e. early adaptations that are likely to have good returns on investment, have been developed and applied. These are sometimes termed **no- or low-regret adaptation frameworks** (e.g. IPCC, 2012; DFID, 2014).[12] Alongside this, there has been the development of methods to address the particular challenge of uncertainty as identified in Chapter 3, with decision support for the appraisal of adaptation options using **decision-making under uncertainty (DMUU)**. The two are linked, but their application can vary, as shown below:

- Frameworks for early adaptation prioritization and sequencing over time. These are broad typologies that can help in developing adaptation policy and programmes (Warren *et al.*, 2016), and they are often used for initial scoping of options at the project level.
- Decision-support tools for adaptation. These are more formalized methods that are used for appraisal. For some adaptation options, conventional decision-support tools can be used; but for longer-term decisions, this includes the use of DMUU. While they can be applied as part of policy or programme applications, they are most relevant and applicable for detailed project appraisal (Watkiss *et al.*, 2014).

In addition, in many countries, there is **a shift towards mainstreaming adaptation in fisheries and aquaculture policy**. More details of these approaches and examples from application in the fisheries and aquaculture sectors are presented in turn below.

Early adaptation frameworks

Early adaptation frameworks can help to identify adaptation priorities for the next five years or so, which is the focus in early NAPs or adaptation projects (Fankhauser, Smith and Tol, 1999; Hallegatte, 2009; Ranger, Harvey and Garbett-Shiels, 2014). This type of adaptation framework was recommended in the recent FAO publication on the impacts of climate change on fisheries and aquaculture (Poulain, Himes-Cornell and Shelton, 2018). The recent literature (DFID, 2014; Warren *et al.*, 2018) identifies three priorities for these early adaptation frameworks:

- Interventions that address the existing **adaptation deficit**.[13] This is the current (economic) impact of current climate variability and weather extremes, such as tropical storms. All countries have an adaptation deficit, and many adaptation options can have potential benefits in reducing this current deficit, providing immediate economic benefits, as well as building future climate resilience. These are often known as no- and low-regret actions. Many of these options overlap with current good practice in the fisheries sector, and there is some evidence for their

[12] No-regret adaptation is defined as options that "generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs." A variation of no-regret options are win–win options, which are options that have positive co-benefits, which could include wider social, environmental or ancillary benefits. These are differentiated from low-regret options, which may have low costs or high benefits, or low levels of regret, or may be no-regret options that have opportunity or transaction costs in practice.

[13] Defined in the IPCC AR5 Glossary as: "the gap between the current state of a system and a state that minimizes adverse impacts from existing climate conditions and variability." Some authors contest this definition as it implies that the aim should be to minimize impacts, whereas from an economic perspective, they should be managed down to a point where the benefits of action are greater than the costs, which implies some level of residual damage is optimal.

costs and benefits. These include capacity building (institutional strengthening and technical assistance for climate change and adaptation), awareness raising (of opportunities and threats), enhanced weather and climate services, and risk transfer (e.g. insurance) and risk reduction.

- Early interventions to ensure that adaptation is considered in early decisions that have long lifetimes, and which will be exposed to future climate change, such as major infrastructure. These help to avoid "lock-in" to the large future risks of climate change that are difficult or costly to reverse or change later. However, in order to make sure these early investments make economic sense, they need to consider the concepts of DMUU, with a greater focus on flexibility, robustness, etc.
- Early adaptation steps for decisions that have long lead times, or early adaptation to start preparing for long-term major climate change, using iterative approaches (i.e. planning, monitoring, pilots and research) to help inform future strategies as part of adaptive management. These provide economic benefits from the value of information, learning and option values.

At the programmatic level, especially in the national context, all three of the above priorities are needed. In other words, they are not mutually exclusive. Therefore, there is a focus on portfolios of context-specific adaptation strategies. These can be presented as an adaptation pathway over time, and can be linked to policy cycles.

This focus on early adaptation is considered particularly important for fisheries. It is expected that some fish populations and ecosystems will be more at risk from early climate change impacts. These will include those fish populations that are already near their physiological limits, that are compromised in terms of their resilience due to existing anthropogenic factors, such as overfishing or pollution, or that are in locations most likely to suffer climate change impacts (OECD, 2010). However, it is also stressed that, in the longer term, the response in the fisheries sector – at least in some regions – will need to be transformational and will involve major changes.

Decision-support tools for adaptation

Once options have been identified in broad terms, or a shortlist of possible low-regret options has been identified, it is possible to use appraisal to assess them in more detail. This can include the analysis of the costs and benefits of options. This is particularly relevant when moving to the project level. However, the type of decision-support tools for adaptation vary with the application. The key difference is between immediate no- and low-regret options, and those that involve longer periods and thus uncertainty.

No- and low-regret options. In methodological terms, no- and low-regret options can be assessed using conventional economic appraisal, as they are focused on options that have almost immediate benefits (and thus discounting is less of an issue or not

FIGURE 3
Conventional methods for assessing no- and low-regret adaptation options

Cost-benefit analysis	Analysis of project benefits versus project costs, with sensitivity testing (or switching values) for key parameters
Cost-effectiveness analysis	Analysis of benefits (non monetary) using a common metric, expressed per unit cost, to allow least cost analysis
Multicriteria analysis	Analysis of project using wide range of criteria (monetary and non-monetary) to rank projects

Source: Watkiss *et al.* (2014).

relevant). They can therefore be considered using similar approaches to conventional fisheries and aquaculture economic appraisal. The most commonly used methods are CBA, cost-effectiveness analysis (CEA) and multicriteria analysis (MCA). These are often applied in fisheries management (Activity 3.3: Management option evaluation and selection, FAO EAF toolbox [FAO, 2011–2019]) – as summarized in Figure 3 and Box 4.

BOX 4

Conventional decision-support methods

Cost–benefit analysis (CBA) is commonly used in government economic appraisal. Social CBA values all relevant costs and benefits to society (including non-market effects), and then estimates a net present value or a benefit-to-cost ratio. This method has been used in adaptation assessment, including for the fisheries sector,[1] although it is most appropriate for early no- and low-regret options. However, CBA requires the quantification of all costs and benefits, and the latter is often difficult for fisheries adaptation and non-market benefits. It is also more challenging for non-technical adaptation options such as capacity building and institutional strengthening. This means there is often a need to extend CBA to an extended multimetric appraisal that includes risk and uncertainty.[2]

Cost-effectiveness analysis (CEA) compares options by assessing the cost per unit of benefit in order to identify the options that are the most cost-effective (highest benefit for lowest cost). It avoids monetary valuation of benefits and quantifies benefits in physical terms. It can be used to rank alternative options, and identify the least-cost path for targets using marginal abatement cost curves. It has become the main appraisal tool for climate mitigation, assessing the cost per tonne of GHG abated. The approach has not been used extensively in the fisheries sector, and it can be challenging to apply for adaptation, as it needs to identify a single relevant metric of benefits. It also omits the full analysis of all relevant costs and benefits, and thus the potential for co-benefits. This limits the use of CEA for many ecosystem-based approaches.

Multicriteria analysis (MCA) considers quantitative and qualitative data together in ranking alternative options. It assesses and scores options against a range of decision criteria, some of which are physical or monetary, and some qualitative. The various criteria can then be weighted to provide an overall ranking of options. The approach has been used quite widely for fisheries, and has relevance for fisheries adaptation, not least because it can address various challenges (non-market sectors, and distributional effects). For adaptation, criteria can be included to consider uncertainty or various elements of successful adaptation.[3] This approach is particularly useful in the absence of quantitative data, although the analysis can be somewhat subjective in nature. The IPCC[2] notes that MCA is frequently used because it can consider economic and non-economic indicators, including impacts on vulnerable groups and ecosystems, but also highlights the subjectivity of weights for criteria, including the distribution effects.

[1] ECONADAPT. 2015. *Review of the costs and benefits of adaptation. References that back this up* [online]. [Cited 27 September 2019]. https://econadapt.eu/sites/default/files/docs/Econadapt-policy-report-on-costs-and-benefits-of-adaptaiton-july-draft-2015.pdf

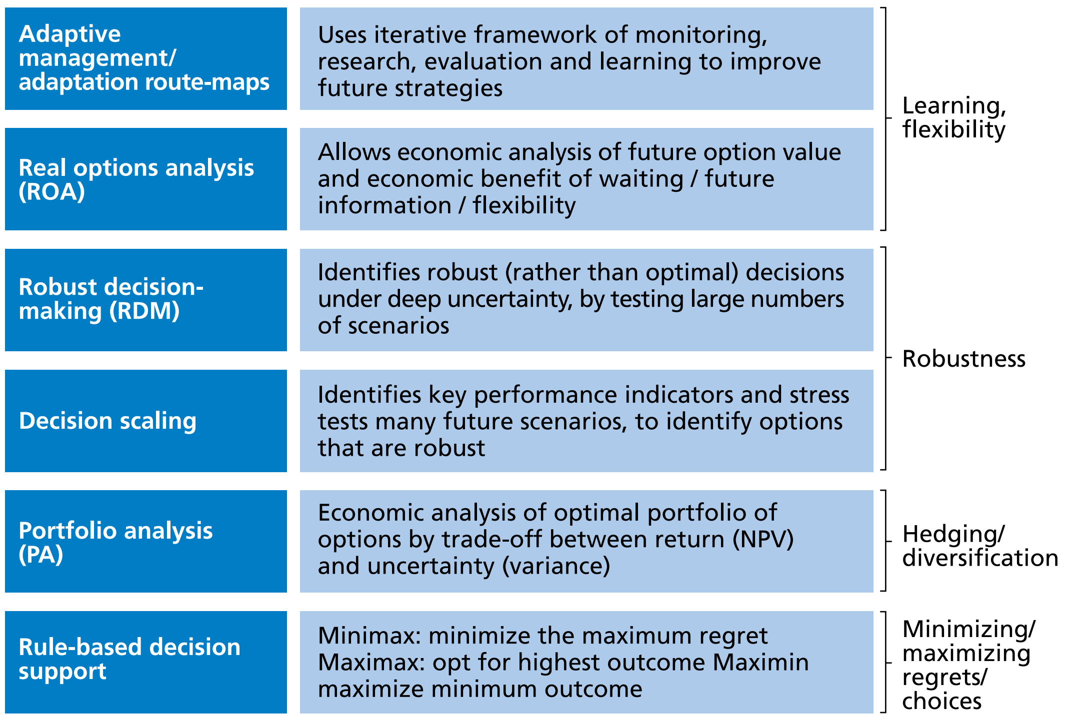
[2] Chambwera, M., Heal, G., Dubeux, C., Hallegatte, S., Leclerc, L., Markandya, A., McCarl, B.A, Mechler, R. & Neumann, J.E. 2014. Economics of adaptation. In C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*, pp. 945-977. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, New York, USA, Cambridge University Press.

[3] Mediation. 2013. *Method overview: decision support methods for adaptation* [online]. Briefing Note 1. Summary of methods and case study examples from the mediation Project. [Cited 27 September 2019]. http://mediation-project.eu/output/technical-policy-briefing-notes

These tools vary in the way they address the methodological issues raised in Chapter 3 relating to discounting, equity, uncertainty and non-monetary values. These conventional decision-support tools are in particular relevant for early adaptation, where the decision lifetime is short and the focus is on delivering early benefits. However, as highlighted in Chapter 3, many fisheries and aquaculture adaptation options are associated with socio-economic or non-market benefits, or involve areas that are more challenging to quantify in terms of benefits (e.g. capacity building). For this reason, they are often considered using extended cost–benefit approaches, or with decision-support methods that can include qualitative as well as quantitative aspects, such as MCA. It is also possible to use conventional CBA and test for unknowns by using switching values,[14] for example, to assess how large the benefits would need to be to justify the costs of the intervention, and then to assess qualitatively how likely it is that the project or investment could achieve this benchmark.

Longer-term decisions. For options that involve longer-term decisions, i.e. beyond the no- and low-regret options above, a more detailed set of appraisal methods are applicable. These are often termed decision-making under uncertainty (DMUU). These methods are more focused on options appraisal, particularly at the project level, and they involve a set of more formalized approaches to address the uncertainty issues identified in Chapter 3. The main approaches are summarized in Figure 4, with more information included in Box 5.

FIGURE 4
Decision-making under uncertainty



Source: Updated from Watkiss *et al.* (2014).

[14] The value of an uncertain cost or benefit at which the best way to proceed would switch, for example, from approving to not approving a project, or from including or excluding some extra expenditure to preserve some environmental benefit (HMT, 2011).

BOX 5

Decision-making under uncertainty

Adaptive management is an iterative cycle of monitoring, research, evaluation and learning that is used to improve future management strategies.[1] It is a process rather than a tool. The approach is relevant for adaptation given the high uncertainty and the long lifetimes, and is sometimes referred to as an adaptation pathways approach. One variation of the approach is to use thresholds (biophysical or policy) that trigger changes in adaptation options or policy (adaptation-tipping points).[2] These are sometimes presented as adaptation route maps,[3] also termed dynamic adaptation policy pathways.[4] These approaches are not formal economic methods, but they can include extended cost–benefit analysis. These adaptive management approaches have very high relevance for the marine fisheries sector, where there are likely to be shifts over time, but where uncertainty is large.

Real option analysis quantifies the investment risk with uncertain future outcomes. It is useful to consider the value of flexibility over the timing of an investment, or the adjustment over time in a number of stages, in response to unfolding events. This allows for consideration of flexibility, learning and future information (option values). In the adaptation context, it can be used to assess whether there is a value to waiting for (climate) uncertainties to be resolved to avoid negative outcomes, of whether it is beneficial to invest in more flexible adaptation solutions that can be changed later. It involves extended cost-benefit analysis, but does require probabilistic-type information to work. The approach can be applied as a formal economic method for adaptive management.

Robust decision-making is a method premised on robustness rather than optimality.[5] It involves testing options or strategies across a large number of plausible "futures" to identify which perform well over the range, rather than optimally to one central scenario. It can be used in cases of deep uncertainty (when there is no probabilistic information). Some studies test options against climate change only, while others examine wider futures that also consider socio-economics and policy.[6] The approach does not involve economic analysis per se, but most studies include costs, and some cost–benefit analysis. It has potential for fisheries, although there do not appear to be applications to date in the literature.

Decision scaling is an approach that links bottom-up vulnerability assessment with multiple sources of top-down climate information.[7] It identifies performance indicators and acceptable thresholds, and assesses the performance of the performance indicators to the current climate to develop climate response functions. It then uses multiple futures (multimodel climate information) to stress-test performance. The approach has been used for adaptation, in particular for water and hydropower investments. It does have some applicability for fisheries investment decisions, notably through the use of key fisheries performance indicators, although to date there have been no applications.

Portfolio analysis provides a quantitative way to maximize the return on investments using a portfolio. The principle is that spreading investments over a range of asset types spreads risks. Portfolio analysis highlights the trade-off between the returns on an investment and riskiness, and can maximize the expected rate of return and minimize the total portfolio variance. For adaptation, it can select combinations of options that together are effective over the range of possible future climates.[8] It uses an extended cost–benefit analysis framework. There are studies[9] that look at restoration/regeneration of natural systems (forests), and it is possible to see similar applications for fisheries, notably with the risk of species migration (and uncertainty).

Rule-based decision support involves a set of decision rules or criteria that can be used for decision-making under uncertainty. These include:[10] the minimax regret rule, which is a cautious decision-support criterion and approach where the decision maker aims to

minimize the maximum regret; the maximax rule, which is an optimistic decision-support criterion and approach in which the decision maker opts for the option with the highest possible outcome; and the maximin rule, which is a pessimistic decision-support criterion and approach in which the decision maker aims to maximize the minimum outcome.

[1] Intergovernmental Panel on Climate Change (IPCC). 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, by C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley, eds. Cambridge, UK, and New York, USA, Cambridge University Press. 582 pp.

[2] Werners *et al*. 2013. *Adaptation turning points: decision support methods for adaptation* [online]. MEDIATION Project, Briefing Note 9. [Cited 27 September 2019]. www.mediation-project.eu/platform/pbs/pdf/Briefing-Note-9-LR.pdf

[3] Reeder, T. & Ranger, N. 2011. *How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project*. Washington, DC, World Resources Report.

[4] Haasnoot, M., Kwakkel, J.H., Walker, W.E. & ter Maat, J. 2013. Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, 23(2): 485–498. DOI: 10.1016/j.gloenvcha.2012.12.006

[5] Groves, D.G. & Lempert, R.J. 2007. A new analytic method for finding policy-relevant scenarios. *Global Environmental Change*, 17(1): 73–85. https://doi.org/10.1016/j.gloenvcha.2006.11.006

[6] Lempert, R.J. & Groves, D.G. 2010. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. *Technological Forecasting and Social Change*, 77: 960–974. https://doi.org/10.1016/j.techfore.2010.04.007

[7] Ray, P.A & Brown, C.M. 2015. *Confronting climate uncertainty in water resources planning and project design: the decision tree framework* [online]. Washington, DC, World Bank. [Cited 27 September 2019]. doi:10.1596/978-1-4648-0477-9

[8] Hunt, A. 2009. *Economic aspects of climate change impacts and adaptation in the UK*. University of Bath. (PhD thesis)

[9] Crowe, K.A. & Parker, W.H. 2008. Using portfolio theory to guide reforestation and restoration under climate change scenarios. *Climatic Change*, 89: 355. https://doi.org/10.1007/s10584-007-9373-x

[10] Metroeconomica. 2004. *Costing the impacts of climate change in the UK: overview of guidelines*. UKCIP Technical Report. Oxford, UK, UKCIP.

Recent years have seen the growing use of these methods for adaptation. The first application relates to when there are early decisions that have a long lifetime, and it is possible to include adaptation in this early decisions to reduce future climate risks. This is primarily associated with decisions such as infrastructure investment. In this case, the main objective is to make decisions under uncertainty. The second main application relates to the use of iterative approaches to address the long term (i.e. mid-century climate impacts) as part of adaptation pathways, enabling learning and changes over time in response to the evidence. Note that in this case the decision is being made later in time (unlike the first application). In some cases, these elements are combined, i.e. with methods that look at design as part of longer-term iterative approaches.

A review of the academic and grey literature (ECONADPT, 2017) identified about 50 DMUU adaptation studies that included economic analysis. However, to date, there has been little application of DMUU in the fisheries sector.

There is a large body of DMUU applications for coastal investment and protection. Groves and Sharon (2013) applied robust decision-making to planning coastal resilience for Louisiana, the United States of America. There have also been several applications of real options analysis (ROA) to coastal protection. For example, Scandizzo (2011) applied ROA to assess the value of hard infrastructure, restoration of mangroves and coastal zone management options in Mexico, concluding that ROA highlights the value of gradual and modular options. There have also been applications to port infrastructure, using adaptive management approaches, for example, with the International Finance Corporation port study in Cartagena, Colombia (IFC, 2011), and examples of flexibility in port design for the port of Avatiu in Cook Islands (ADB, 2014).

There have been some applications to fisheries directly. Wellman, Hunt and Watkiss (2017) undertook a cost–benefit study and used adaptive management (with some light-touch ROA) for seaweed farming in Zanzibar, the United Republic of Tanzania. This considered various adaptation options to address the problems of increasing sea surface temperature and impacts on near-shore seaweed farming productivity. The analysis considered three options, growing different species in deeper water using floating rafts, as well as a longer-term iterative programme to gather information on temperature changes around islands, for use in long-term strategic decisions based on likely climate scenarios. There has also been an application of ROA to better study climate information in relation to coral protection and regrowth options, in response to deep-water fishing and aragonite saturation horizon shoaling, and acidification, and their effects on the extent and quality of cold-water *Lophelia* reefs in the Northeast Atlantic (in their role in providing a highly productive habitat for a number of fish species). The ROA element comes from the potential learning over time in the decision-making process, and the prospect that new information will become available on the impacts, and benefits of options to address these impacts, for these reef systems (Jackson *et al.*, 2013).

There are some fisheries studies that have used adaptation pathways thinking, including adaptation turning points. Werners *et al.* (2013) analysed fish stock maintenance under climate change with an adaptation pathway approach, looking at salmon reintroduction in the Rhine River (although this did not include valuation). It is highlighted that longer-term iterative adaptive management is considered highly relevant for the fisheries sector, including fisheries policy, because it allows a cycle of monitoring and research to help build the evidence base on emerging climate impacts, and in turn, to inform future fisheries management. This includes investment in biophysical monitoring (sea surface temperature, acidification levels, etc.) as well as monitoring of fish species and distribution, complemented with modelling analysis. It also includes early research into potentially major long-term impacts (acidification). Watkiss and Cimato (2019) undertook a very initial economic analysis using such an approach, looking at fisheries in the United Kingdom of Great Britain and Northern Ireland, which indicated positive benefit-to-cost ratios.

Applying DMUU, at least when using the formal methodologies, tends to be a time- and resource-intensive process, requiring significant technical expertise. These techniques are complicated to apply even where data are good, and thus very challenging to apply in the developing country context (see Bhave *et al.*, 2016). Indeed, many of the applications of DMUU to date are theoretical in nature and involve stylized examples rather than real project investments. This limits their formal application to projects with the necessary resources (i.e. larger projects). However, the concepts of these approaches are extremely useful, and they can be used in simpler applications more generally. Indeed, there is a growing focus on developing “light-touch” versions of these methods for more general application.

Mainstreaming adaptation in fisheries policy

Alongside the appraisal of targeted adaptation options (as part of adaptation policies or projects), there is a focus on mainstreaming climate change adaptation into fisheries policy itself. Mainstreaming is the integration of climate change adaptation into current policy and development, rather than implementing measures in stand-alone projects or programmes (OECD, 2015a). This requires a broader analysis of policy objectives and wider costs and benefits, and it means that adaptation becomes a cross-cutting activity in existing fisheries policy.

Mainstreaming has important advantages as it can leverage resources and activities associated with existing fisheries (or development) budgets. Therefore, it can shift entire national and sector development plans along more climate-smart pathways. However, it does raise additional challenges given the difficulty in delivering cross-cutting and cross-sectoral policy and programmes.

There is some evidence on mainstreaming adaptation from the literature, i.e. the integration of climate change. This provides some important lessons on the success factors involved in mainstreaming (Cimato and Watkiss, 2017).

Effective mainstreaming requires the identification of suitable entry points in the policy and development planning process, noting that these will differ across sectors and national contexts. This is likely to be centred on sector development planning (medium-term plans) for fisheries, but will also cascade down to local development plans. However, the importance of the latter depends on the level of decentralization, as well as the geographical scale of the fisheries involved.

As there is a large adaptation financing gap (see UNEP, 2014, 2018), the presence of climate finance is also a key factor for developing countries. While climate finance flows for adaptation are increasing (CPI, 2017), the flows to the fisheries sector are low (relative to other sectors, notably agriculture and water).

Successful mainstreaming usually involves that the presence of a high-level champion (to push mainstreaming across government), the involvement of strong ministries (i.e. finance and economic planning, rather than environment). A further critical finding is that there is a strong need for technical assistance and capacity building to enable mainstreaming to occur. There is a need for pragmatism when developing mainstreaming, and success will often be contingent on the timing of action and the ability to take advantage of intervention opportunities, for example, the preparation of a new fisheries policy or sector plan.

Other mainstreaming studies (WRI, 2018) identify similar issues, but also identify success factors around policy frameworks (and commitments) that help push forward the process of mainstreaming, the presence of coordination mechanisms across government that support mainstreaming goals, and information and tools

This highlights the fact that for countries that adopt a strong mainstreaming modality, there will be a need to ensure these success factors are in place in order to enable effective adaptation integration to occur.

Conclusion

This chapter has identified some of the emerging approaches to address the challenges of adaptation. It has identified the use of frameworks for early adaptation prioritization and sequencing over time. These are broad methods that can help develop adaptation policy and programmes, and they are often used for initial scoping of options at the project level. These can help to identify immediate no- and low-regret adaptation options, but also early adaptation to tackle longer-term risks. For the latter, further decision-support tools have emerged, which are more formalized methods for DMUU and are particularly relevant for project appraisal. The chapter has also reviewed the use of such approaches in the fisheries and aquaculture sector. While there have only been a limited number of applications to date, these early frameworks and DMUU

methods have very high relevance for the sector, and a priority is to develop further applications. Finally, the chapter has also highlighted that there is a shift toward adaptation mainstreaming in many countries. While this has potential benefits, it does require additional factors, and the review has identified some of the success factors to help increase integration.

5. Towards guidance on the economics of adaptation

As highlighted in the previous chapter, there are a number of adaptation frameworks that can help with the initial sequencing and prioritization of early adaptation options. These can be linked to a set of decision-support tools, which match to the type of adaptation being considered, and identify the most appropriate conventional or DMUU approach to support economic appraisal.

However, a key question concerns how to use these approaches in practice, especially in the context of the FAO adaptation to fisheries and aquaculture toolbox. In this context, it is important to recognize there are different types of adaptation decisions, at various levels of decision-making:

- Some studies will be focused at the **national or strategic** level and will involve more policy-level analysis.
- Other studies will be focused at the **programme or project level** and will be more focused on options appraisal.

As outlined in Chapter 4, a national-level approach will focus on early adaptation frameworks, while a detailed project may use decision-support tools including DMUU. For the latter, the type of adaptation problem being addressed will determine the most appropriate tool to use. To illustrate, the consideration of adaptation in a new fisheries quay investment will be focused on infrastructure investment and could use techniques that consider uncertainty in infrastructure investment (e.g. decision scaling or ROA), while the integration of climate change into fisheries policy might look at some of the adaptative management approaches, for example, developing iterative pathways.

In addition, the approach will be influenced by the importance of the issues outlined in Chapter 3, i.e. whether there are major issues of uncertainty, whether discounting is an issue, and whether it is necessary to consider distributional effects (e.g. with equity weights) or non-monetary measures, as these will have a major influence on adaptation options. It is important to be clear about these assumptions (see Chapter 3) in order to ensure a balanced and reliable comparison between the different options.

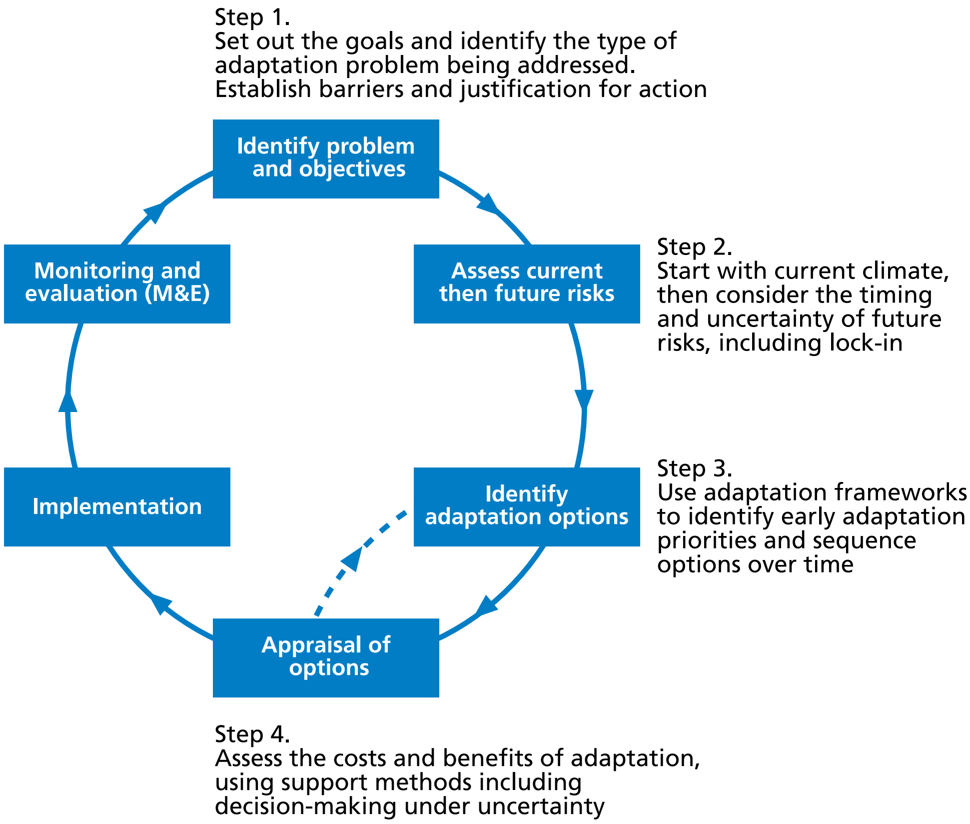
This chapter[15] investigates these issues, providing some early analysis of possible guidance for the economics of adaptation for fisheries and aquaculture. This needs to be seen in the context of the overall adaptation policy cycle, which is discussed first in the following section.

Adaptation policy cycle

The use of this FAO Technical Paper *Decision-making and Economics of Adaptation to Climate Change in the Fisheries and Aquaculture* sits within a broader cycle of adaptation decision-making and appraisal (the adaptation policy cycle). There are a number of versions of the adaptation cycle (e.g. UKCIP, 2003 [Willows and Connell, 2003]; PROVIA, 2013 [Bisaro and Hinkel, 2013]; EEA, 2015), but they generally have a set of common steps, as set out in Figure 5. Figure 5 also shows some of the key aspects at each of the early stages, and how these relate to this publication.

[15] This chapter was further developed as part of the project Supporting Member Countries Implement Climate Change Adaptation Measures in Fisheries and Aquaculture (GCP/GLO/959/NOR), executed by FAO with funding from the Norwegian Agency for Development Cooperation (Norad). This took forward the economics work with some workshops and early case study applications, which provided examples and applications. Based on these two initiatives, this chapter sets out some (relatively) simple guidance. It provides an outline of steps and examples for identifying and rolling out adaptation actions at the national level. It can be used independently from the rest of this publication.

FIGURE 5
Adaptation policy cycle and key entry points for economics



Steps 1 and 2 will be undertaken as part of general adaptation planning, rather than adaptation economics, but a number of relevant issues are highlighted below. The main focus here is on steps 3 and 4, and on how the information in this publication can be used in practice, drawing on case studies.

This chapter provides some initial guidance on using economics in a **scoping phase** to identify a long list of possible adaptation options, and to help structure these options so that economic aspects are considered. This uses adaptation frameworks that can help prioritize early options for addressing short-, medium- and long-term climate risks. It then discusses approaches for detailed economic appraisal, to consider their detailed costs and benefits and help select the preferred option. This includes discussion of decision-support methods, including DMUU.

Step 1. Identify problems and objectives

The starting point for the adaptation policy cycle is to define the objectives and goals and to map out the problem that the policy, programme or project is trying to address. This will be undertaken in line with the FAO fisheries and aquaculture adaptation toolbox, but a number of issues are highlighted that help support the subsequent economic aspects in steps 3 and 4.

First, it is important to identify the timescale of the decision, i.e. not just in terms of potential risks, but also in terms of adaptation. For example, it is important to identify whether the focus is on informing near-term adaptation (e.g. a NAP, or an immediate project proposal). Second, it is also important to frame adaptation within the existing context of the decision, for example, whether the application is a stand-alone

adaptation policy or investment, or whether it is looking to integrate climate change adaptation into an existing decision. In the case of the latter, it is critical to understand the underlying decision context and objectives, not just those of adaptation.

There is a role for economics at this early stage in setting out the economic rationale for action. There are often barriers that make it difficult for individuals, businesses and governments to plan and implement adaptation actions. These include economic, political economy and governance barriers, arising from market, information, policy and governance failures (Cimato and Mullan, 2010). It is therefore useful to identify these barriers, and how to overcome them, to help build up the economic rationale for adaptation, taking into account the most vulnerable groups (Poulain, Himes-Cornell and Shelton, 2018). This moves beyond a narrow focus on what "technical" option (or options) to implement, and captures the reason to act – as well as the best way of addressing the specific barriers (Cimato and Watkiss, 2017).

Step 2. Identify current climate related risks, then the future risks of climate change

A number of methodological approaches have been used to assess the vulnerability, risks and impacts[16] of climate change on fisheries and aquaculture (Barsley, De Young and Brugère, 2013; Brugère and De Young, 2015). This guidance does not seek to reproduce or update this, but it highlights issues to consider when undertaking these assessments, as they help support the subsequent economic analysis and appraisal in steps 3 and 4. These are:

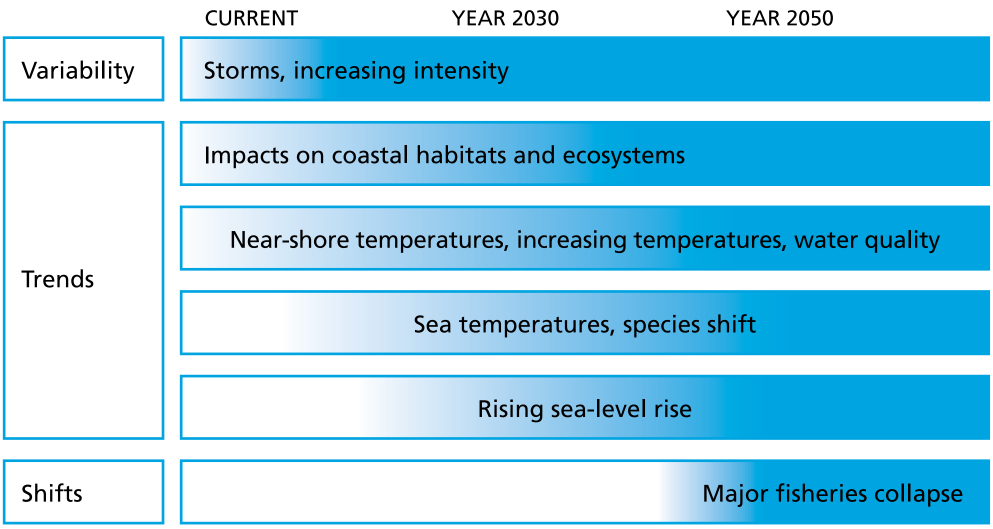
- The need to start first with current risks, then look to the future.
- The need to consider future climate change risks over time, including uncertainty and potential major threshold risks.
- Identification of the "target groups" for which the adaptation tools will be used.
- The type of adaptation decisions and the risks of lock-in.

Many climate change assessments, and adaptation studies, start with a very detailed assessment of future long-term climate change scenarios and climate model projections. This makes the entire approach very science-led. Recent applied studies have highlighted that this type of science-first approach is generally unhelpful for informing adaptation decisions (Warren *et al.*, 2016). Instead, the starting point is to look at current risks first. The key aspects are to understand how current weather and climate events are affecting the fisheries and aquaculture sector today, and whether there have been recent changes in trends, i.e. over recent years, that are increasing risks or impacts and/or creating new opportunities.

Once current risks have been understood, the next step is to consider future climate change. There is a lot of information on the potential risks of climate change to fisheries and aquaculture (Barange *et al.*, 2018). For the subsequent analysis of economics, it is useful to look at the patterns of these **climate risks over time** (Figure 6). The key issue is to build up an understanding of when potential risks might emerge and who will be impacted. An illustration is provided below. When considering climate risks, it is also important to consider uncertainty (see Chapter 3). This includes the uncertainty over future levels of climate change, i.e. whether the world is on a 2 °C or 4 °C pathway, but also the uncertainty from different climate model projections for each of these pathways.

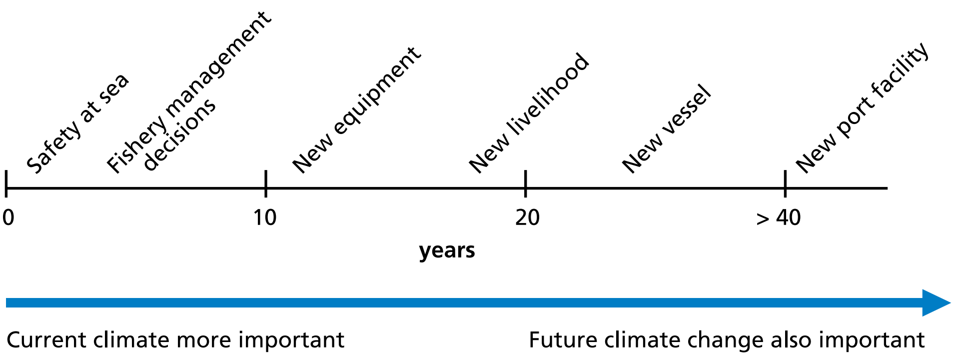
[16] This chapter uses the IPCC core concepts (IPCC, 2015) and the concept of risk, based on the components of hazard, exposure and vulnerability.

FIGURE 6
Sequencing of climate risks over time



The final relevant issue is to identify the type of problem that the adaptation policy, programme or project is seeking to address, and to identify the lifetime of decisions. Decisions with a longer lifetime are likely to be exposed to more severe future climate change, when the climate signal is stronger. In contrast, decisions that involve a short lifetime should focus more on current climate variability. This is illustrated in Figure 7 with some examples from the fisheries sector. Major investments with a long lifetime (e.g. new port facilities) should consider future climate change, such as long-term sea-level rise. However, the choice of new equipment for boats has a shorter lifetime, and it is likely to be more useful to focus on current risks and early climate trends. This links to a related issue of the risks of lock-in. Some decisions are extremely difficult or expensive to change later. They involve a degree of irreversibility and, therefore, there is a risk of locking-in future climate risks. Examples include coastal fisheries infrastructure (new port facilities), but they could also include major policy shifts.

FIGURE 7
Examples of the lifetime of decisions in the fisheries and aquaculture sector



Step 3. Identify and sequence adaptation options

The next step is to identify adaptation options to address the potential climate risks. Most studies identify a long list of initial options, and then try and filter these down to a promising shortlist, for further subsequent analysis. Examples of adaptation options were given in Chapter 2 (based on Poulain, Himes-Cornell and Shelton, 2018). However, it can be difficult to identify the promising options, especially given there is often a very long list of possible risks, and a long list of adaptation options.

As set out in the Chapter 4, the use of frameworks for identifying early adaptation priorities is therefore extremely useful at this stage in the adaptation policy cycle, with the three areas of potential early investment: (i) no- and low-regret options that address current climate risks; (ii) early interventions to ensure that adaptation is considered in decisions that have long lifetimes or lock-in; and (iii) early adaptive management activities for decisions that have long lead times, or early adaptation to start preparing for long-term major climate change. At the programme level, especially in the national context, all three of these may be needed. Examples are given in Box 6. An example of this was presented in the Economics of Climate Change Study (United Kingdom of Great Britain and Northern Ireland), to look at potential opportunities for fisheries sector (Figure 8). This type of analysis can then be followed up by a more detailed pathway and roadmap for specific risks, i.e. to start thinking about the potential sequencing of options and choices for new policy, or to develop options that can then be analysed in more detail using one of the decision-support tools as part of an economic appraisal.

BOX 6

Examples of early adaptation framework options

No- and low-regret options. There are numerous examples of no- and low-regret adaptation options for fisheries and aquaculture. As examples, Bell *et al.* (2018)[1] identify early priority adaptation options for the Pacific island countries and territories. These were aimed at maintaining the benefits of coastal fisheries by minimizing the gap between the sustainable harvest and the fish needed for food security. There are also existing studies on the benefits of weather and climate services for fisheries, including early warning systems (safety at sea) and climate services information, which are often classified as low-regret options.[2] They also include the costs and benefits of coastal marine protection[3] as well as marine protected areas.[4] For aquaculture, Philips (2018)[5] give examples of no-regret options include actions that reduce the impacts of current climate variability (monitoring and early warning).

Early adaptation in decisions with long lifetimes. There are a number of adaptation examples where climate-smart decisions are needed. They include coastal protection and port investments, where there is the opportunity to include climate in design, such as the case of including flexibility in port design for the port of Avatiu in Cook Islands.[6] Lifetime and lock-in issues are important for aquaculture, especially for coastal and surface water, because of the high upfront investment costs and the potential for larger climate impacts near shore and on surface water, where there is less potential for species migration. Therefore, there is a need to make these investments climate smart.[5]

Early adaptative management activities. There are fisheries studies that have used adaptation pathways thinking. Studies include analysis of a longer-term iterative programme to gather information on temperature changes for use in long-term strategic decisions for seaweed farming,[7] as well as the inclusion of adaptive management in national fisheries policy.[8] There is also an example of adaptation pathways approach being

used for salmon restoration,[9] and the more formalized economic analysis of this for cold water reefs,[10] with information used to help analysis coral protection and regrowth options, in response to deep-water fishing, aragonite saturation horizon shoaling and acidification.

[1] Bell, J., Allain, V., Gupta, A.S., Johnson, J.E., Hampton, J., Hobday, A.J., Lehodey, P., Lenton, A., Moore, B.R., Pratchett, M.S., Senina, I., Smith, N. & Williams, P. 2018. Chapter 14: Climate change impacts, vulnerabilities and adaptations: Western and Central Pacific Ocean marine fisheries. In Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 2018. *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options*. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO. (also available at http://www.fao.org/3/i9705en/i9705en.pdf).

[2] Clements, J. & Anderson, G. 2013. *The value of climate services across economic and public sectors* [online]. [Cited 27 September 2019]. www.climate-services.org/wp-content/uploads/2015/09/CCRD-Climate-Services-Value-Report_FINAL.pdf

[3] Londono-Diaz, L. & Vargas-Morales, M. 2015. An insight into the economic value of reef environments through the literature: the case of the Seaflower Biosphere Reserve. *Boletín De Investigaciones Marinas Y Costeras*, 44(1): 93–116. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0122-97612015000100005&lng=en&nrm=iso

[4] Mangos, A. & Claudot, M.A. 2013. *Economic study of the impacts of marine and coastal protected areas in the Mediterranean*. Plan Bleu Papers 13. Valbonne, France, Plan Bleu; Eftec. 2014. *Valuing the UK marine environment – an exploratory study of benthic ecosystem services. Appendix II – Science report* [online]. [Cited 27 September 2019]. http://randd.defra.gov.uk/Document.aspx?Document=12390_eftecABPmerBenthicESstudyAppendixII-FinalScience_report.pdf

[5] Philips, P.-R., ed. 2018. *Climate change impacts on fisheries and aquaculture (2018): a global analysis*. Volume I. UK, John Wiley & Sons Ltd Publications.

[6] Asian Development Bank (ADB). 2014. *Climate proofing ADB investment in the transport sector: initial experience*. Manila. (also available at www.adb.org/sites/default/files/publication/152434/climate-proofing-adb-investment-transport.pdf).

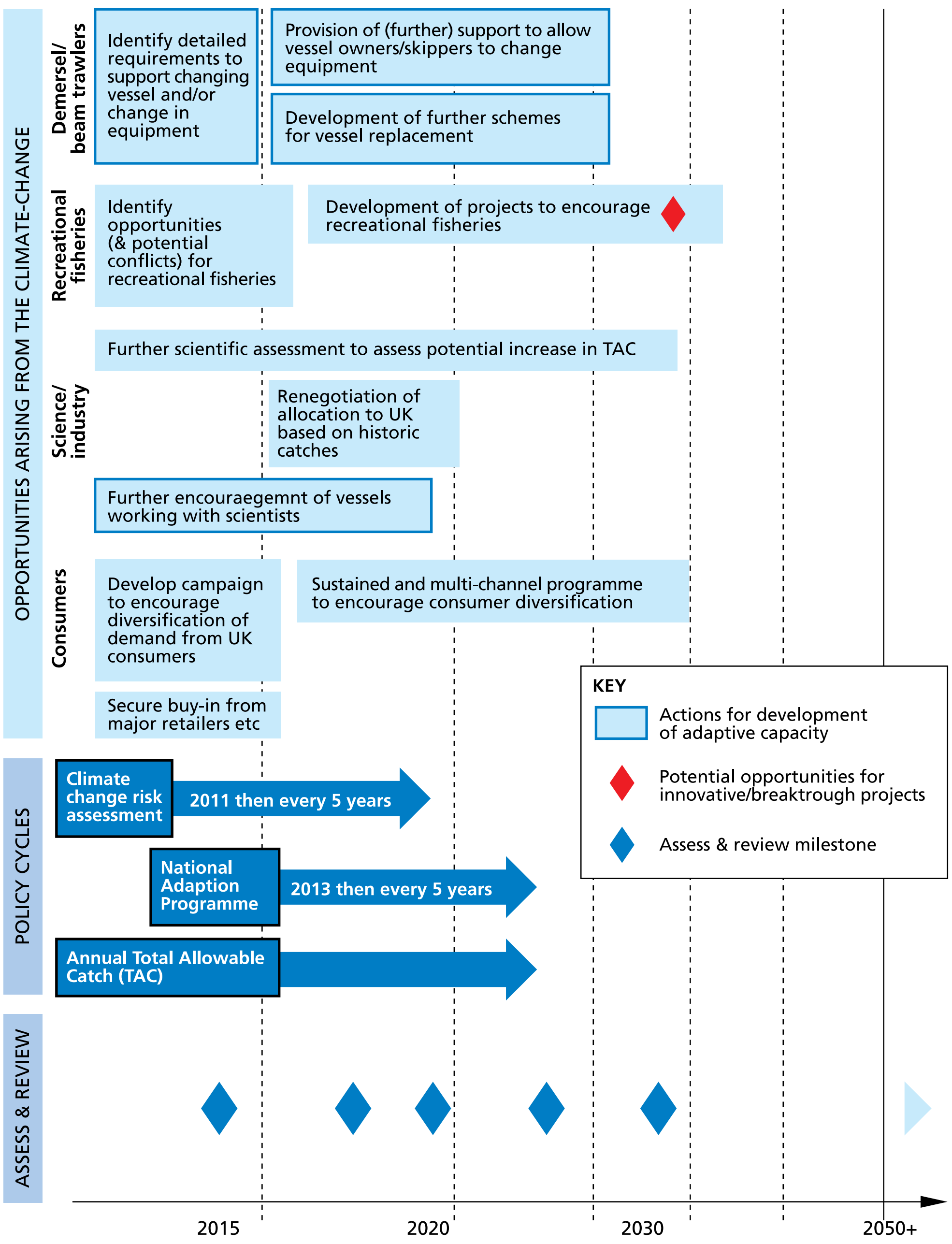
[7] Wellman, J., Hunt, A. & Watkiss, P. 2017. Adapting to climate change in Zanzibar's seaweed farming sector. In: *Case Studies, Deliverable 9.2 of the ECONADAPT study* [online]. [Cited 27 September 2019]. https://econadapt.eu/sites/default/files/docs/Deliverable%209-2%20Approved%20for%20publishing.pdf

[8] Frontier Economics, Ibaris & Ecofys. 2013. *Economics of climate resilience natural environment. Theme: Sea Fish CA0401* [online]. [Cited 27 September 2019]. http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016; Watkiss, P. & Cimato, F. 2019. Appendix: Fisheries. *In: The impacts of climate change on meeting government outcomes in England*. Report to the UK Committee on Climate Change.

[9] Werners *et al*. 2013. *Adaptation turning points: decision support methods for adaptation* [online]. MEDIATION Project, Briefing Note 9. [Cited 27 September 2019]. www.mediation-project.eu/platform/pbs/pdf/Briefing-Note-9-LR.pdf

[10] Jackson, E.L., Hall-Spencer, J.M., Hunt, A., Herman, P., Davies, A.J., Howell, K. & Kershaw, P. 2013. *Anthropogenic impacts on cold-water coral reefs in the North East Atlantic*. Deliverable 10.3. European Commission DG Research KNOWSEAS Project. Grant Agreement no.: 226675.

FIGURE 8
Adaptation roadmap for fisheries opportunities in the United Kingdom



Source: Frontier Economics, Ibaris and Ecofys (2013).

In many cases, the application of a scoping analysis may be sufficient. This might apply for a national aggregated analysis, or an early project stage analysis. However, in other cases, a more formalized appraisal may be needed. This may be required as part of country policy assessment, such as a requirement in regulatory impact assessment, or it may be required as part of the prescribed application process, for example, an appraisal for an application to a climate fund (e.g. an Adaptation Fund or Green Climate Fund project) or as part of the conditions for a development assistance project. This moves the cycle on to Step 4.

Step 4. Appraise adaptation options using economics

Once a shortlist of adaptation options has been made, it is sometimes necessary to undertake a more detailed appraisal of these options, taking into consideration the challenges raised in Chapter 3. The decision-support methods outlined in Chapter 4 can be applied to undertake this appraisal, but the type of approach that is relevant will depend on the decision context and the type of adaptation.

In cases where the appraisal is focused on **short-term no- and low-regret adaptation**, conventional decision-support tools can be used (see Box 4), such as CBA or MCA. In cases where early adaptation options are associated with non-market benefits, or involve non-technical aspects where quantification of benefits is difficult (e.g. institutional strengthening), this may require extended cost–benefit approaches, or decision-support methods that can include qualitative as well as quantitative aspects. The FAO EAF Planning and Implementation Tools provide useful information on many of the approaches for option identification including information on CBA (tool 9) and MCA (tool 31) (FAO, 2011–2019). The Mediation project gives additional information on the use of MCA for adaptation (Van Ierland, de Bruin and Watkiss, 2013).

However, when there is a need to consider **longer-term climate change and, therefore, uncertainty**, it may be more appropriate to use the DMUU methods (see Box 5). These tools are particularly relevant for project-level analysis. The Mediation Project published guidance on a number of these approaches including: robust decision-making (Watkiss and Dynzynski, 2013); real options analysis (Watkiss, Hunt and Blyth, 2013); portfolio analysis (Hunt and Watkiss, 2013); and adaptation pathways (Werners *et al*., 2013.). There is also guidance on decision scaling published by the World Bank (Ray and Brown, 2015) and guidance on the Climate Risk Informed Decision Analysis (CRIDA) (Mendoza *et al*., 2018). However, as highlighted above, there are only a few applications to the fisheries and aquaculture sector to date.

As highlighted above, there is not one DMUU method that is "best" for all adaptation contexts in the fisheries and aquaculture sector. Indeed, each of the methods set out in Chapter 4 lends itself to particular types of adaptation decision (Watkiss *et al.*, 2014). It is important to identify what the characteristics of the decision are, and then look at how these might match to relevant tools, taking into consideration the issues raised in Chapter 3. If the lifetime is long and there is lock-in involved, this would suggest that economic approaches such as decision scaling, robust decision-making or ROA could be more important. If there are reasons for a highly precautionary approach, i.e. major downside risks in making mistakes, such as from major port failure, this would suggest overdesigning options might be warranted, i.e. using rule-based decision-support methods to minimize regrets (although it would still be useful to consider whether lower-cost or flexible alternatives are available to address this). Finally, if the focus is on longer-term major risks, and there is the potential to learn over time as with fisheries and/or aquaculture policy, it can be useful to consider more iterative approaches (adaptation route-maps or ROA).

As highlighted in Chapter 4, DMUU approaches can involve significant time and resources. Formalized applications of these approaches can be used for major programmes or projects, but in many cases the nature of the project (and available resources) may limit application. In these cases, there is the potential to use light-touch approaches, i.e. that use the concepts of these methods, but undertake simple level analysis. For example, it is possible to use the characteristics of real options (decision trees and the consideration of learning and/or flexibility) but without the formal derivation of probabilities and detailed economic analysis.

The analysis of the decision characteristics of a project can be used to identify potentially suitable approaches for particular adaptation projects, as illustrated in Table 4. The capture fisheries sector does not involve the same degree of long lifetimes and lock-in as other sectors, as there is less investment in long-lived infrastructure or land-use change. In capture fisheries, the main areas are associated with coastal fisheries infrastructure (new landing areas, and port facilities), and major capital investment (vessels and equipment). Nonetheless, these investments are early priorities for adaptation to ensure climate-smart development, i.e. to ensure that future climate risks, but also uncertainty, are taken into account, and there are some examples of studies and relevant options. However, these lifetime and lock-in issues are perhaps more important for the aquaculture sector, especially for coastal and surface waters, because of the high upfront investment costs and the potential for larger impacts (near-shore and surface water, where there is less potential for species migration).

Table 4
Examples of decision approaches for project types

Project or programme	Discussion	Possible methods
Early warning system (weather service) for fishers	Low-regret measure. Some challenges around valuation of socio-economic benefits.	Current decision support, e.g. cost–benefit analysis or multicriteria analysis.
New port facilities	Infrastructure with long lifetime and some lock-in (difficult or costly to change later). Opportunity to include adaptation during design, with robust or flexible approaches; hence, need to consider future risks and uncertainty.	Potential decision-making under uncertainty application. Possible use of decision scaling or flexibility with real options analysis.
Monitoring and research programme to inform future fisheries policy	Provision of information and learning to monitor trends and use this to change policy over time. Potential issues of possible threshold levels (biophysical).	Adaptive management or adaptation route maps (tipping points).
National adaptation programme or plan for the fisheries sets	Broad set of possible risks, and adaptation options	Adaptation framework to identify early priorities and look at sequencing over time. Can be used to build up a portfolio of different options over time in combination, as part of a roadmap.

For a national fisheries or aquaculture application, it is likely that a portfolio of options will be the best approach – and these may mean the use of early scoping approaches will be more relevant, complemented with specific DMUU analysis where there are major finances involved.

Existing funded adaptation projects and national plans

Finally, there is a growing evidence base on actual adaptation implementation. Much of this has emerged from the finance provided by the international climate finance funds (e.g. Global Environment Fund projects). As these have been implemented, they provide useful case study material, as well as information on adaptation costs available. In some cases, there is CBA of options as part of the application and appraisal process. These provide useful information on early adaptation costs, including implementation costs.

The Global Environment Fund has funded a number of projects, although many of these are focused on sustainable fisheries and aquaculture and ecosystem health

in general. However, there are some targeted adaptation projects, i.e. where climate change is the main justification for the project, and in response, activities are focused on reducing climate risks.[17] This distinction is important in adaptation finance tracking and reporting, i.e. in line with the OECD Development Assistance Committee Rio Markers (OECD Development Assistance Committee, 2016), where adaptation is the primary objective.[18]

Many of these projects provide a source of additional empirical data on the costs of early no- and low-regret fisheries development activities, including conservation and ecosystem-based approaches. There are also a number of fisheries projects funded under the Adaptation Fund for a value of about USD 5 million to USD 10 million each over a period of four years. Examples include Building Adaptive Capacities of Small Inland Fishermen Community for Climate Resilience and Livelihood Security, Madhya Pradesh, India, and Adaptation to the Impacts of Climate Change on Peru's Coastal Marine Ecosystem and Fisheries, as well as several projects that cover coastal communities or islands (Adaptation Fund, 2019).

There is an approved Green Climate Fund project for Bangladesh that has a strong fisheries component (FP069: Enhancing Adaptive Capacities of Coastal Communities, Especially Women, to Cope with Climate Change Induced Salinity). This highlights how climate-induced salinities will adversely impact small-scale fishers, and in response it is addressing the barriers related to awareness and access to resilient livelihood practices, and promoting climate-resilient livelihoods, i.e. diversification, especially aquaculture, to fisheries-based groups. The proposal included an initial CBA for each of the livelihoods, reporting positive returns.

There have also been some fisheries components in the Pilot Programme for Climate Resilience. A programme in Jamaica (USD 4.8 million) strengthened the fisheries policy and regulatory framework (Pilot Programme for Climate Resilience Jamaica, undated). It included steps to make it climate-smart, investing in diversification of viable alternative livelihoods that enhance sustainable fisheries, and capacity building and awareness raising among the fishing and fish farming communities.

As well as these implemented projects, there are national-level initiatives, as part of the UNFCCC programme that are developing targeted climate adaptation plans.

The NAP process enables parties to identify, formulate and implement medium- and long-term adaptation needs, and strategies and programmes to address those needs. Fifteen NAPs had been submitted (as at December 2019 [UNFCCC, 2019a]. These do not have a strong focus on fisheries, although Saint Lucia's National NAP 2018–2028 (Government of Saint Lucia, 2018) includes the Sectoral Adaptation Strategy and Action Plan for the Fisheries (Fisheries SASAP) 2018–2028.

Finally, the Paris Agreement asks each country to outline and communicate their post-2020 climate actions. Known as nationally determined contributions (NDCs), these set out the proposed efforts by each country to reduce national emissions and adapt to the impacts of climate change. The current NDCs are focused on short-term needs-based assessments for the period 2020–2030 (as at September 2019, 184 countries had submitted their first NDC [UNFCCC, 2019b]. For adaptation, the developing-

[17] Examples include: Climate Adaptation and Resilience in Cambodia's Coastal Fishery Dependent Communities; Strengthening Adaptative Capacities to Climate Change through Capacity Building for Small Scale Enterprises and Communities Dependent on Coastal Fisheries in The Gambia; Strengthening Resilience and Adaptive Capacity to Climate Change in São Tomé and Príncipe's Agricultural and Fisheries Sectors; FishAdapt: Strengthening the Adaptive Capacity and Resilience of Fisheries and Aquaculture-dependent Livelihoods in Myanmar; Climate Change Adaptation in the Eastern Caribbean Fisheries Sector; Community-based Climate Resilient Fisheries and Aquaculture Development in Bangladesh; Building Climate Change Resilience in the Fisheries Sector in Malawi; Enhancing Climate Change Resilience in the Benguela Current Fisheries System; and other projects that include climate components (e.g. SWIOFISH in the South West Indian Ocean).

[18] These projects directly address climate drivers, and seek to implement measures to reduce current and future climate risks. This issue is also important for climate finance tracking and the share of expenditure that can be attributed to adaptation, i.e. so-called Rio Markers of the OECD measure the progress in international financing of development cooperation for climate change adaptation (OECD Development Assistance Committee, 2016). The OECD distinguishes between expenditures that pursue these goals as a primary objective (where a 100 percent allocation is assigned), and a second category where it is a significant objective, but there is another primary objective.

country NDCs set out country plans for domestic climate actions, funded either through international or domestic finance. A recent review of the NDCs (UNEP, 2018) identified that about 50 non-Annex I countries[19] have included costed estimates of adaptation financing needs. A recent study (Gallo, Victor and Levin, 2017) reports that many of these consider marine aspects, although much of this is associated with coastal protection, rather than fisheries.

Conclusion

This chapter provides insights on the application of economics for fisheries and aquaculture adaptation. It highlights the role for economics in the adaptation policy cycle, from the initial framing of adaptation, through to the early identification of options, and finally in detailed economic appraisal. It sets out how adaptation frameworks can help prioritize early adaptation priorities during national- or scoping-level analysis, and how decision-support tools can be used for the subsequent detailed economic appraisal. It also highlights that the type of method, particularly for detailed economic appraisal, depends on the type of adaptation problem. While conventional decision support methods (such as CBA) can be used for short-term, no- or low-regret options, DMUU may be relevant for decisions with longer lifetimes and lock-in. Moreover, pathways approaches are particularly helpful in long-term decision-making to address future major risks. How these methods will be deployed is up to the relevant stakeholders, according to their own context and assumptions (for example, which discount rates they apply, and whether they apply equity weights or non-monetary measures) (see Chapter 3). The chapter has also summarized the recent uplift in climate finance, and provided examples of fisheries and aquaculture adaptation projects that are emerging.

Finally, based on the overall analysis in this publication, a number of future priorities have been identified. Given the low evidence base on the economics of fisheries and aquaculture adaptation, the key priority is to advance the application of economic analysis to adaptation case studies in the sector in order to provide more practical information. This should seek to test and demonstrate the various decision methods explored above, for a variety of different projects and contexts, in order to provide a better understanding of the merits of these approaches and their applicability. These could also be used to provide good practice examples and guidance for future application of the FAO adaptation toolbox for fisheries and aquaculture.

[19] Annex I countries include industrialized (developed) countries and "economies in transition".

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This publication reviews available information on the costs and benefits of climate change adaptation in the fisheries and aquaculture sector. It highlights the challenges in applying conventional appraisal and decision-support tools to adaptation, and then reviews emerging frameworks (including no- and low-regret actions, addressing potential lock-in, and early planning for long-term adaptation), as well as economic tools to appraise adaptation options. It identifies that the available evidence is low, and that a key priority is to advance the application of economic analysis to adaptation case studies in order to provide a better understanding of the merits of assessment approaches and their applicability to the sector. This publication can also be used to provide good practice examples and supplementary guidance for application of the adaptation toolbox developed by FAO in 2018 to help guide communities, countries and other key stakeholders in their adaptation efforts.

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