



PART 3

**HIGHLIGHTS
OF SPECIAL STUDIES**

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Climate change implications for fisheries and aquaculture: overview of current scientific knowledge

Climate change is bringing substantial changes to the world's capture fisheries, which are already under stress from overfishing and other anthropogenic influences. Inland fisheries – most of which are in developing African and Asian countries – are at particularly high risk, threatening the food supply and livelihoods of some of the world's poorest populations. There are also consequences for aquaculture, which is especially significant for populations in Asia. States need to act to ensure that the people who depend on fish for food and livelihoods have the capacity, new policies and resources to adapt to the changing waters.

The effects of climate change on the world's capture fisheries and aquaculture resources and the people who depend on them for their food and livelihoods are examined in a recent technical paper published by FAO.¹ In three parts (each written by leading experts), the technical paper reviews: the physical effects of climate change and their impacts on marine and inland capture fisheries and aquaculture; the consequences of these changes for fishers and their communities; and the consequences for aquaculture. The latter two parts investigate options for adaptation as well as mitigation in the subsectors. The technical paper represents a synthesis of about 500 technical reports and articles on the subject and presents a comprehensive picture of what is known about the effects of climate change on fisheries and aquaculture (Figure 37).

ECOLOGICAL AND PHYSICAL IMPACTS OF CLIMATE CHANGE

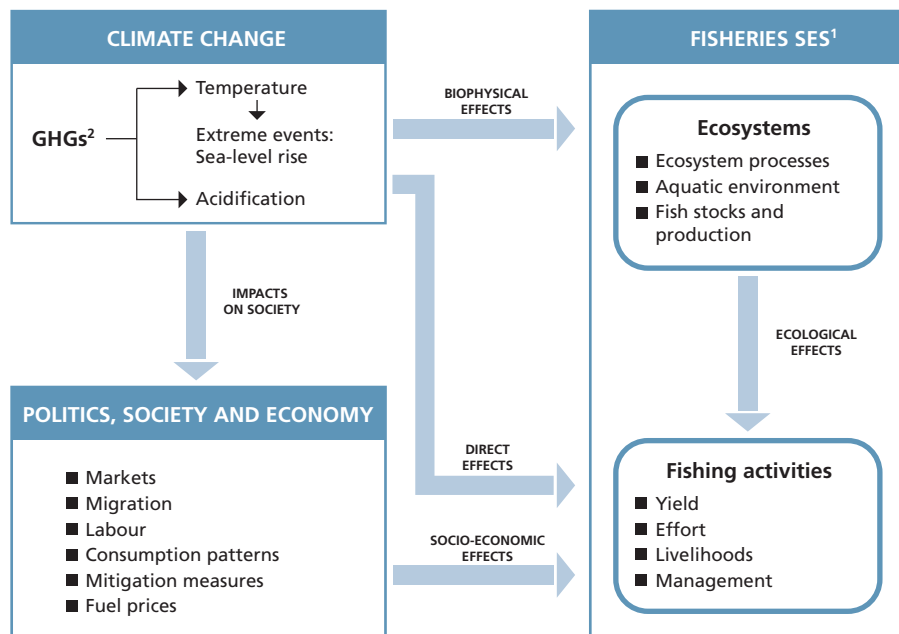
Under climate change, the oceans are warming but this warming is not geographically homogeneous. The combined effect of temperature and salinity changes caused by climate warming is expected to reduce the density of surface waters and thus increase vertical stratification. These changes are likely to reduce nutrient availability in the surface layer and, therefore, primary and secondary production in a warmed world. Moreover, there is evidence that upwelling seasonality may be affected by climate change, with impacts across the food web. The consequences of climate change will probably affect community composition, production and seasonality processes in plankton and fish populations. Increasing acidity (decreasing pH) of the world's oceans is a significant and pervasive longer-term threat to coral reefs. In the short term, increased temperatures linked to coral bleaching may lead to steady degradation of reefs and other ecosystems. In the long term, increasing water acidification and a weakening of the structural integrity of reefs is forecast. The potential for coral reef systems to adapt to these environmental stresses is uncertain.

As temperatures warm, marine fish populations at the poleward extents of their ranges will increase in abundance whereas populations in more equatorward parts of their range will decline in abundance. In general, climate change is expected to drive the ranges of most terrestrial and marine species towards the poles, expanding the range of warmer-water species and contracting that of colder-water species. The most rapid changes in fish communities will occur with pelagic species that are expected to shift to deeper waters to counteract rising surface temperatures. Moreover, the timing of many animal migrations will be affected. Ocean warming will also alter the predator–prey matches because of the differential responses between plankton components (some responding to temperature change and others to light intensity).



Figure 37

Examples of direct and indirect pathways of climate change



EXAMPLES OF IMPACTS

INDIRECT ECOLOGICAL	DIRECT PHYSICAL	INDIRECT SOCIO-ECONOMIC
<ul style="list-style-type: none"> ■ Change in yield ■ Change in species distribution ■ Increased variability of catches ■ Changes in seasonality of production 	<ul style="list-style-type: none"> ■ Damaged infrastructure ■ Damaged gear ■ Increased danger at sea ■ Loss/gain of navigation routes ■ Flooding of fishing communities 	<ul style="list-style-type: none"> ■ Influx of migrant fishers ■ Increasing fuel costs ■ Reduced health due to disease ■ Relative profitability of other sectors ■ Resources available for management ■ Reduced security ■ Funds for adaptation

¹ Social-ecological systems.

² Greenhouse gases.

Source: T. Daw, W.N. Adger, K. Brown and M.-C. Badjeck. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri, eds. *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*, pp. 107–150. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp.

There is evidence that inland waters are also warming but that there are differential impacts of climate change on the river runoff that feeds these waters. In general terms, high-latitude and high-altitude lakes will experience reduced ice cover, warmer water temperatures, a longer growing season and, as a consequence, increased algal abundance and productivity. In contrast, some deep tropical lakes will experience reduced algal abundance and declines in productivity, probably owing to reduced supply of nutrients. Regarding freshwater systems in general, there are also specific concerns over changes in timing, intensity and duration of floods, to which many fish species are adapted in terms of migration, spawning and transport of spawning products, as a result of climate change.

The technical paper also summarizes the consequences of climate change along “rapid”, intermediate and long time scales. These encompass impacts on physiology

of fish (including consequences for aquaculture), ecology of short-lived species and changes in species distributions and abundance. Information is lacking for the long time scale and there are considerable uncertainties and research gaps that the paper outlines.

FISHERS AND THEIR COMMUNITIES

Fisheries-dependent economies, coastal communities and fisherfolk are expected to experience the effects of climate change in a variety of ways. These include: displacement and migration of human populations; effects on coastal communities and infrastructure due to sea-level rise and changes in the frequency, distribution or intensity of tropical storms; and less stable livelihoods and changes in the availability and quantity of fish for food.

The vulnerability of fisheries and fishing communities depends on their exposure and sensitivity to change, but also on the ability of individuals or systems to anticipate and adapt. This adaptive capacity relies on various community assets and can be constrained by culture, current institutional and governance frameworks or marginalized access to adaptive resources. Vulnerability varies between countries and communities and between demographic groups within society. Generally, poorer and less empowered countries and individuals are more vulnerable to the effects of climate change, and the vulnerability of fisheries is likely to be higher where the resources already suffer from overexploitation, the ecosystems are degraded and the communities face poverty and lack sufficient social services and essential infrastructure.

Fisheries are dynamic social-ecological systems and are already experiencing rapid change in markets, exploitation and governance. The combined effects of these changes and the biophysical and human impacts of climate change make it difficult to predict the future effects of climate change on fisheries social-ecological systems.

Human adaptation to climate change includes reactive or anticipatory actions by individuals or public institutions. These range from abandoning fisheries altogether for alternative occupations to developing insurance and warning systems and changing fishing operations. Governance of fisheries will need the flexibility to account for changes in stock distribution and abundance. Governance aimed towards equitable and sustainable fisheries, accepting inherent uncertainty and based on an ecosystem approach is generally thought to be the best approach to improve the adaptive capacity of fisheries.

Greenhouse gas contributions of fisheries and related supply chain features are small when compared with other sectors but, nevertheless, can be reduced with identifiable measures already available. In many instances, climate change mitigation could be complementary to and reinforce existing efforts to improve fisheries sustainability (e.g. reducing fishing effort and fleet capacity in order to reduce energy consumption and carbon emissions). Technological innovations could include energy reduction in fishing practices and more efficient post-harvest and distribution systems. There may also be important interactions for the sector with respect to environmental services (e.g. maintaining the quality and function of coral reefs, coastal margins, inland watersheds), and potential carbon sequestration (Box 12) and other nutrient management options, but these will need further research and development.

AQUACULTURE

Aquaculture now accounts for almost 50 percent of fish consumed by humans, and this share is expected to increase further to meet future demand. Of considerable concern is the long-term ability of capture fisheries production to produce the fishmeal and fish-oil supplies used as feed components in aquaculture. Alternatives, such as soybean, corn meal, rice bran and others, have not been perfected according to fish requirements, and the increased demand for these agricultural products created by expanding aquaculture could also have consequences.



Blue carbon: the role of healthy oceans in binding carbon

The facts

Black and brown carbon emissions from fossil fuels, biofuels and wood burning are major contributors to global warming. Green carbon, the carbon stored in plants and soils, is a vital part of the global carbon cycle. Blue carbon is the carbon captured by the world's oceans and represents more than 55 percent of the green carbon. The carbon captured in living organisms in oceans is stored in the form of sediments from mangroves, salt marshes and seagrasses.

In addition to absorbing heat and regulating the earth's climate, oceans are the largest long-term sink for carbon (see figure). Oceans store some 93 percent of the earth's carbon dioxide (CO₂) and capture more than 30 percent of the CO₂ released annually. Most of the carbon captured is stored not for decades or centuries but rather for millennia. Importantly, restoration of green and blue carbon habitats alone could mitigate emissions by up to 25 percent.

Blue carbon sinks are also central to the productivity of coastal zones, which provide a wide range of benefits to humans (e.g. as buffers against pollution and extreme weather events, as sources of food and livelihood security and social well-being) and services estimated at more than US\$25 trillion per year. Approximately 50 percent of the world's fisheries stem from these coastal waters.

The threats

The annual rate of loss of coastal marine vegetal ecosystems (2–7 percent) is up to four times that of rainforests and is caused *inter alia* by unsustainable natural resource use, poor coastal development practices, and poor watershed and waste management.

Surface water temperatures are increasing, decreasing the amount of CO₂ that can be dissolved in water. Combined with changes in acidification, water circulation and mixing and loss of blue carbon habitats, this means that the oceans' ability to absorb and store CO₂ is decreasing.

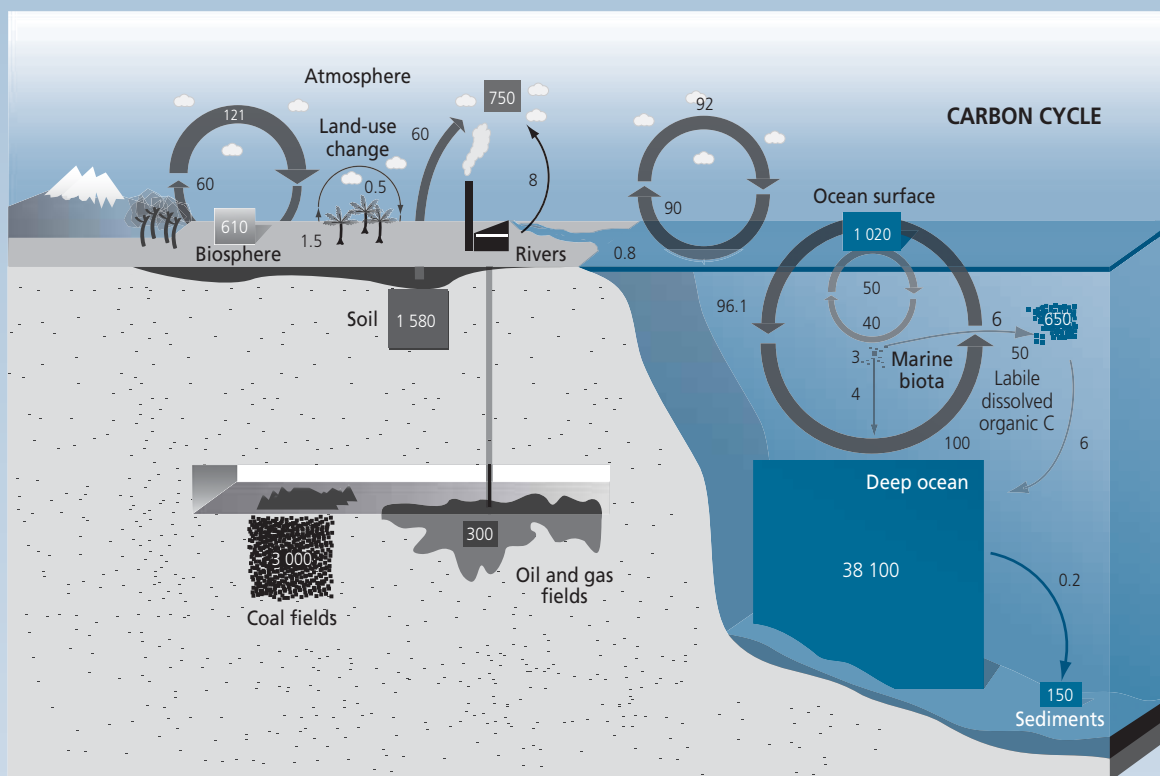
Coastal populations are in the front line of climate change and often the most vulnerable to its effects. Climate change will have impacts across all dimensions of food security as well as increasing risks at sea and the threat of damage to or loss of infrastructure and housing.

While coastal populations are growing, inflexible institutional frameworks persist in limiting adaptation strategies. In addition, monitoring and early-warning systems are deficient, and emergency and risk planning are not integrated into sectoral development.

The options

1. Establish a global blue carbon fund for the protection and management of coastal and marine ecosystems and ocean carbon sequestration.
2. Immediately and urgently protect seagrass meadows, salt marshes and mangrove forests through effective management.
3. Initiate management practices that reduce and remove threats, and that support the robust recovery potential inherent in blue carbon sink communities.
4. Maintain food and livelihood security from the oceans by implementing comprehensive and integrated ecosystem approaches to increase the resilience of human and natural systems to change.
5. Implement win-win mitigation strategies in the ocean-based sectors, including efforts to:
 - improve energy efficiency in marine transport, fishing and aquaculture sectors as well as marine-based tourism;

THE WORLD'S CARBON CYCLE



Carbon fluxes and stocks 1 020 Storage: gigatonnes of C \curvearrowright Fluxes: gigatonnes of C per year

Source: Intergovernmental Panel on Climate Change.

- encourage sustainable, environmentally sound ocean-based production, including algae and seaweed;
- curtail activities that negatively affect the oceans' ability to absorb carbon;
- ensure that investment for restoring and protecting the capacity of the oceans' blue carbon sinks to bind carbon and provide food and incomes is prioritized in a manner that also promotes business, jobs and coastal development opportunities;
- catalyse the natural capacity of blue carbon sinks to regenerate by managing coastal ecosystems for conditions conducive to rapid growth and expansion of seagrass, mangroves and salt marshes.

Source: C. Nellemann, E. Corcoran, C.M. Duarte, L. Valdés, C. De Young, L. Fonseca and G. Grimsditch, eds. 2009. *Blue carbon: the role of healthy oceans in binding carbon*. A Rapid Response Assessment. Nairobi, United Nations Environment Programme, and Arendal, Norway, GRID-Arendal (also available at www.grida.no/publications/rr/blue-carbon/).

Global aquaculture is concentrated in the world's tropical and subtropical regions, with Asia's inland freshwaters accounting for 65 percent of total production. Significant aquaculture activities occur in the delta areas of major rivers. Sea-level rise in the coming decades will increase salinity intrusion further upstream, affecting brackish-water and freshwater culture practices. Adaptation would involve moving aquaculture practices further upstream or shifting to more salinity-tolerant strains of cultured species. Such measures are costly, with significant effects on the socio-economic status of the communities involved. On the other hand, aquaculture in temperate zones will be more affected by water warming to levels that will exceed the limit for many farmed species and will require changes in farmed species.

The increase in extreme weather events may affect aquaculture in several ways: physical destruction of aquaculture facilities, loss of stock and spread of disease. The risks will be larger in more open exposed sites.

Climate change is expected to affect static waters profoundly by increasing the concentration of some chemicals in the water to toxic levels and by changing the stratification of the waters, leading to increased depletion in oxygen and increasing mortality of cultured stocks. However, adaptive measures can be applied if careful monitoring and suitable strategies are in place.

Climate change also offers opportunities for aquaculture. Some inland waters could experience an increase in the availability of phytoplankton and zooplankton, which would boost aquaculture production. While increased salinity in deltas will push some aquatic farming upstream, it could also provide additional areas for shrimp farming, often a higher-value commodity, albeit one with higher energy consumption.

Unlike land-based animal husbandry, which accounts for 37 percent of all human-induced methane emissions, farmed aquatic species emit no methane. Aquaculture of molluscs and the expanding seaweed culture make a minimum contribution, if any at all, to carbon dioxide emissions, while they could contribute to carbon sequestration to some extent and also provide raw material for biofuels (algae). This enhances the value of aquaculture as an important source of animal protein with a smaller carbon footprint and relevant potential for additional mitigation of carbon release into the atmosphere.

Semi-intensive pond aquaculture constitutes one of the most widespread farming systems in Asia and these ponds can be highly productive. If well managed, these ponds can enhance carbon capture and could make a significant contribution to the sequestration of carbon in freshwater and brackish-water systems.

From drain to gain in capture fisheries rents: a synthesis study

Over the last three decades, the difference between the potential and actual economic benefits from marine fisheries has grown dramatically. The joint World Bank/FAO report, *The Sunken Billions*,² argues that the world's capture fishery resources are non-performing assets with rates of return, or yields, not exceeding zero – costing the world economy an estimated US\$50 billion per year in forgone resource rent. Now, FAO Fisheries and Aquaculture Technical Paper No. 538³ provides a synthesis of case studies on resource rent losses in the world's capture fisheries. It draws upon case studies in the literature as well as 17 case studies commissioned by the World Bank's PROFISH Global Program on Fisheries and FAO as part of the "Rent Drain" study project. The commissioned cases studies support the conclusions in *The Sunken Billions* and show that economic overexploitation of capture fishery resources is spread throughout the world, to be found both within developed and developing fishing states regardless of their economic systems.

How did the world's capture fishery resources end up as non-performing assets? By the middle of the twentieth century, fishery managers in industrialized countries,

realizing that stocks were being overexploited, attempted to improve the design and enforcement of resource management measures. However, it became apparent that introducing harvest controls through the implementation of total allowable catches (TACs), or the equivalent thereof, alone generally led to the emergence of excess fleet capacity and severe economic waste. Subsequently, TACs were complemented with "limited entry schemes". However, even if the numbers of vessels were effectively controlled, technological advances in fishing technology meant that fishing capacity increased and resource depletion, economic waste (in the form of excess vessel capital) and lost economic rents (the result of exploiting standing stocks much below optimal stock sizes) continued to grow, exacerbated by fishery subsidies. The extension of economic zones, in the 1980s, followed by the 1995 United Nations Fish Stocks Agreement (UNFSA), did not improve the institutional framework for resource management to such an extent that resource investment occurred and economic waste disappeared, in part because of the problems associated with shared stocks.

FAO Fisheries and Aquaculture Technical Paper No. 538 attempts to identify what needs to be done to ensure that the world's capture fishery resources make their full potential contribution to the world economy. The paper concludes that massive resources need to be invested in the overexploited fish stocks. In this case, as with any positive investment, costs and sacrifices must be borne first in the hope of an economic return in the future. Establishing effective resource investment programmes within the exclusive economic zones (EEZs) of coastal states will be difficult, particularly in the developing world. How to go about such investment programmes is at the core of this study.

TYPES, OR LEVELS, OF FISHERIES IN NEED OF ECONOMIC REFORM

The root cause of the rent drain in capture fisheries lies in the perverse (from society's point of view) incentive structure confronting fishers in "common pool" types of fisheries. The fishers are given every incentive to regard the fishery resources as non-renewable resources to be mined. If measures are taken to restrict harvesting (in order to conserve the fishery resources) but nothing effective is done to limit fleet access to the fishery, the restricted harvest, TAC or the equivalent, becomes the "common pool", with the inevitable emergence of excess fleet and human capital, leading to resource rent dissipation. Unless the fishers are effectively blocked from responding to the perverse incentives, or the incentives themselves are altered, reversing the rent drain becomes an all but hopeless task.

Realizing the goal of maximizing resource rent requires that the perverse incentive problem be resolved. However, in many capture fisheries, this on its own will not be enough. As explained below, a major rebuilding of the resources will need to be undertaken if the goal is to be achieved. Given these two requirements, one can think of fisheries requiring reform as being at three levels. Level 1 consists of fisheries in which the resource managers have, by some means, succeeded in maintaining the stocks at, or building the stocks up (resource investment) to, the optimal level, but in which, through continued existence of perverse fisher incentives, the resource rent has been allowed to drain away. Resource investment is not required, but the correction of fisher incentives is. For these fisheries, the reversal of the rent drain, while not without its difficulties, is a simpler undertaking than is the case in Level 2 and Level 3 fisheries.

Level 2 consists of fisheries that are essentially the reverse of Level 1 fisheries. The perverse fisher incentive problem has been effectively addressed. Resource rent is being generated, but not maximized, because the resource is well below the optimal level owing to past overexploitation. Rebuilding the resource to the optimal level is an exercise in investment in natural capital in the form of fishery resources. Any investment in real capital, be the capital produced or natural, is a costly, and possibly lengthy and uncertain, undertaking. The fact that the incentive problem has been dealt with may mean that the required resource investment programme can be undertaken with some reasonable hope of success.



Level 3 consists of fisheries in which the perverse fisher incentives are unaddressed, in which the resource is well below the optimal level, and in which any resource investment that is occurring is negative (the average biomass is falling). The first objective of management in such fisheries must be to ensure that the rate of resource investment is no lower than zero.

Resource rent capture in fisheries with effective resource management but with perverse incentives – case studies of Level 1 fisheries

Pacific halibut is a good example of a shared (transboundary) stock that was saved from significant depletion and is therefore a strong candidate for inclusion in the Level 1 category. The fishery stands as one of those rare instances in which the fishing industry demanded the implementation of government fisheries regulation before serious damage had been done to the stock.

The Government of Canada was also aware of the consequences of harvest controls unaccompanied by controls over fleet size. Indeed, it had pioneered the introduction of limited entry schemes, commencing with the British Columbia salmon fishery. The implementation of the Canadian EEZs gave the Government of Canada the opportunity to introduce limited entry schemes in both its sablefish fishery and in Canada's segment of the Pacific halibut fishery. It had seized these opportunities by the early 1980s. However, both limited entry schemes were accompanied by what can be described as an Olympic-style TAC, i.e. the vessels granted access to the fishery were to compete for shares of the TAC. This was standard practice for limited entry schemes at that time.

What one can conclude from this Level 1 fishery experience is:

- The incentive-blocking approach to resource management, as it pertained to fleet and human capacity, was completely ineffective. The inability to control capacity led to a rent-destroying, non-cooperative game among the fishers.
- The subsequent introduction of catch shares in the form of individual transferable quotas (ITQs) did, in these instances, lead to a resource-rent-creating cooperative game among the fishers. That said, one must guard against concluding from this experience that ITQs offer the only route to achieving cooperative games among fishers. There will be many cases in which ITQs are inappropriate. However, alternatives exist. In their detailed paper on small-scale fisheries in developing fishing states, Kurien and Willmann⁴ argue that ITQs are indeed inappropriate for many, if not most, of these fisheries. The desired results – turning fisher competition into cooperation – can, they argue, be achieved through the establishment of community-based fisheries management schemes. Public authorities would continue to play an important management role, so that the schemes might best be described as comanagement schemes. In order to effect the transformation of fisher competition into cooperation, substantial management capacity is demanded of the resource managers. To take one example, if the resource managers in the Canadian case described had proved to be incapable of establishing an effective monitoring scheme, the ITQ schemes would have degenerated into non-cooperative fisher games, with all that that implies.

A question not hitherto considered is: Could the same results produced by catch-rights-based management be achieved through the traditional incentive-adjusting technique of taxes (positive and negative)? No answer is immediately available. It is noted that, for reasons good or ill, taxes have been little used in fisheries management.

The Canadian Level 1 experience leads to a further implicit conclusion. Let it be supposed that resource rebuilding is called for, and that a successful resource investment programme is implemented. If this resource investment programme is not accompanied by a management scheme designed to prevent the emergence of excess capacity, the return on the resource investment – expressed as an increase in sustainable resource rent – will equal zero. Thus, it is all but pointless, from an economic perspective, to undertake a resource investment programme until the incentive problem has been resolved.

Resource rent capture in fisheries with ineffective resource management but with appropriate incentives – case studies of Level 2 fisheries

The Icelandic cod fishery can be seen as the archetypal Level 2 fishery. The fishery is the most valuable of the Icelandic demersal fisheries, with a potential annual landed value of US\$1 billion. An ITQ scheme was introduced into the fishery in 1984, and then strengthened in 1991.⁵ The perverse fisher incentive problem appears to have been dealt with successfully. The fishery is currently generating significant rents, estimated to be in the order of US\$240 million per year as of 2005.⁶

However, that said, the fishery had been heavily overexploited prior to the introduction of ITQs. The introduction of ITQs, combined with reductions in the TAC, has brought overexploitation of the resource to a halt, but it has not succeeded in rebuilding the resource. It is estimated that the biomass is less than 60 percent of the optimal stock size. It is estimated further that the rent forthcoming from the fishery is no more than 36 percent of the maximum.⁷ Thus, if one accepts the estimates, one is forced to the conclusion that the potential return on investment in the resource is substantial. The problem is how to put into effect an effective resource investment programme.

One can now consider the feasible set of fishery resource investment opportunities and two issues that need to be addressed. The issues prove to be closely related. The first pertains to the optimal resource investment programme, which, in turn, is concerned in the first instance with the optimal rate of positive resource investment. The most rapid rate of positive resource investment is achieved by declaring an outright harvest moratorium until the optimal biomass level is achieved. As a general rule of thumb, once the target stock of capital (of any form) has been identified, one should move towards the target with all possible speed unless there are penalties associated with rapid rates of investment. The second issue pertains to the incentive structure that must be in place for the relevant fishers in order for the resource investment programme to have any reasonable chance of success.

Concerning the second issue, the optimal rate of positive resource investment, an example is provided by a case study on the Lake Victoria Nile perch fishery.⁸ The biomass of the resource is estimated to be between 37 and 50 percent of the optimal biomass, depending on whether the logistic or the Fox biological model is used. The study examines the possible resource investment programmes, and compares the one that would maximize the present value (PV) of rent from the resource through time with what the author of the study terms a “reasonable” investment programme. The PV-maximizing programme involves declaring a harvest moratorium for about three years until the optimal biomass level, or close to the optimal biomass level, is achieved. In other words, the PV-maximizing resource investment programme consists of investing in the resource at the maximum rate of speed. The “reasonable” resource investment programme calls for some harvesting during the resource investment phase. In so doing, it calls, in turn, for a slower rate of investment in the resource.

One could ask whether investing in the resource at the most rapid rate would not cause severe disruption to the fishing industry, and to the communities dependent upon the industry for employment. The answer depends critically on what economists term the “malleability” of the produced capital in the fishing fleet and the human capital involved in the fishery. The malleability of such capital concerns the ease with which it can be shifted into and out of the fishery, with perfectly “malleable” fleet and human capital being capital that can be easily and costlessly shifted in and out of the fishery. This is clearly not the case in the Lake Victoria Nile perch fishery.

From all of this, an obvious conclusion follows. The optimal resource investment programme must be expected to vary from fishery to fishery in both Level 2 and Level 3 fisheries. The resource managers must design an incentive scheme that will give the fishers an incentive to invest in the resource. The first question is whether the fishers are to be called upon to bear all or part of the cost of the resource investment. If the fleet and human capital is perfectly malleable, then the problem does not arise. In the many cases in which the fleet and human capital is less than perfectly malleable,



one could, in the first instance, think of a scheme in which the state bore the cost of investment by compensating the fishers for temporarily reduced harvest opportunities.⁹ However, such schemes could be accompanied by the threat of possibly severe moral hazard issues.

If the fishers are to bear a part or all of the cost of the resource investment, then the incentive-adjusting schemes discussed in the context of Level 1 fisheries carry a much greater burden. Eliminating the “race for the fish” is not enough. The design must be such that the fishers are assured a significant share of the investment payoff, with the proviso that the payoff be contingent upon the success of the resource investment. Thus, it would seem to be obvious that, if harvest rights are employed, they should be long in term, in fact (if not in strict law), and the harvest shares should be expressed as a percentage of the TAC.

The fishers should also have a considerable degree of certainty about future resource management policy. If, for example, the resource managers’ policy is perceived by fishers as being capricious, then the fishers will, if rational, heavily discount all future returns from the resource investment.

Beyond this, one can say little about the optimal incentive scheme other than that it will require a great deal of planning and thought and that it is certain to vary from fishery to fishery.

Resource rent capture in fisheries with ineffective resource management and with perverse incentives – case studies of Level 3 fisheries

Level 3 fisheries, in which the fisher incentives have not been corrected and in which negative resource investment is still occurring, constitute the ultimate challenge in terms of rent restoration. The vast majority of the world’s capture fisheries, including most developing countries’ small-scale fisheries that are so critical to food security and poverty alleviation, continue to remain in this category. Among the case studies, mention can be made of the Thai demersal and pelagic fisheries in the Gulf of Thailand, the Chinese fisheries in the Bohai and Yellow Seas, and the Vietnamese fisheries in the Gulf of Tonkin.

The Arafura shrimp fishery

While posing tremendous management challenges and difficulties, the case studies indicate that progress can nonetheless be achieved in developing, as well as developed, fishing states. One of the more dramatic cases of success is that of the Indonesian Arafura shrimp fishery.¹⁰

Up until early in this decade, the fishery was plagued with rampant non-compliance and poaching by Indonesians and foreigners, with consequent overexploitation of the resource and dissipation of the resource rent. It is estimated that, in 2000, the biomass was no more than 50 percent of the optimal level. The resource rent was positive, but was equal to less than 6 percent of the optimal level.¹¹ Under new fisheries legislation promulgated in 2004, surveillance and enforcement were greatly strengthened, and the right incentives were created by devolving management authority upon the provincial government, which, in turn, gained the active support and cooperation of the relevant fishing communities.

By 2005, the biomass had increased to almost 75 percent of the optimal level, and the resource rent was estimated to be more than 90 percent of the optimal level. As the shrimp resource is a fast-growing one, quick payoffs to resource investment are to be expected. Nonetheless, the results are remarkable.

Management of internationally shared fisheries

The greatest difficulties in attaining effective cooperation are encountered in the management of internationally shared fishery resources. These are either discrete high seas stocks, often highly migratory, or stocks that are found in the EEZs and adjacent high seas, i.e. straddling stocks. Under the terms of the UNFSA, highly migratory and straddling stocks are to be managed through regional fisheries management

organizations (RFMOs) that are to have both coastal states and relevant distant-water fishing states as members.¹² The Northwest Atlantic Fisheries Organization (NAFO), the Northeast Atlantic Fisheries Commission, and the Western and Central Pacific Fisheries Commission are all examples of such RFMOs.

The case studies present an example of an RFMO that is working reasonably well, the Northeast Atlantic Fisheries Commission managing the Norwegian spring-spawning herring, and one that provides an example of a Level 3 fishery, namely the RFMO governing the Northeast Atlantic and Mediterranean bluefin tuna fishery. The RFMO for this bluefin tuna fishery takes the form of the International Commission for the Conservation of Atlantic Tunas (ICCAT).

The bluefin tuna fishery

When in a healthy state, the Northeast Atlantic and Mediterranean bluefin tuna fishery ranges from the Canary Islands to Norway and through the Mediterranean to the Black Sea. The harvested fish are some of the most valuable in the world, with an individual fish being able to command a price of up to US\$100 000.

At present, some 25–30 states are involved in the fishery. At the peak of the fishery, up to 50 states were involved. The number of active states involved in the fishery has been substantially reduced because, argues Bjørndal,¹³ the resource has been severely depleted. Bjørndal maintains that the resource-rent-maximizing spawning stock biomass (SSB) is in the order of 800 000 tonnes. The current SSB is estimated to be in the order of 100 000 tonnes. This is the lowest SSB for the resource in recorded history. Indeed, the resource faces a significant risk of outright collapse.¹⁴

The current resource rent is actually positive, being estimated by Bjørndal at about US\$35 million per year. However, the continuation of this level of rent is uncertain given the parlous state of the biomass. The US\$35 million per year can be compared with Bjørndal's estimate of annual resource rent, under optimal conditions, of about US\$550 million.

The root of the problem is straightforward enough. The cooperative game that is the ICCAT-based RFMO governing the tuna resources has degenerated into a competitive game. According to Bjørndal, the management advice provided by the ICCAT is largely ignored. The economics of non-cooperative management of shared fishery resources predicts that the shared fishery can readily take on all of the characteristics of a pure open-access one. Bjørndal maintains that the fishery is to all intents and purposes just that. The steady, almost inexorable, decline in the SSB in the past 30 years is entirely consistent with a pure open-access fishery.

With the support of the EU, the ICCAT has called for the implementation of a resource recovery programme, i.e. a programme of resource investment. However, given the severely reduced state of the biomass, MacKenzie, Mosegaard and Rosenberg¹⁵ argue that recovery may take many years even if fishing mortality is drastically reduced. In other words, the states currently exploiting the resource will be called upon to bear heavy investment costs.

The Norwegian spring-spawning herring

A stark contrast is provided by the case of Norwegian spring-spawning herring. The resource has historically been one of the largest and most valuable in the Northeast Atlantic. When healthy, the resource migrates from its spawning grounds in Norwegian waters as far west as Iceland. In so doing, the resource passes through international waters, which means that it is to be classified as a straddling stock.

The resource crashed in the late 1960s and early 1970s, and its SSB was reduced to 2 000 tonnes, 0.08 percent of the critical minimum level of 2.5 million tonnes. Massive resource re-investment was called for and it did occur. Today, the resource is healthy, with the SSB at more than 6.5 million tonnes.¹⁶ So what went right?

First, the remnants of the resource were confined to Norwegian waters. Thus, it ceased, for the time being, to be a shared fishery resource. Second, as indicated above, the Norwegian fleet and human capital involved in the fishery was highly malleable



with respect to the fishery. It was politically easy for the Norwegian resource managers to declare a harvest moratorium, which more or less remained in place for 20 years. Finally, there was an element of luck in that environmental conditions allowed for a recovery of the resource from its desperately low state.

While not without its periodic difficulties, the cooperative game in the form of the Norwegian spring-spawning herring cooperative management arrangement has over time proved to be stable and effective in terms of both conservation and resource rent generation. In contrast to the Northeast Atlantic and Mediterranean bluefin tuna cooperative resource management arrangement, the number of “players” was small (a cooperative straddling stock fishery game with only five “players” is small indeed). There were no would-be new members appearing on the horizon. One can conjecture that the absence of a new-member problem was not unconnected with the fact that two of the “players” were, and are, politically very powerful – the EU and the Russian Federation.

Bjørndal demonstrates that the resource rent from the fishery could be increased by fine tuning the harvesting arrangements. Nonetheless, the resource rent is very substantial and would have seemed unachievable 35 years ago.

Abandoned, lost or otherwise discarded fishing gear

INTRODUCTION

Fishing gear has been lost, abandoned or discarded¹⁷ for many centuries since fishing began. However, increases in the scale and technologies used in fishing operations in recent decades mean that the extent and impact of abandoned, lost or otherwise discarded fishing gear (ALDFG) has increased significantly with the use of synthetic materials, the overall increase in fishing capacity and the targeting of more distant and deepwater grounds. Growing concern over ALDFG reflects the numerous negative impacts, particularly its ability to continue to fish (often referred to as “ghost fishing”) with associated impacts on fish stocks, and potential impacts on endangered species and benthic environments. It is also a concern because of its potential to become a navigational hazard at sea, with associated safety risks.

The issue of ALDFG has been raised at the United Nations General Assembly on several occasions, and as ALDFG is part of a wider problem of marine pollution, it comes under the remit of the International Maritime Organization (IMO). The mandate of the IMO includes the International Convention for the Prevention of Pollution from Ships (MARPOL), and the IMO’s Marine Environmental Protection Committee established a correspondence group in 2006, which includes FAO, to review Annex V of the MARPOL (Box 13). The United Nations Environment Programme (UNEP) is also dealing with the issue of ALDFG as part of a broader Global Initiative on Marine Litter, which is being implemented through the UNEP Regional Seas Programme.

The FAO Committee on Fisheries (COFI) considers marine debris and ALDFG an area of major concern. The FAO Code of Conduct for Responsible Fisheries (CCRF) encourages states to tackle issues associated with fishing impact on the marine environment. Article 8.7 of the CCRF specifically addresses the requirements of the MARPOL.

At the regional level, the Asia-Pacific Economic Cooperation (APEC) has recognized the problem of ALDFG. In seeking solutions to the problem, the Bali Plan of Action (September 2005) agreed to support efforts “to address derelict fishing gear and derelict vessels, including the implementation of recommendations from research already undertaken in the APEC context”. At the national level, some countries have taken unilateral action against ALDFG components of marine litter. The Marine Debris Research, Prevention, and Reduction Act came into law in late 2006 in the United States of America. It establishes programmes to identify, assess, reduce and prevent marine debris and its effects on the marine environment and navigation safety. Some states

in the United States of America also have their own laws addressing the problem of marine debris, while other states have made substantial progress through voluntary programmes.

In 2009, a joint FAO/UNEP report,¹⁸ to which this article refers, examined the magnitude and composition of ALDFG, its impacts and its causes. In order to establish an appropriate response to the problem of ALDFG, the report gathered and presented available information and examples from around the world on existing measures to address ALDFG, and recommended actions to be taken.

In order to establish an appropriate response to the problem of ALDFG, the report provides available information and examples from around the world on the following aspects of ALDFG in particular and marine litter in general:

- the magnitude and composition of ALDFG;
- the impacts of ALDFG and the associated financial costs;
- the reasons why fishing gear is abandoned, lost or otherwise discarded;
- the measures being taken to combat ALDFG and the degree of success achieved in mitigating ALDFG impacts.

Box 13

Review of MARPOL Annex V and related guidelines

The Marine Environmental Protection Committee (MEPC) of the International Maritime Organization (IMO) is currently conducting a review of Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL) and its guidelines for the application of the regulations within the Annex. The MEPC has established a correspondence group (CG), of which FAO is a member, to carry out the review. Whereas the CG is considering a wide range of issues related to abandoned, lost or otherwise discarded fishing gear (ALDFG), Annex V is only specific in relation to the prohibition of disposal into the sea of all plastics including, but not limited to, synthetic ropes and synthetic fishing nets. It also provides exceptions to the rule that include "the accidental loss of fishing nets, provided that all reasonable precautions have been taken to prevent such loss". Although Annex V takes due account of the possibility that gear may have to be discarded for safety or environmental reasons, the guidelines may have to address traditional and small-scale fisheries, particularly in relation to the location, retrieval, identification and how and where to dispose of such gear so retrieved. In this regard, more emphasis is likely to be placed on the availability of shore-based facilities for the disposal of fishing gear and garbage arising from the operation of fishing vessels.

With regard to the identification of lost fishing gear, the guidelines for the application of Annex V contain pertinent references for the need to consider the development of technology for more effective fishing gear identification systems. Although progress has been made, many systems of marking currently in use fall short of identifying the ownership of ALDFG, and this is one of the issues being addressed in the process of reviewing and amending Annex V of the MARPOL. In addition, the matter was again brought to the attention of the Committee on Fisheries (COFI) in 2007, at which time there was widespread support within the COFI to address the issue further.



MAGNITUDE OF MARINE LITTER AND ALDFG

Marine litter is either sea-based or land-based, with fishing activity just one of many different potential sources. The report concludes that there is no overall figure for the contribution of ALDFG to marine litter. A number of estimates suggest very different contributions of fishing activity to total marine litter based on locality. Close to or on the shore, the majority of litter originates from land-based sources.

When considered on a global basis, and including litter that does not wash up on beaches, it appears likely that merchant shipping contributes far more to marine litter than does ALDFG from fishing vessels. There are also significant differences in terms of the weight and the type of impacts on the environment of marine litter from merchant shipping and synthetic forms of ALDFG. Attempts at broad-scale quantification of marine litter enable only a crude approximation of ALDFG, which is likely to comprise less than 10 percent of global marine litter by volume, with land-based sources being the predominant cause of marine debris in coastal areas, and merchant shipping the key sea-based source of litter.

Table 15 summarizes ALDFG indicators from a number of fisheries around the world.¹⁹ The table demonstrates the wide variability of loss rates from different fisheries and also highlights the patchiness of data on ALDFG. Reports of gear loss do not necessarily equal the same volume of ALDFG remaining in the environment indefinitely, as some may subsequently be retrieved by other operators in the fishery.

Abandoned, lost or otherwise discarded fishing gear tends to accumulate and often reside for extended periods in ocean convergence zones. Mass concentrations of marine debris in areas such as the equatorial convergence zone are of particular concern, as they may create "rafts" of assorted debris, including various plastics, ropes, fishing nets and cargo-associated wastes. It should be noted that literature on marine litter in general and ALDFG in particular uses a mixture of volume, abundance and weight, complicating global estimates and compromising their robustness.

The UNEP Global Programme of Action²⁰ estimates that as much as 70 percent of the entire input of marine litter to the world's oceans sinks to the bottom and is found on the seabed, both in shallow coastal areas and in much deeper parts of the oceans. Accumulation of litter in offshore sinks may lead to the smothering of benthic communities on soft and hard seabed substrates.

IMPACTS OF ALDFG

The ability of ALDFG to "ghost fish" is one of its most significant impacts and is highly specific to a number of factors. These include the gear type (whether it has been abandoned as a set gear maximized for fishing or discarded or lost where it is less likely to fish effectively) and the nature of the local environment (especially in terms of currents, depth and location). Environmental impacts of ALDFG can be grouped as follows:

- *Continued catch of target and non-target species.* The state of the gear at the point of loss is important. For example, some lost nets may operate at maximum fishing efficiency and will thus have high ghost fishing catches, whereas ALDFG that collapses immediately and has lower fishing efficiency will probably have less ghost fishing potential. Fish dying in nets may attract scavengers that are subsequently caught in the nets, resulting in cyclical catching by the fishing gear. Furthermore, ghost fishing of gill and entangling nets and traps is probably higher than other ALDFG.
- *Interactions with threatened or endangered species.* Especially when made of persistent synthetic material, ALDFG can affect marine fauna such as seabirds, turtles, seals and cetaceans through entanglement or ingestion. Entanglement is generally considered to be the more likely cause of mortality.
- *Physical impacts on the benthos.* It is likely that ALDFG has little impact on the benthic fauna and the bottom substrate unless dragged along the bottom by strong currents and wind or when physically dragged during retrieval, potentially harming fragile organisms like sponges and corals.
- *Accumulation of synthetic material into the marine food web.* Modern plastics can last up to 600 years in the marine environment, depending upon water conditions, ultraviolet light penetration and the level of physical abrasion. However, the impact

of synthetic fragments and fibres in the marine environment, which result from the degradation of larger items, is not known. Thompson *et al.*²¹ examined the abundance of microplastics in beaches, estuarine and subtidal sediments and found them to be particularly abundant in subtidal sediments.

- *Accidents and loss of life.* A key socio-economic impact is the navigational threat of ALDFG to marine users. It is very difficult to rate or compare the magnitude

Table 15
Summary of gear loss, abandonment and discard indicators from around the world

Region/fishery	Gear type	Indicator of gear loss (data source)
North Sea & NE Atlantic	Bottom-set	Gillnets 0.02–0.09% nets lost per boat per year (FANTARED 2, 2003)
English Channel & North Sea (France)	Gillnets	0.2% (sole & plaice) to 2.11% (sea bass) nets lost per boat per year
Mediterranean	Gillnets	0.05% (inshore hake) to 3.2% (sea bream) nets lost per boat per year (FANTARED 2, 2003)
Gulf of Aden	Traps	20% lost per boat per year (Al-Masroori, 2002)
ROPME Sea Area United Arab Emirates	Traps	260 000 lost per year in 2002 (G. Morgan, personal communication, 2007)
Indian Ocean Maldives	Tuna longline	3% loss of hooks/set (Anderson & Waheed, 1998)
Australia (Queensland)	Blue swimmer crab trap	Fishery 35 traps lost per boat per year (McKauge, undated)
NE Pacific Bristol Bay	King crab trap fishery	7 000–31 000 traps lost in the fishery per year (Stevens, 1996; Paul, Paul & Kimker, 1994; Kruse & Kimker, 1993)
NW Atlantic	Newfoundland cod gillnet fishery	5 000 nets per year (Breen, 1990)
	Canadian Atlantic gillnet fisheries	2% nets lost per boat per year (Chopin <i>et al.</i> , 1995)
	New England lobster fishery	20–30% traps lost per boat per year (Smolowitz, 1978)
	Chesapeake Bay	Up to 30% traps lost per boat per year (NOAA Chesapeake Bay Office, 2007)
Caribbean Guadeloupe	Trap fishery	20 000 traps lost per year, mainly in the hurricane season (Burke & Maidens, 2004)

Sources: Based on:

- G. Macfadyen, T. Huntington and R. Cappell, R. *Abandoned, lost or otherwise discarded fishing gear*. UNEP Regional Seas Reports and Studies No. 185; FAO Fisheries and Aquaculture Technical Paper No. 523. Rome, UNEP/FAO. 2009. 115 pp.
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- G.H. Kruse and A. Kimker. 1993. *Degradable escape mechanisms for pot gear: a summary report to the Alaska Board of Fisheries*. Regional Information Report 5J93-01. Kodiak, USA, Alaska Department of Fish and Game.
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- R.J. Smolowitz. 1978. Trap design and ghost fishing: an overview. *Marine Fisheries Review*, 40(5–6): 2–8.
- NOAA Chesapeake Bay Office. 2007. *Derelict fishing gear study fact sheet, July 2007* (available at chesapeakebay.noaa.gov/).
- L. Burke and J. Maidens. 2004. *Reefs at risk in the Caribbean*. Washington, DC, World Resources Institute (also available at www.wri.org/biodiv/pubs_description.cfm?PubID=3944).



of the wide range of socio-economic costs as literature is very scarce and there are particular problems in quantifying and comparing social costs. Estimating the costs associated with compliance, rescue and/or research associated with ALDFG is complex, and it does not seem to have been attempted to date.

CAUSES OF ALDFG

It is important to recognize that, owing to the environment in which fishing takes place and the technology used, some degree of ALDFG is inevitable and unavoidable. As with the magnitude of ALDFG, the causes of ALDFG vary between and within fisheries. When one considers that gear may be abandoned, lost or discarded, it is clear that some ALDFG may be intentional and some unintentional. Correspondingly, the methods used for reducing ALDFG need to be matched to the causes.

Direct causes of ALDFG can also result from a variety of pressures on fishers, including: enforcement pressures causing those operating illegally to abandon gear; operational pressures (including those resulting from hazardous weather conditions) resulting in gear being abandoned or discarded; economic pressure leading to dumping of unwanted fishing gear at sea rather than disposal onshore; and spatial pressures resulting in the loss or damage of gear through gear conflicts. Indirect causes include the unavailability of onshore waste disposal facilities as well as their accessibility and cost of use.

MEASURES TO ADDRESS ALDFG

Measures to address ALDFG specifically can be broadly divided into measures that prevent (avoid the occurrence of ALDFG in the environment), mitigate (reduce the impact of ALDFG in the environment) and cure (remove ALDFG from the environment). Experience to date illustrates that many of these measures can be applied at a variety of levels (international, national, regional, local) and through a variety of mechanisms. To reduce the problem of ALDFG successfully, and more generally to reduce its contribution to marine debris, it is likely that actions and solutions will need to address all three types of measures, i.e. preventive, mitigating and curative.

Some measures may need to be supported by a legal requirement, while others may be just as effective if introduced on a voluntary basis and when incentives are provided. Therefore, the likely success of introduced measures may depend strongly on whether the correct approach is taken with regard to a mandatory or voluntary, incentivized approach.

Preventive measures

Preventive measures are identified as the most effective way of tackling ALDFG as they avoid the occurrence of ALDFG and its associated impacts. Such measures include: gear marking; the use of onboard technology to avoid loss or improve the location of gear; and the provision of adequate, affordable, accessible onshore port reception and collection facilities. It is also acknowledged that effort reduction measures, such as limits on the amount of gear that can be used (e.g. pot and trap limits) or the soak-time (the length of time gear can remain in the water), could reduce operational losses. Spatial management (e.g. zoning schemes) is also a useful tool in addressing gear conflict, which can be a significant cause of ALDFG.

The implementation of the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated (IUU) Fishing²² when it enters into force will be critical in addressing IUU fishing, which is also a significant contributor to ALDFG as illegal fishers are unlikely to comply with regulation including any measures to reduce ALDFG. Furthermore, the agreement can be used to strengthen requirements for gear marking.

The provision of appropriate collection facilities is a preventive measure as it can reduce the likelihood that a fisher will discard unwanted gear at sea. Annex V Regulation 7 of the MARPOL²³ stipulates: "the Government of each Party to the

Convention undertakes to ensure the provision of facilities at ports and terminals for the reception of garbage, without causing undue delay to ships, and according to the needs of the ships using them.” However, scale and capacity issues have prevented the provision of adequate reception facilities at many fishing ports and harbours, and these need to be addressed.

The increasing use of the Global Positioning System (GPS) and seabed mapping technology by fishing vessels affords benefits in terms of both reducing initial gear loss and improving the location and subsequent recovery of lost gear. Transponders are now a common feature in many large-scale fisheries, with the satellite tracking of vessels for safety and for monitoring, control and surveillance (MCS) purposes. The use of transponders on gear such as marker buoys or floats to improve the ability to locate lost gear is becoming more widespread. Small-scale fishers should also be encouraged to make wider use of available technology so that they can better identify the position of static gear.

In the revision process of Annex V of the MARPOL, mentioned above, reporting procedures have been discussed, including the fact that currently all ships of 400 GT and above have to keep a garbage record book. However, this does not apply to smaller ships. Furthermore, there is no direct instruction to report ALDFG to the flag state or to any coastal state in whose waters the ship (fishing vessel) may be operating. It has therefore been suggested that existing reporting requirements such as catch reporting systems (e.g. logbooks) and observer programmes should be extended to include the reporting of ALDFG, possibly as a mandatory requirement. A “no-blame” approach could be incorporated into any such requirements with respect to liability for losses and their impacts and any related recovery costs.

Spatial management can avoid ALDFG by actively segregating marine users or, more commonly, by better ensuring that marine users are aware of the likely presence of fishing gear in the water. This reduces the navigational hazard of fishing gear and thus reduces the likelihood that gear will be damaged or moved. Spatial management at the local level may reduce ALDFG through fostering a stewardship approach to an area, especially when such management is based on a community or comanagement approach.

The use of fishing effort and output restrictions will also have impacts on the incidence of ALDFG. For static gear, the amount of gear in the water and the time it is left in the water (soak-time) both influence the probability that gear will be lost or discarded, and restrictions on effort can thus reduce ALDFG.

Mitigation measures

Mitigation measures to reduce the impact of ALDFG are limited in their extent and application as many may increase costs through reduced effectiveness of gear or higher gear prices. Consequently, the development of innovative materials has been slow and the return to biodegradable netting by the industry has been very limited. Trials are continuing on net materials that increase sound reflectivity and hence could reduce the bycatch of non-target species such as cetaceans (Box 14). These and other innovative solutions are being encouraged through initiatives such as the International Smart Gear Competition of the World Wide Fund for Nature (WWF).

Curative measures

Curative measures are inevitably reactive to the presence of ALDFG in the environment and will therefore always be less effective than avoiding ALDFG in the first instance. However, curative measures have been shown to be cost-effective when considering the costs of leaving the ALDFG *in situ*. Measures can be seen to be broadly sequential in the identification, removal from the environment and appropriate disposal of ALDFG. They include: efforts to locate lost gear using various technologies, such as the side scan sonar for seabed surveys; the introduction of systems to report lost gear; gear recovery programmes; and the disposal or recycling of ALDFG material.



Awareness

Raising awareness of the ALDFG problem is a cross-cutting measure that can aid the development and implementation of any of the measures described above. It can target fishers themselves, port operators, marine users or the general public through local, national, regional or international campaigns. Education can, if effective,

Box 14

The role of technology in mitigating abandoned, lost or otherwise discarded fishing gear

Degradable escape panels and “rot cords” can be used to reduce ghost fishing by traps and are required in some fisheries, although they are less evident in net fisheries. The spiny lobster fishery in Florida (United States of America) has had such a requirement since 1982,¹ and the fisheries management plan for king and tanner crab in the Bering Sea states that “an escape mechanism is required on all pots; this mechanism will terminate a pot’s catching and holding ability in case the pot is lost”.² In Canada, recreational fishing traps require features “to ensure that if the trap is lost, the section secured by the cord will rot, allowing captive crabs to escape and to prevent the trap from continuing to fish”.³ Also in Canada, the 2008 Pacific Region Integrated Fisheries Management Plan for crab traps includes various requirements related to biodegradable escape mechanisms.

There have been some efforts to develop biodegradable and oxydegradable plastics for use in the fishing industry. For example, the Australian and New Zealand Environment Conservation Council was instrumental in promoting the use of biodegradable materials in bait bag manufacture and supporting the development of biodegradable ice bags.⁴

Mitigating against ghost fishing of bycatch and non-target species (cetaceans, turtles, seabirds, etc.) by abandoned, lost or otherwise discarded fishing gear can be supported using the same measures as in the active fishery, e.g. acoustic beacons (“pingers”) and reflectors in gillnet and set net fishing gear. Trials are also progressing with substances that reflect sound, such as barium sulphate, with such substances being added to nylon nets during production. The additive does not affect the performance or the look of the net in any way, but it reflects sound waves in ranges used by echo-locating animals.⁵ Other developments, such as those supported by the World Wide Fund for Nature (WWF) through its International Smart Gear Competition, have produced weak ropes that are operationally sound but break with the action of marine mammals, and magnets attached to longlines to repel sharks.

¹ T.R. Matthews and S. Donahue. 1996. *By-catch in Florida’s spiny lobster trap fishery and the impact of wire traps*. Report submitted to the South Atlantic Fishery Management Council.

² North Pacific Fishery Management Council. 2008. *Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs* (available at www.fakr.noaa.gov/npfmc/fmp/crab/CRAFMP2008.pdf).

³ Fisheries and Oceans Canada. 2007. *Pacific region recreational fishing – recreational fishing gear* (available at www.pac.dfo-mpo.gc.ca/recfish/Law/gear_e.htm).

⁴ I. Kiessling. 2003. *Finding solutions: derelict fishing gear and other marine debris in Northern Australia*. Hobart, Australia, Charles Darwin University, National Oceans Office.

⁵ G. Schueller. 2001. Nets with porpoise in mind. *Environmental News Network*, 19 February 2001 (available at www.eurocbc.org/page523.html).

facilitate a change in behaviour and result in self-policing by stakeholders, and it has the potential to extend beyond those directly targeted to change behaviour in society.

In many fisheries, operational losses resulting from extreme weather events may to some extent be prevented if the level of awareness to approaching rough weather can be raised through, for example, radio and, where practical, the use of cellular phones or other information dissemination methods to allow precautionary measures to be put in place to minimize risk to fishers, installations and gear in advance of approaching bad weather.

CONCLUSIONS

Many of the measures to address ALDFG can be applied at a variety of geographic scales (international, national, regional, local) and through a variety of mechanisms, from legal requirements through to voluntary schemes. Measures to address ALDFG must be tailored to reflect the need for differing solutions for gear that is: (i) abandoned, (ii) lost, or (iii) discarded. They must also deal with the wide range of different causes as discussed above. Thus, actions must reflect a high degree of specificity of causes across different fishing methods and fisheries. While some generalized and international measures are certainly appropriate and necessary, it is also likely that great care will need to be taken in specifying solutions that adapt and tailor possible measures to the specificities of the particular fishery concerned.

In order for the issue of ALDFG to be tackled effectively, it is critical that there be greater education and awareness of the extent of the problem, its impacts and causes, and of the wide variety of measures that can be used to reduce ALDFG. This article is itself an attempt to foster such awareness and to build on growing concern at the level of the United Nations General Assembly and among many international and regional organizations, as well as among states, the fishing industry and civil society. Greater education and awareness will serve to foster much-needed collaborative efforts between institutions and stakeholders to address the problem of ALDFG more effectively.

More research is urgently needed on many aspects of ALDFG, including a quantification of the scale involved, the contribution of different fisheries to ALDFG, and the potential technological solutions to the problem. Also of special importance is the need to understand better why certain measures are effective in certain situations and why others are not; reasons may be strongly correlated with their relevance, acceptability and enforcement in specific locations but have not been well studied. Another significant gap in knowledge results from the lack of cost–benefit analyses conducted of particular measures, or of how to prioritize among them. However, it would appear likely that “prevention is better than cure”. Preventive measures are likely to be preferable to curative ones because, by preventing gear loss, they can prevent many of the potentially high costs associated with ALDFG once it has entered the environment (e.g. ghost fishing, navigational risks), which *ex-post* measures are less able to do.²⁴ What is clear is that there are very many measures, be they preventive, mitigating or curative, that can and should be taken now to address ALDFG so as to reduce the significant environmental, economic and social impacts, even if current knowledge of ALDFG is not as comprehensive as it should be.

Private standards and certification in fisheries and aquaculture: current practice and emerging issues

INTRODUCTION

Private standards and related certification are becoming significant features of international fish trade and marketing. In 2009, FAO reported on the range of market-based standards and labels in fisheries and aquaculture.²⁵ However, there is scant empirical evidence on the market significance of private standards. A recent FAO study²⁶ analyses two main types of private standards that affect fish trade



and marketing in order to shed light on the overall implications for fisheries and aquaculture. It focuses on:

- “ecolabels” or private standards and certification schemes related to the sustainability of fish stocks;
- private standards and certifications related to food safety and quality, from retailers’ in-house specifications to international food safety management schemes (FSMSs) designed for food generally but increasingly applied to fish and seafood.

The FAO study analyses implications of private standards in fisheries and aquaculture for a range of stakeholders. It asks:

- What role do private standards play in overall governance for fisheries sustainability and food safety? Do they complement, duplicate or undermine public regulatory frameworks?
- Do they impose deadweight compliance costs for the various stakeholders in the supply chain or can they facilitate market opportunities? How are the costs and benefits distributed among stakeholders?
- How do they affect developing countries and small-scale producers and processors? Can they help facilitate international trade by encouraging good practices and by compensating for local institutional shortfalls or, instead, do they amount to a significant barrier to trade that threatens to undermine the internationally agreed mechanisms of the World Trade Organization (WTO)?

ECOLABELS AND MARINE CAPTURE FISHERIES

It is difficult to estimate the volume of ecolabelled certified products on the international market. The two largest international schemes (both sponsored by non-governmental organizations [NGOs]), the Marine Stewardship Council (MSC) and Friend of the Sea (FOS), claim to cover 7 percent and 10 percent, respectively, of the world’s capture fisheries. However, together this amounts to less than one-fifth of wild capture landed product. Probably only a small percentage of certified raw material ends up as a labelled product. Of the MSC’s 6 million tonnes of seafood landed from certified fisheries, only about 2.5 million tonnes ends up carrying the MSC label.²⁷ Ecolabelled fish and seafood is also highly concentrated in certain species. While the MSC claims to cover 42 percent of the world’s global salmon catch and 40 percent of the “prime whitefish” catch, the Alaskan salmon and pollock fisheries account for more than half (56 percent) of MSC products on sale. About 80 percent of FOS-certified fish is Peruvian anchovy.²⁸ Despite the exponential growth in the number of ecolabelled products on the market overall, they are also concentrated in certain markets only. The main demand for ecolabelled products appears to be in pockets of the European market (Germany, Netherlands, United Kingdom) and in the United States of America (especially in the food service industry). FAO research²⁹ suggests that markets conducive to sales of ecolabelled fish and seafood typically have:

- an environmentally aware population with a strong civil society active in the environmental or sustainability area;
- retail of fish and seafood products dominated by supermarkets (typically large retailers in highly competitive markets) rather than fresh fish markets;
- consumption patterns based on a traditionally limited range of fish and seafood species leading to lower substitutability of product;
- strong tradition and presence of highly processed fish and seafood products.

The costs and benefits of ecolabelling and certification accrue differently to different stakeholders. Retailers are the main drivers of the ecolabelling phenomenon and reap the most rewards in terms of value-addition to their brand and reputation, risk management, ease of procurement, and potential price premiums, at relatively little or no cost (relating to chain of custody certification or licence fees). In contrast, fishers assume the main cost burden. The actual costs of certification, including experts’ fees, can range from a few thousand US dollars to up to US\$250 000 depending on the size and complexity of the fishery and on the scheme chosen. One research study

has confirmed that the fishing industry itself usually foots the bill for certification.³⁰ In terms of benefits, there is some evidence of more secure supply relationships based on certification, consolidation of position in existing markets, and of new niche markets for environmentally friendly products. However, there is only spotty evidence of price premiums accruing to certified fish and seafood.³¹ Reported price premiums are typically associated with more secure supply relationships, either with food services (and to a lesser extent, supermarkets) or access to niche markets.

To date, fisheries in developing countries represent a small minority of certified fisheries, most of which are large-scale. Developing countries' underrepresentation is due to three main factors:

- There is a lack of an economic imperative for certification. Developing countries have a limited presence in the markets, species, types of products and supply chains where pressure to be certified is greatest. Despite some exceptions, developing country fishers (especially small-scale fragmented fisheries environments) are less linked into direct supply relationships with large-scale buyers where the pressure for certification is most intense.
- Ecolabelling schemes do not translate well into the typical conditions of the fisheries environment in developing countries (insufficient fisheries management regimes, data deficiencies, small-scale multispecies fisheries).
- The high costs of certification are often prohibitive for small-scale or resource-poor operators.

However, developing countries might be missing out on the potential opportunities that certification has to offer. As demand for ecolabelled products grows and spreads to fisheries in species relevant to developing country capture fishers (such as shrimp³² and other tropical species), developing country producers might feel more pressure to participate in ecolabelling schemes.

PRIVATE STANDARDS AND CERTIFICATION FOR FOOD SAFETY AND QUALITY IN FISHERIES AND AQUACULTURE

National and international regulatory frameworks to ensure food safety systems that function across national borders are well entrenched. The joint FAO/WHO Codex Alimentarius Commission is the global reference for national food safety strategies. However, fish exporters still face safety and quality control regimes that vary from one jurisdiction to the next, as well as a growing proliferation of standards being introduced by the private sector. In addition to their firm-specific product and process specifications, many large retailers, commercial brand owners and food service industry firms require their suppliers to be certified:

- For processed fish and seafood: To a national or international FSMS, such as the British Retail Consortium (BRC), International Food Standard (IFS), Safe Quality Food Institute (SQF) or Global Gap. These are designed for food generally but are increasingly applied to fish and seafood products. They are based on the Hazard Analysis and Critical Control Point (HACCP) system and are the most important schemes in terms of the impacts of private standards on the food industry generally.
- For aquaculture: To one or other of the schemes that merge quality and safety with environmental protection, animal health and even social development, such as the Aquaculture Certification Council (ACC). Global Gap is also active in aquaculture while the WWF has set up (in 2010) the Aquaculture Stewardship Council, following its "aqua dialogues" and standards development for 12 aquaculture species.

A few public safety and quality certification schemes also exist. For example, Thai Quality Shrimp is a public certification verifying the safety and environmental credentials of Thai shrimp farmers. A relatively new development is the use of private voluntary standards in public food safety policy frameworks. For example, the United States Food and Drug Administration (FDA) has a pilot programme to evaluate third-party certification schemes for imported farmed shrimp – including the ACC and Thai Quality Shrimp – which might eventually allow products from



facilities certified by those bodies expedited entry into the United States of America. In this way, governments are using market mechanisms as tools to gain traction in their own food safety policy frameworks.

The pressure on producers (fish farmers) and processors (of both wild capture and farmed fish) to comply with private standards depends on the market, how that market is structured, and the type of product being sold. As in the ecolabels arena, large-scale retailers and food firms are not equally demanding of all their suppliers or product lines. Requirements are more stringent for private-label and highly processed fish and seafood products than for basic commodity fish and seafood. For fish and seafood processors producing brand products or private-label products, certification would be essential. The pressure to comply with private standards is more intense for suppliers to markets in northern Europe, where a higher proportion of fish and seafood is sold in supermarkets, where there is a greater predominance of processed and value-added products, and where there are more private-label products. In terms of requirements for certified aquaculture, the United States market is also important. The pressure is lower in southern Europe (overall the biggest European seafood consumers), where whole fish and fresh fish remain standard fare. The more direct the supply relationship is and the more integrated the supply chain is, the more private standards are likely to enter the equation – there is relatively more integration in aquaculture, where there is scope to produce to specification.

Although the costs of certification are difficult to determine with precision, estimated costs need to be weighed against the potential benefits, which might include:

- access to new markets where certification offers access to an integrated value chain and long-term contractual supply relationships as well as access to more sophisticated market segments (private-label, high-value-added products);
- improved quality management and products, and subsequent reductions in costly rejections based on poor sanitary status or inferior quality and in the costs of recalls and the negative publicity they cause;
- more stable supply relationships – probably meaning less price volatility (although there is no evidence of a price premium generally).

COMMON POLICY AND GOVERNANCE ISSUES

The impact of private standards – ecolabels, safety and quality or aquaculture certifications – is not uniform across markets, species or types of products. Demands for ecolabelled fish and seafood, and certified aquaculture products, are currently concentrated in certain species and in certain markets. The demands for fish and seafood to be certified to a private FSMS increase according to the level of value-addition involved, and affect products destined for sale in supermarkets and/or as commercial brand and private-label products.

However, the impact of private standards in the trade and marketing of fish and seafood is likely to increase as supermarket chains consolidate their role as the primary distributors of fish and seafood products, and as their procurement policies move away from open markets towards contractual supply relationships. As the leading retail transnationals extend their global reach, their buying strategies will probably progressively influence retail markets in Africa, East Asia, Eastern Europe and Latin America. Key issues related to the overall impact of private standards in fisheries and aquaculture and how they affect various stakeholders require resolution.

Assessing the quality and credence of private standards and related certification

The proliferation of private standards causes confusion for many stakeholders – fishers and fish farmers trying to decide which certification scheme will bring most market returns, buyers trying to decide which standards have most credence in the market and will offer returns to reputation and risk management, and governments trying to decide whether to take a “hands off” or “hands on” approach to private certification schemes. Transparency and good governance in private voluntary schemes are imperative. A mechanism for judging the quality of schemes is required.

CHALLENGES AND OPPORTUNITIES FOR DEVELOPING COUNTRIES

Fish and seafood are important income earners for many developing countries. Developing countries are crucial for current and future global supplies of fish and seafood products. They account for about half by value, and about 60 percent by volume, of all seafood traded internationally. Furthermore, they produce more than 80 percent of aquaculture products, which currently supply 47 percent of global fish food, up from a mere 7 percent in the early 1970s.

As noted above, certification to private standards schemes can be problematic for many developing countries. Some private certification schemes have taken these concerns on board and have attempted to develop ecocertification methodologies more suited to data-deficient small-scale fisheries and fish farms. However, developing country operators remain underrepresented particularly among the ranks of certified fisheries (ecolabels) and certified fish processors (FSMSs). They are becoming better represented in aquaculture, where there have been proactive strategies to organize small-scale farmers into associations or “clusters”.³³ In general, certified operators from developing countries tend to be those that are large-scale and involved in more integrated supply chains with direct links to developed country markets (through equity or direct supply relationships).

While some developing countries have argued that private standards pose a barrier to trade, there is no solid evidence of markets “drying up” as a result of demands for certification. Demands for certified products tend to be concentrated in markets and species that are not the main species traded by developing countries. Moreover, evidence suggests that meeting mandatory public standards in developed country markets currently poses more of a barrier to trade than do requirements to meet private standards. For developing countries to take advantage of the opportunities presented by private standards, they must first be able to meet the requirements of mandatory regulatory requirements in importing countries. This would create the foundations for future responses to private standards, if and when demand spreads to typical developing country species. Any technical cooperation in developing countries would be best focused on ensuring that the public systems are appropriate.

While certification is problematic for many developing country fishers, farmers and processors, it might also provide a tool for engagement with large-scale buyers. The challenges and costs of certification need to be weighed against the potential opportunities to access high-value or niche markets in key importing countries, and to participate in direct supply relationships, with less price volatility than selling through traditional auction markets. There is also potential for more value-addition in developing countries that have a competitive advantage in lower labour costs.

Developing countries are a crucial part of international fish and seafood supply chains. Any attempts to further develop global governance for food safety or fisheries and aquaculture sustainability will fail if developing countries are not an integral part of the equation.

Impacts on international trade and WTO mechanisms

The impact of private standards on international trade has been raised for discussion in relation to two WTO agreements: the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) and the Agreement on Technical Barriers to Trade (TBT Agreement). Ongoing concerns of WTO member countries in relation to private standards include those related to:

- the content of private standards and their consistency with international WTO obligations;
- the discriminatory costs of and access to private certifications;
- a lack of clarity about the jurisdiction over private-sector actors;
- the changing interface between public and private standards.

Some countries have argued that private standards go beyond relevant international public standards and that those related to food safety include product and process specifications (non-safety and quality criteria) that have no particular



scientific rationale and are, therefore, inconsistent with the obligations of the SPS Agreement. In terms of ecolabels, some countries fear that the allowance of non-product-related process and production methods could open the door to developed countries to impose their domestic policy frameworks related to either fishing methods and/or other standards (social responsibility), thereby giving further grounds for discrimination against developing country products. Further analysis is required in order to determine the consistency or not of private standards with international standards and obligations of both the SPS Agreement and the TBT Agreement.

While governments have the right to challenge the actions of other governments within the context of the WTO, the grounds for challenging non-governmental actors are less clear. Requirements for only ecolabelled fish and seafood could mean that products can be excluded from certain markets owing to perceptions of the buyer or retailer about whether governments (from exporting countries) have lived up to their obligations for good fisheries management. What recourse governments have to challenge these assessments and their implications is still largely unknown. Jurisdiction over non-governmental actors, transnational firms or coalitions of firms is problematic. The SPS Agreement and the TBT Agreement offer little direction on this front and "there is no jurisprudence on this matter".³⁴

Other trade-related issues are emerging. For example, could public-sector financial support for ecolabel certification be considered a "subsidy" and/or notifiable in the context of WTO mechanisms? If a government pays outright for certification, is that a subsidy to its industry? If it leads to a trade advantage or improved market access, then should it be notifiable? As the boundaries between public and private standards and requirements start to blur, there are implications for trade that need to be closely monitored.

Some countries have argued that private standards help to expand trade. Others counter that they discriminate against developing countries. Further enquiry and evidence of the actual effects of private standards on trade opportunities, especially for developing countries, are needed. While volumes of certified fish products remain modest, the impact on trade is likely to be slight. However, it is a fast-moving area that needs to be closely monitored. Work continues in the area at both the WTO and FAO.

Aquaculture development in Southeast Asia: the role of policy

INTRODUCTION

Fish is important in the diet of much of Southeast Asia (here considered to consist of Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Thailand and Viet Nam). It is a major source of animal protein in a region where levels of animal protein in human diets are below the world average.

The region has a long history of aquaculture, but rapid expansion began only after 1975. Before then, total output was still less than half a million tonnes. By 1987, the region was producing one million tonnes, excluding aquatic plants. Thereafter, each decade has seen a doubling of output, with production of food fish exceeding five million tonnes in 2005. By 2005, the region already produced a significant proportion of world aquaculture output: 10 percent by volume and 12 percent by value, excluding aquatic plants. Moreover, the region's share of world volume has been growing.

Accounting for one-quarter of all food fish produced in the region, aquaculture is an important contributor to food security. It also provides rural employment and income. For example, more than half a million people are employed in aquaculture in Viet Nam; capture fisheries do not employ as many people. Furthermore, it is a major contributor to countries' economies and a sector with promising export potential. In 2005, the value of the seven countries' aquaculture production combined was almost US\$10 billion, only a small proportion of which (2.7 percent) came from aquatic plants.

However, these attributes are not uniform among the region's seven countries; the level and pace of the sector's development have varied across national boundaries.

The aim of the study³⁵ summarized here was to understand the reasons for these differences. In a region that has experienced such a rapid expansion of aquaculture output and where aquaculture development is uneven, there are successes and failures that can provide invaluable lessons from which countries within and outside the region can learn as they strive to develop aquaculture. For a sector playing such an essential role in the region's food security, rural livelihoods and foreign exchange, it was felt equally important to ascertain whether or not the growth of the sector is likely to continue in the future.

POLICY LESSONS

The analysis of the history of development of aquaculture in the region reveals that the rapid expansion of the sector occurred in response to market demand and profit opportunities, with some government involvement. Governments were more enabling than proactive; they endorsed aquaculture as a source of livelihood or export earnings, but they did not provide generous incentives to farmers. It is only recently that, motivated by the sector's contribution to economic development, food security and the balance of payments, some governments have been proactive, deliberately promoting the sector with such incentives. Having learned from earlier mistakes in the region, most governments also intervene with regulations to limit *laissez-faire* excesses. It seems, therefore, that differences in national government policies could explain much of the difference in countries' aquaculture growth.

Myanmar, for example, has demonstrated the usefulness of aquaculture legislation in promoting the sector in a more orderly fashion. By legalizing aquaculture in 1998, the legislation encouraged farms to register. While water rights in agriculture still have priority over aquaculture, farmers have been permitted to convert rice paddies in the Irrawaddy Delta to shrimp farms. The result has been a rapid expansion in area devoted to shrimp farming and in output. From almost zero a decade earlier, shrimp output reached almost 49 000 tonnes in 2005. However, in terms of leases for aquaculture farms, Viet Nam appears to have developed the most effective policies. The leases are for long periods, ranging from 20 to 50 years; they are also transferable. In Myanmar, they may be for only three years; too brief to provide an incentive to improve property. In Viet Nam, officials are obliged to process applications for permits within 90 days of the application; otherwise, the permit is assumed granted.

Seed production and seed quality have also been a focus of policies and regulations in the region. All seven countries have public hatcheries that undertake research, training and technology dissemination and produce fingerlings. Some fingerlings are destined to small-scale farmers at subsidized prices, as in the Philippines; others are oriented to particular regions, as in Viet Nam. Public hatcheries may also concentrate on particular species deemed to have potential commercial value, as in Malaysia. However, in all countries except Cambodia, public hatcheries have been outnumbered by private hatcheries. The latter have developed in parallel with the industry. Indonesia's experience with public shrimp hatcheries has demonstrated the dynamism of the private sector. By the time public stations had been constructed, they were already redundant because of the appearance of private hatcheries.

Some countries have deliberately encouraged private hatcheries by providing incentives to domestic and foreign investors. These incentives, which consist of soft loans or tax exemptions and which have succeeded in increasing seed production, can be oriented to particular species. To improve seed quality from the private sector, regulations and inspections are used in Indonesia and Thailand. However, monitoring and enforcement are expensive; they also require skilled personnel that may be unavailable, as in Cambodia. The Philippines has improved culture traits of farmed species by encouraging collaborative research with universities.

Among the policies used to lower feed expenses, the most important cost in fish farming, are reductions in tariffs on imported feed; this helps domestic producers to become more efficient. Viet Nam has enticed foreign investment into the feed sector, which has increased feed availability and lowered costs. The availability and low cost of



feed have increased its demand from farmers and stimulated investment in domestic feed industries. To lower the foreign exchange burden of imported fishmeal, Indonesia and Malaysia are actively conducting research in the use of local ingredients. In some countries, feed standards are controlled by regulations, but as with seed quality, monitoring can be constrained by lack of financial resources or skilled personnel.

A further policy that has been selectively used to promote investment in aquaculture is the provision of incentives to potential investors. Indonesia and the Philippines have offered subsidized credit, sometimes focused on small-scale farmers. The Philippines has abandoned this policy as it gave undue advantages to large-scale farmers. Provision of loans without collateral to small-scale farmers has been a successful policy in Malaysia. In Myanmar, policies focusing on carp farmers have not worked; not only is collateral required, but loan limits are also very low.

Fiscal exemptions and foreign investment have also been successfully used to encourage development in aquaculture. A number of countries offer tax holidays, exemptions or reductions on income tax, land taxes, sales taxes and import duties. Such incentives are not unique to aquaculture; they may be granted to other food-producing sectors, as in Malaysia. They can be species-specific or location-specific, as in Myanmar and Viet Nam. In Myanmar, foreign investment can take the form of joint ventures exclusively, while in the Philippines there are maximum limits on foreign participation. A minimum requirement for these policies to be successful is to guarantee capital and profit repatriation. While foreign investment in aquaculture within the seven countries is generally low, foreign participation in Viet Nam has been increasing rapidly. In Viet Nam, incentives also have a regional bias; the aim is to entice aquaculture development to the mountainous regions where fish protein is most needed.

MAJOR STRENGTHS AND WEAKNESSES

The region provides several lessons to learn from, but it has also generated problems of its own, which could limit the expansion of aquaculture output.

With the possible exception of Indonesia, the major constraint on aquaculture expansion in the region is a shortage of land. Different governments have taken different approaches to tackling this problem. The Government of Thailand has limited the brackish-water area available for marine shrimp. In the Philippines, no official limit has been set, but no additional land is available either; less than one-third of the original 400 000 ha of mangroves remain, but they are protected against encroachment. Development in the mid-1980s occurred in agricultural land, primarily in sugar plantations. Because land area cannot be increased, a solution is to intensify land-based production. Another option is to move to marine cage culture. Already, more seabass and grouper farming occurs in sea cages than in ponds, with higher returns. The Philippines is also moving to sea cage culture of milkfish.

Except in Indonesia and Malaysia, availability of freshwater is the second-most important constraint. In addition to agriculture and the farming of freshwater aquaculture species, freshwater is used in brackish-water shrimp culture to reach optimal salinity levels. Its use in aquaculture is frequently regarded as a loss for agriculture. In Myanmar, agriculture has been given priority for water-allocation rights.

A third constraint is the availability and cost of feed. Carnivorous species such as grouper or quasi-carnivorous species including shrimp require fish protein. Fishmeal has to be imported, often from as far away as South America, which can be costly. Substantial quantities of fresh fish are also often used to feed carnivorous species, which adds to the negative image of aquaculture. Ecologically, there are arguments that demand for fish to feed fish will put much pressure on the wild species, and the practice may not be sustainable. Socially, there are claims that the aquaculture industry transforms low-value protein sources that could be used to feed the poor into an expensive commodity for the wealthy. For this reason, Cambodia prohibited the culture of snakehead in 2004.

Low seed-quality standards could further limit the success of the industry in the region. Unavailability of quality seed encouraged the establishment of public fish stations to provide subsidized fingerlings to the poor, improve broodstock and supply fish for restocking public waters. In the Philippines, some public stations offer seeds that are below industry standards, which forces private hatcheries to lower their standards to remain competitive. The issue is not unique to the Philippines. In most countries, there is pressure for ensuring seed standards by compulsory certification of hatcheries.

Another constraint is the supply of adequate energy. Intensification often requires pumping and aeration and, hence, energy. Recirculation systems and wind-powered pumps are in use on a limited scale in freshwater aquaculture, but their capital cost is high. An inability to design a low-cost, high-volume pump for saltwater shrimp farming has also restricted their use. Solar-powered pumps suffer from the same problems.

The region also suffers from pollution and environmental degradation problems. The most severe form of pollution takes a direct toll on the species being raised owing to high levels of toxicants. The excessive use of inputs and poor husbandry practices led to severe production setbacks in Indonesia, Philippines and Thailand. Damage may also occur from urbanization and industrialization, both of which are increasing in Southeast Asia. A less severe form of pollution may not kill the harvest but may make it unfit for human consumption.

Limited expertise among officials as well as farmers is a serious hindrance to development in some countries. Policies and regulations may be enacted, but unless there are sufficient government personnel with adequate skills to monitor and enforce them, they will remain ineffective. Similarly, technology dissemination requires personnel who have the expertise to undertake research and extension. Cambodia and Myanmar, for example, lack sufficient capacity in these areas.

FUTURE DIRECTIONS

Despite the above caveats, aquaculture will in all likelihood remain important for the region in the near and medium-term future. On the supply side, the region already produces a significant proportion of the world's aquaculture output; this trend has strengthened in recent years. The region as a whole has adequate technical expertise and brackish-water and freshwater species whose culture is both technically feasible and economically viable.³⁶ Most countries have sufficient coastline for marine fish farming with considerable potential for cage culture of marine finfish; mariculture is the fastest growing aquaculture environment in the region.

Although expansion of certain species such as seabass and groupers remains constrained by seed availability and feed costs, other species (including milkfish) offer high returns – their upward production trend is likely to continue. With the exception of Cambodia and Myanmar, governments in the region have actively supported aquaculture by providing research and, in many cases, incentives³⁷ and have ambitious plans for aquaculture development. There is no indication that this policy will change. In most countries in the region, an enabling investment environment, through good governance, is in place and has resulted in production increases.

On the demand side, markets for farmed species are well established, and the region's population is projected to grow by 16 percent by 2015. Per capita incomes and urbanization, two of the robust determinants of fish demand, are increasing rapidly in most of the region's countries. Therefore, domestic demand for fish is likely to continue growing. Because production from the capture fisheries has reached its maximum sustainable yields in most countries, aquaculture supply is likely to expand in order to meet this growing demand. Furthermore, the region as a whole has a comparative advantage in a number of species, including shrimp, which augurs well for continued expansion of these species, particularly for export markets.

In addition to freshwater fish and shrimp, other species such as grouper also enjoy strong demand. While there are concerns about the use of trash fish to feed these



species, the culture of such high-value species offers a means of raising the living standards of the poor. The profit margins on grouper are much higher than those on milkfish.

Human dimensions of the ecosystem approach to fisheries³⁸

INTRODUCTION

Management of fisheries has always taken place in the context of societal goals and aspirations. In the first half of the twentieth century, those goals were dominated by a desire to increase landings. However, in the second half of the century, it became apparent that many fish stocks were being overexploited and that the relationship between fisheries and the ecosystems in which they were found could not be ignored. From this growing awareness came the ecosystem approach to fisheries (EAF). The EAF is an integrated approach to fisheries management, striving to balance diverse societal objectives (Box 15), with its basis in the CCRF.

Although the EAF has reached a point of general acceptance, difficulties are being encountered in its application in many areas. Some fisheries managers have seen the EAF as requiring extensive additional research and as adding costly complications that could not be funded with available budgets. The FAO Technical Guidelines for Responsible Fisheries No. 4.2³⁹ provided insights into the principles and concepts underlying the EAF, but further guidance was requested regarding the human dimensions of EAF and their manifestations in the form of policies, legal frameworks, social structures, cultural values, economic principles and institutional processes.

The FAO Fisheries Technical Paper No. 489 aims to facilitate the introduction of the EAF in the day-to-day work of fishery administrations by providing this additional information. It consolidates a range of available concepts, tools and experiences relevant to EAF implementation from social, economic and institutional viewpoints, and examines how these aspects are an integral part of EAF application.

The paper covers key issues facilitating the implementing of the EAF: (i) defining the boundaries, scale, scope and context of the EAF at hand; (ii) the various benefits and costs involved in the EAF, from social, economic, ecological and management perspectives, and the decision-making tools that can assist EAF implementation; (iii) internal incentives and institutional arrangements that can be created or used for promoting, facilitating and funding the adoption of EAF management; and (iv) external (non-fisheries) approaches for financing EAF implementation. A companion document to the FAO Technical Guidelines for Responsible Fisheries No. 4.2.2⁴⁰ on the same theme, it includes a wide range of tools and examples from around the world that may serve as starting points for solving practical problems linked to the introduction of the EAF.

THE HUMAN CONTEXT FOR AN EAF

In any given fishery in which implementation of EAF management is being planned, it is important to understand the current state of the fishery and its natural and human environment – the context in which the EAF is being developed.

For example, knowing the context will help clarify if the particular EAF will be incremental or a complete overhaul of an existing management approach, intersectoral or intrasectoral, local or international, involving intensive scientific research or relying on the best available information, etc. Establishing this EAF context will involve not only understanding the fishery and ecosystem from both the natural science and human perspectives, but also society's goals and values with respect to ecosystem goods and services, the social and economic context (at the micro and macro levels) in which the fishery operates, the policy and institutional frameworks in place, as well as the political realities and power dynamics affecting the governance of resources. A good understanding of these issues and other realities surrounding the use of

Box 15

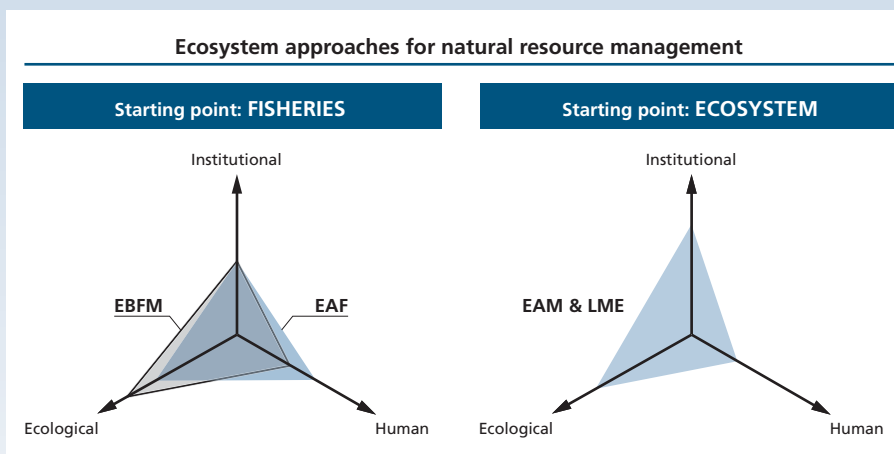
Ecosystem approaches for natural resource management – similarities and differences in starting points and focuses

Differences are found among the many ecosystem approaches to natural resource management being implemented by different organizations around the world today. It is difficult to quantify these nuances or to provide a scale on which the approaches could be placed. One notable distinction that could be made refers to whether the process starts from a fisheries perspective or from a more holistic ecosystem overview. The ecosystem approach to fisheries (EAF) and ecosystem-based fisheries management (EBFM) have their focus in fisheries management while, for example, the ecosystem approach to management (EAM) and large marine ecosystem (LME) approaches tend to start from a defined ecosystem in which fisheries is one sector among several others.

Another distinction that could be made concerns the discipline-centred perspective of the different approaches:

- institutional – governance aspects including cross-sectoral coordination and collaboration;
- human – socio-economic well-being and attainment of economic societal objectives;
- ecological – health of biological ecosystem components and environmental sustainability.

In line with their ecosystem-based starting point and holistic outlook, EAM and LME generally have a stronger explicit focus on ecological and – particularly with regard to LME – institutional aspects than the fisheries-based approaches EAF and EBFM. Comparing EAF and EBFM, the latter could be regarded as relatively more inclined towards ecology than the former, which seeks to balance human and societal economic needs with ecological functions. The figures below attempt to illustrate these nuances in focus and perspective.



Sources: G. Bianchi. 2008. The concept of the ecosystem approach to fisheries in FAO. In G. Bianchi and H.R. Skjoldal, eds. *The ecosystem approach to fisheries*, pp 20–38. Rome, FAO. 363 pp.
P. Christie, D.L. Fluharty, A.T. White, L. Eisma-Osorio and W. Jatulan. 2007. Assessing the feasibility of ecosystem-based fisheries management in tropical contexts. *Marine Policy* 31(3): 239–250.



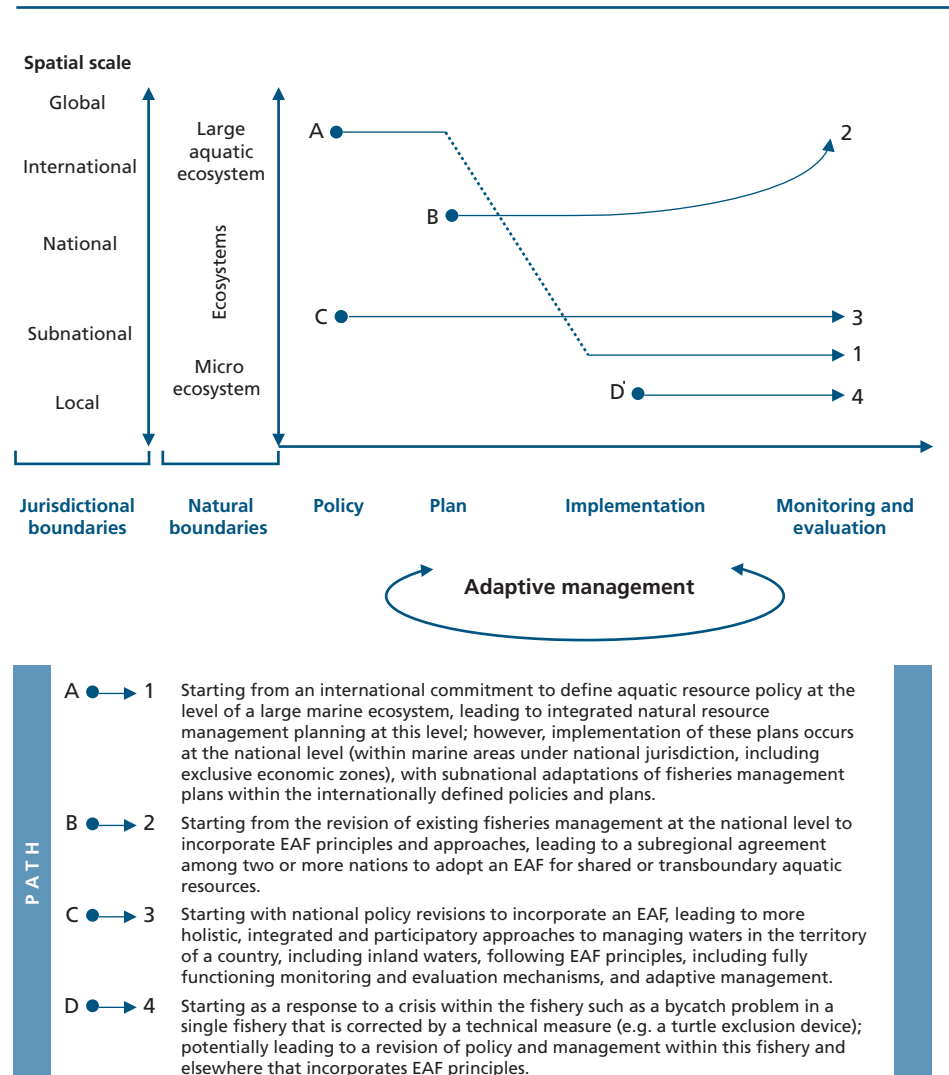
aquatic resources is essential to guide EAF policies, objectives and plans – in their absence, policies and plans may very likely fail to assist in the move towards sustainable fisheries.

The human aspects that play a role in determining the nature and effectiveness of an EAF include the power and governance structures in place, the economic “push” and “pull” mechanisms driving the fishing activities, the sociocultural values and norms associated with fishing, and the external contexts (e.g. global markets, natural phenomena, emergencies and political changes) that affect the ability to manage fisheries.

Social, economic and institutional aspects contribute as much to the set of complexities faced within fishery management as do those relating to fish species and the aquatic environment itself. For example, a fishery typically faces the complexities of: (i) multiple and conflicting objectives; (ii) multiple groups of fishers and fishing fleets, and conflicts among them; (iii) multiple post-harvest stages; (iv) complex social structures, and sociocultural influences on the fishery; (v) institutional structures,

Figure 38

Example entry points and paths for an ecosystem approach to fisheries (EAF)



Source: FAO. 2009. *Fisheries management. 2. The ecosystem approach to fisheries. 2.2 The human dimensions of the ecosystem approach to fisheries.* FAO Technical Guidelines for Responsible Fisheries No. 4, Suppl. 2, Add. 2. Rome. 88 pp.

and interactions between fishers and regulators; and (vi) interactions with the socio-economic environment and the larger economy.

DRIVING FORCES FOR AN EAF

The list of potential factors driving fisheries managers, a community or a society to adopt the EAF is as extensive and varied as the list of potential reactions to these drivers. The initiation of an EAF may take place at various stages of the EAF process, may target different scales and may evolve differently along the EAF path. Figure 38 presents four example starting points (A–D) and paths (1–4) of EAF initiation and implementation.

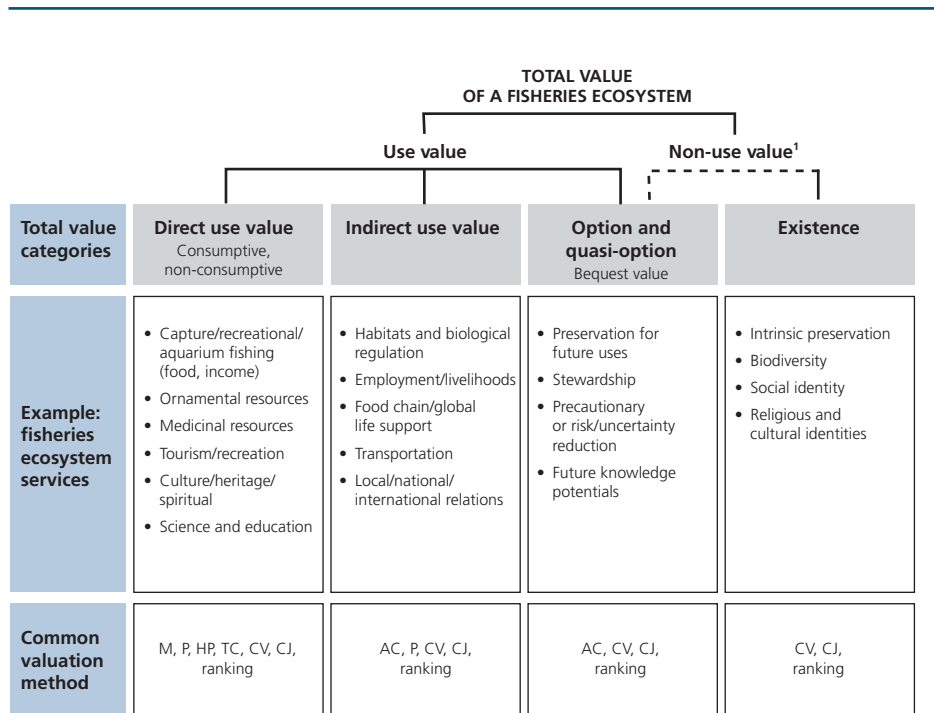
COSTS AND BENEFITS OF APPLYING AN EAF

The widespread support for the EAF reflects its potential to produce a range of ecological and social benefits (Table 16). It should cause an increase in sustainable employment and income generation, a reduction in the risk of fishery collapses, and various aesthetic benefits. At the same time, there are potential costs involved in implementing an EAF, ranging from direct costs of implementation (e.g. increased management costs) to possible indirect or induced costs, resulting from how the EAF is implemented (e.g. reduced employment or revenues in the short term). It is important to understand the range of such benefits and costs involved in EAF implementation – be they ecological, management administration, economic or social – together with their likelihood of occurrence, and their potential impacts.



Figure 39

Total value of a fisheries ecosystem



¹ The dotted line indicates the overlap between direct use values and future, potential use values, i.e. some people and societies value these services today because of their potential to be used in the future.

Notes: M = market methods; P = production approaches; HP = hedonic pricing; TC = travel cost; CV = contingent valuation; CJ = conjoint analysis; AC = avoidance cost.

Sources: Adapted from Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being. A Framework for Assessment. Chapter 6: Concepts of ecosystem value and valuation approaches.* Island Press, Washington, DC. S. Farber, R. Costanza, D.L. Childers, J. Erickson, K. Gross, M. Grove, C.S. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren and M. Wilson. 2006. Linking ecology and economics for ecosystem management. *BioScience*, 56(2): 121–133.

A crucial matter to consider in any management action, and particularly in the implementation of as profound a shift as the introduction of EAF management, is that of the distributional impacts of the changes. Managers need to consider: (i) To whom do the various benefits and costs accrue? (ii) When do the various benefits and costs occur? (iii) At what scale do the benefits and costs occur?

Table 16
Benefits and costs of implementing an ecosystem approach to fisheries (EAF)

Type	Benefits
Ecological	<ul style="list-style-type: none"> ■ Healthier ecosystems (directly or with EAF linkages to effective integrated coastal and ocean management [ICOM]) ■ Increased global production of goods and services from aquatic ecosystems (a global benefit) ■ Improved fish stock abundance (due to healthier ecosystems) ■ Reduced impact on threatened/ endangered species ■ Reduced bycatch of turtles, marine mammals, etc. ■ Less habitat damage (due to more attention to fishing impacts) ■ Lower risk of stock or ecosystem collapse ■ Reduced contribution of fisheries to climate change (if EAF leads to lower fuel usage) ■ Improved understanding of aquatic systems
Management	<ul style="list-style-type: none"> ■ Better integration in management across fisheries, other uses, etc. ■ Clearer expression of management objectives, leading to greater societal benefits ■ Better balancing of multiple objectives ■ Better balancing of multiple uses, leading to increased net benefits ■ More robust management owing to broadening from single-species tools ■ Improved compliance owing to more "buy-in" to management, through better participation
Economic	<ul style="list-style-type: none"> ■ Increase in benefits to fishers per fish caught (bigger fish from a healthier ecosystem) ■ Increased catches (especially in long term) ■ Increased contribution to the economy (especially long term) ■ Reduced fishing costs (if EAF results in reduced bycatch) ■ Increased net economic returns (if EAF involves reduced fishing effort, towards maximum economic yield) ■ Higher-value fishery (if increased availability of food to top predators increases stock sizes) ■ Greater livelihood opportunities for fishers (e.g. in tourism, if abundance of charismatic species increases through EAF) ■ Increased non-use (e.g. cultural) and existence values (the latter resulting from appreciation of healthier aquatic systems and a greater abundance of aquatic life, etc.)
Social	<ul style="list-style-type: none"> ■ Positive impacts on food supply in long term (if greater catches become possible) ■ Synergistic positive effect of coordinated EAF across fisheries and/or nations (large marine ecosystem) ■ Greater resilience (if there is emphasis on multiple sources of fishery livelihoods) ■ Greater resilience (if increased bycatch results in more livelihood opportunities) ■ Reduced conflict (if EAF processes deal effectively with interfishery issues)

Source: C. De Young, A. Charles and A. Hjort. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp.

In addition, managers need to be familiar with the values used to express benefits and costs and associated valuation methods. The various benefits and costs of EAF implementation reflect the range of human values of fisheries social-ecological systems from the local level to the global level. Therefore, it is important to recognize that the benefits could arise in various forms. Figure 39 provides examples of the use and non-use services of relevance to fisheries ecosystems as well as a few of the common

Table 16 (cont.)

Type	Costs	
Ecological	<ul style="list-style-type: none"> ■ Decreased fish stocks (if fishery management is now less effective than previously) ■ Increased habitat damage (if management is now less effective or creates induced impacts) ■ Shift in fishing effort to unprotected areas, leading to a loss of genetic biodiversity 	<ul style="list-style-type: none"> ■ Greater highgrading/dumping, and thus more wastage (if catch and/or bycatch is restricted) ■ Reduced fish catches (if more predators, e.g. seabirds, seals, because of better protection)
Management	<ul style="list-style-type: none"> ■ Increased cost of management ■ Increased cost of research ■ Increased cost of data collection and data management ■ Increased cost of coordination across fisheries and aquatic uses ■ Increased cost of additional and more participatory meetings ■ Increased cost of monitoring, observers, etc. 	<ul style="list-style-type: none"> ■ Increased risk of non-compliance (if regulations too complex or unacceptable) ■ Increased risk of collapse of management system (if too demanding of resources) ■ Risk of management failure (if excessive faith placed in "new" EAF paradigm) ■ Poor management results and loss of support (if EAF imposed or implemented improperly)
Economic	<ul style="list-style-type: none"> ■ Reduced catches (especially in short term) ■ Loss of income to negatively affected fishers ■ Increased income disparity among fishers (if EAF impacts are uneven) ■ Reduction in government revenues from licences, etc. (if there is reduced effort) 	<ul style="list-style-type: none"> ■ Reduction in benefits to fishers (if lower government support) ■ Reduced contribution to economy (short term) ■ Reduced employment in short term and possibly long term
Social	<ul style="list-style-type: none"> ■ Negative impacts on food supply in short term (and risk of this also in long term) ■ Greater inequity (if EAF favours those able to invest in appropriate technology) ■ Greater inequity (if there is misplaced allocation of responsibility for EAF costs) 	<ul style="list-style-type: none"> ■ Increased poverty among those adversely affected by EAF (short term, long term, or both) ■ Reduced benefits to fishers (if EAF linked to ICOM, and trade-offs detrimental to fishers) ■ Greater conflict (if EAF leads to enforced interaction among a larger set of societal and/or economic players)



methods used to evaluate these services. Such valuation methods would provide nominal or relative value estimates, which would then be incorporated into a broader evaluation or into decision-making mechanisms, such as cost–benefit analyses, indicator frameworks, national accounting systems, asset mapping, and bioeconomic models. These mechanisms would allow decision-makers and stakeholders to better understand the social, environmental and economic trade-offs related to any management alternatives.

INSTRUMENTS FOR EAF IMPLEMENTATION

Institutional arrangements

In moving from conventional fisheries management towards an EAF, some changes to current institutional and legal frameworks will probably be necessary.⁴¹ These changes include ways of taking account of, and dealing with, the increased scope of this management approach, conveying the need for:

- coordination, cooperation and communication within and among relevant institutions and resource user groups, in the fishery sector and outside, in the planning process and in implementation;
- information regarding the ecosystem and the factors affecting it;
- incorporation of uncertainties into the decision-making;
- ways of involving the broadened definition of stakeholders in decision-making and management.

Legal frameworks

The long-term prospects of applying an EAF will be enhanced by clear and facilitating legal arrangements, supporting the corresponding policy frameworks and institutional frameworks. A supporting legal framework can provide the legal backbone for implementing an EAF and its relevant principles and policies by:

- providing mechanisms for coordination and integration between the fisheries administration and other institutions in charge of ecosystem maintenance and use;
- defining roles and responsibilities clearly and transparently, including the management and regulatory powers of the responsible authorities;
- providing legal mechanisms for conflict management;
- providing mechanisms for stakeholder involvement in decision-making;
- establishing or confirming management and user rights;
- decentralizing decision-making and management responsibilities and establishing mechanisms for comanagement;
- providing for spatial and temporal control on fishing activities.

A legal framework should furthermore provide for the establishment of EAF management plans and clearly designate the institutions responsible for implementing and enforcing such plans. To that effect, the legislation should clarify:

- the decision-making entities at various jurisdictional levels;
- the geographical area that the EAF policy covers;
- the stakeholders bound by the policy;
- the institutions responsible for implementing and enforcing the management plan;
- how institutional and jurisdictional disputes will be resolved.

Capacity building

Developing organizational capacity may be a prerequisite for the introduction of an EAF, and it is likely to be a requirement throughout the process. In an EAF, stakeholders need to understand human–system relationships in relation to the resource system. In many cases, capacity may be built fairly easily and quickly if stakeholders engage in collaborative activities in which complementary skills transfer occurs. Learning by doing within partnerships is an approach well suited to strengthening EAF institutions and one that is usually cost-effective.

Adaptive management

A fundamental consideration that must be dealt with in fisheries management is the reality of uncertainty. Adaptive management takes the view that resource

management policies may be treated as careful “experiments” from which managers can learn and then adapt or change. To make the process effective, it is essential that the experiments and their results be appropriately documented. In this way, the use of adaptive management and learning processes will allow EAF systems to adjust and improve over time as new experiences and knowledge become available.

Information for an EAF

Ecosystem approaches are often perceived as being data-intensive, analytically complex, requiring large amounts of information and extremely costly. This may be true in some cases, but there are many options and entry points for initiating and establishing an EAF that are no more onerous than conventional fisheries management. For example, the “best available [scientific] information” in low-value fisheries could, in some cases, be confined to traditional knowledge and basic fishery assessment. Inadequacy of scientific data should not hinder the application of an EAF, but the implications of uncertainty need to be taken into account through the precautionary approach.

Because EAF information systems need to be manageable and sustainable, it is critical that the research and data collection be linked to what is essential for decision-making. Often, available information will come from various types of knowledge systems (e.g. scientific and traditional) and include both qualitative and quantitative information, which may cause problems of integration. However, tools for and examples of such integration exist.

Incentives as part of the EAF toolbox

There may be a need to create or introduce appropriate incentives, whether institutional, legal, economic or social, that individuals will factor into their decision-making, to induce support for EAF implementation.

Institutional incentives refer to motivations created by institutional arrangements that promote transparency, cooperation, trust and participation on behalf of stakeholders. Adequate institutional arrangements are key to successful management outcomes. Institutional failures – combined with inadequate legal frameworks – have been identified as main obstacles to effective conventional fisheries management.

Legal incentives include effective legislation that creates positive incentives as well as negative ones in the form of significant penalty structures with effective enforcement capability. Clear and enabling legal arrangements that support the corresponding policy and institutional frameworks are key to successful EAF implementation. The legal framework should provide support for: (i) coordination and integration, including roles and responsibilities of different parties; (ii) framework for management processes; (iii) legal status of rights systems; (iv) pro-poor legislation; (v) international norms and agreements; and (vi) conflict resolution.

Economic incentives, or financial incentives, arise from the need to address market failures and aim to establish a situation where economic actors and individuals choose to make more socially correct choices. These financial measures can be divided into two categories: market-based incentives (e.g. ecolabelling and tradable rights) and non-market-based incentives (e.g. taxes and subsidies). The distinction is made to reflect the idea that, in the former, a buyer and seller interact in the market to determine the price of a good or service, whereas, in the latter, it is the governmental authority defining and imposing changes to the profit function of the fishery.

Social incentives relate to the ways group behaviour and group interactions occur and form the context in which an individual makes decisions. Such incentives include: moral structures, religious beliefs, peer pressure, gender relations, policy, social preferences, norms, rules, ethics, traditional value systems, social recognition, trust among the various stakeholders, and common interests.

Perverse incentives are, from an EAF point of view, any policy or management measures that incite people or groups to act in a way that negatively affects an ecosystem’s ability to provide services or, in other words, that lead to inefficient use of ecosystem resources. Examples of perverse incentives include subsidies leading to overinvestment in fishing capacity in a fishery in which management is unable to



control fishing effort. The removal of perverse incentives is a necessary condition for a successful EAF.

CONCLUSIONS

A wide range of social, economic and institutional considerations are relevant to the implementation of an EAF because: (i) the EAF must take place in the context of societal or community objectives, which inherently reflect human aspirations and values; (ii) as the EAF takes into account interactions between fisheries and ecosystems, this includes a wide range of complexities relating to human behaviour, human decision-making, human use of resources, and so on; and (iii) implementing the EAF is a human pursuit, with implications in terms of the institutional arrangements that are needed, the social and economic forces at play, and the carrots and sticks that can induce actions compatible with societal objectives.

Such processes take place in a world of complexity, and the EAF can provide an effective vehicle to better recognize and address the wide range of complexities in fisheries, complexities that bear directly on the success of fisheries management.

Geographic information systems, remote sensing and mapping for the development and management of marine aquaculture

INTRODUCTION

This article presents a summary of the FAO Fisheries Technical Paper No. 458,⁴² whose objective is to bring to light applications of geographic information systems (GIS), remote sensing and mapping to improve the sustainability of marine aquaculture. The perspective is global, and developing countries are the focus. The underlying purpose is to stimulate the interest of individuals in government, industry and in the educational sectors of marine aquaculture to make more effective use of these tools.⁴³

Marine aquaculture is becoming increasingly important in the fisheries sector in terms of both production and value. Of 202 maritime countries and territories, 93 had a mariculture output in the period 2004–08. Of those, 15 countries accounted for 96 percent of the world output. Thus, there appear to be ample opportunities for the expansion of marine aquaculture among those countries not yet producing, or producing relatively little at present. Countries have jurisdiction over development and management of all kinds within their EEZs, and most countries possess vast EEZ areas associated with their homelands or territories. Thus, a lack of space does not at first glance appear to be an impediment to the expansion of marine aquaculture at present.

Marine aquaculture can be viewed as occupying three environments – coastal, off-the-coast and offshore in waters that are “sheltered” by land, “partially exposed” and “exposed” in the unsheltered waters of the open ocean. The development of nearshore aquaculture appears to be impeded by a number of issues relating to competing uses and the environment. Offshore aquaculture shares the same issues in kind, but to a lesser degree, and is currently impeded by a lack of open-ocean technologies and an enabling framework for development.

Geographic information systems, remote sensing and mapping have a role to play in the development and management of marine aquaculture because all of the issues have geographic and spatial components that can be addressed by spatial analyses. Satellite, airborne, ground and undersea sensors acquire much of the required data, especially data on temperature, current velocity, wave height, chlorophyll-a concentration and land and water use. A GIS is used to integrate, manipulate and analyse spatial and attribute data from all sources. It is also used to produce reports in map, database and text format to facilitate decision-making.

The first GIS was the Canada Geographic Information System and it marked the inception of worldwide efforts to formalize and automate geographic principles to solve spatial problems. After more than 40 years of development, GIS are now

a mainstay for addressing geographic problems in a wide variety of fields apart from natural resources.⁴⁴

METHODOLOGY

The approach used in the technical paper was to employ example applications that have been aimed at resolving many of the important issues in marine aquaculture. The focus was on the ways spatial tools have been employed for problem solving, not on the tools and technologies themselves. A brief introduction to spatial tools and their use in the marine fisheries sector preceded the example applications. The most recent applications were selected to be indicative of the state of the art, allowing readers to make their own assessments of the benefits and limitations of use of these tools in order to resolve their own issues. Other applications were selected in order to illustrate the evolution of the development of the tools. The applications were organized according to the main realms of marine aquaculture: culture of fishes in cages, culture of shellfishes and culture of marine plants. Because data availability is a prerequisite for a GIS and one of the prime issues in the use of spatial tools in marine aquaculture, a section was devoted to describing various kinds of data. Similarly, because the ultimate purpose of a GIS is to aid decision-making, a section on decision support tools was also included.

Given that spatial aspects of marine aquaculture have an economic underpinning, it is noteworthy that there is a dearth of GIS applications to the economic aspects of marine aquaculture development and management. This is despite the fact that some existing economic studies and models clearly lay out geographically related cost variables. It has been suggested that a GIS could be applied to several elements of these economic studies to improve choices of trade-offs mainly by spatially hindcasting environmental variables. The few applications of GIS in socio-economics are mainly global studies that encompass all of aquaculture.

Although there is much room for refinement as well as for the expansion of applications to address issues more fully and broadly, it is safe to say that GIS can be advantageously deployed to improve the sustainability of marine aquaculture, particularly for estimating potential for development, siting, zoning and identifying and quantifying competing, conflicting and complementary uses. Put another way, the use of GIS, remote sensing and mapping has reached the point of becoming an essential step in providing the enabling environment for the development of marine aquaculture. A noteworthy gap is that spatial analyses have been little applied to the culture of marine plants, by weight the most important output of marine aquaculture.

A case study was included in the technical paper to illustrate how freely downloadable data (i.e. EEZ boundaries, bathymetry, sea surface temperature, and chlorophyll-a) can be used to estimate marine aquaculture potential. The study was of open-ocean aquaculture potential in the eastern EEZs of the United States of America. It clearly illustrated that it is possible to create a simple GIS to make a first approximation of offshore aquaculture potential for any country wishing to do so.

The techniques used to conduct the spatial analysis were basic to GIS and included: (i) data collection; (ii) selection and assessment of data collected; (iii) data importing; (iv) data standardization (e.g. projection); (v) GIS spatial representations (e.g. interpolation); (vi) thresholding; (vii) overlaying; (viii) querying; and (ix) verification of results.

In order to ensure that the case study would provide a realistic example using an approach that would have wide applicability, it was decided to select species already being cultured in nearshore waters in many countries and for which there are well-established world markets. The cobia (*Rachycentron canadum*), a top predator in nature, is a warm-water fish that provides an example of "fed aquaculture" in that it requires formulated feeds in culture. In contrast, the blue mussel (*Mytilus edulis*), is a cold-water, filter-feeding shellfish and in this latter regard provides an example of "extractive aquaculture". The former is cultured in cages and the latter using several types of suspended devices including longlines.

Setting thresholds was one of the most important steps in the case study. Examples are temperature thresholds relating to the growth rates of all cultured organisms, and



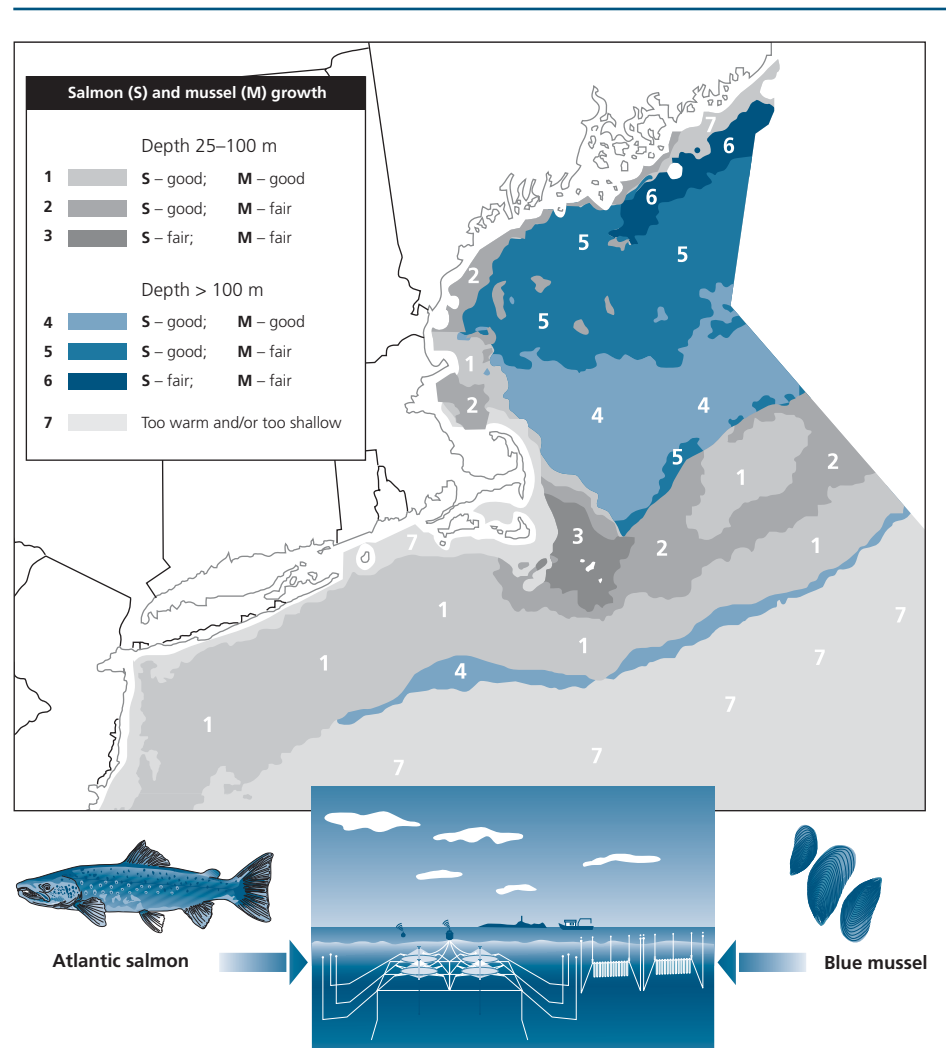
chlorophyll-a relating to the growth of filter feeders such as the blue mussel. Other thresholds relate to minimum and maximum depths suitable for cages and longlines. An important consideration is that it may take a long time to identify, compile and synthesize attribute data to set thresholds on production factors such as depth of cages – this is because of the need for extensive searches of the scientific literature and the Internet as well as for correspondence with experts. Additional variables can be added as they become available, and it may be necessary to modify threshold ranges as new information is obtained from culture practice.

RESULTS

Since publication of the technical paper, the case study analyses have been extended to include an additional species, the Atlantic salmon, *Salmo salar*. The Atlantic salmon was selected because of its global economic importance in cool-water aquaculture. Moreover, it was an attractive candidate because its culture methods are well

Figure 40

Differing potentials for integrated multitrophic aquaculture in the Western Atlantic Ocean¹



¹According to depths suitable for anchored (25–100 m) and free-floating (> 100 m) culture installations off the northeast coast of the United States of America (from Maine to New Jersey).

Sources: Cooperative Institute for New England Mariculture and Fisheries, National Oceanic and Atmospheric Administration, and University of New Hampshire.

established. Thus, the main technological challenge to its culture in the open ocean is one of durable, economic structures in which to contain it. With an average annual sea surface temperature of 20 °C or higher in 87 percent of the EEZ study area, there is relatively little area that is suitable for a cold-water species like the salmon. However, expansion of the study to include the Atlantic salmon offered an opportunity to examine the potential for integrated multitrophic aquaculture in combination with the blue mussel, another cool-water species. Chopin⁴⁵ and Soto⁴⁶ see trophic diversification in offshore aquaculture as an advantage from an environmental and economic perspective, with “service species” from lower trophic levels (mainly seaweeds and invertebrates) performing the ecosystem balancing functions while representing value-added crops. The spatial analysis of the salmon–mussel combination explores this opportunity in the open ocean.

In this analysis, suitability maps for salmon and mussel were first integrated and all combinations reported. Most of the eastern EEZ area of the United States of America is unsuitable for either mussel or salmon in each of the depth zones. However, there are nearly 49 000 km² where good growth of salmon and mussel would occur together in the 25–100 m zone and, correspondingly, 19 000 km² for the same growth conditions in the > 100 m zone.

Figure 40 shows areas with potential for good growth of Atlantic salmon and blue mussel that are within cage depth limits and adjacent to ports in the Atlantic Ocean. This is an environmentally aware, integrated approach in the sense that the mussels consume some of the waste from the salmon. It is economically efficient because, on the one hand, output now includes mussels and not only salmon, and, on the other, capital and operation costs are shared.

The underlying purpose of the case study was to test the approach for later use in a reconnaissance of open-ocean aquaculture potential worldwide using a country-by-country assessment.⁴⁷ The basis for such studies is sufficient spatial data with global coverage that are freely available for download from the Internet. Attribute data have to be identified, compiled and synthesized according to the culture systems and species.

As an example of a more specific kind of analysis, the potential for the culture of cobia in the open ocean is being examined. The limits of the study areas are the outer EEZ boundaries while the inner limits are the shorelines of the coastal countries.

The preliminary results for the cobia indicate a total area of 2.9 million km² that nominally would be within the limits of present cage technologies in terms of depth, 25–100 m, and that would result in good growth in terms of temperature, 26–32 °C. Forty-nine countries or territories possess more than 1 000 km² in this class and, of those, 28 countries possess more than 10 000 km² in this class, predominately developing countries. Correspondingly, the total area suitable for blue mussel that would be within present technology limits and provide the best growth in consideration of temperature and chlorophyll-a concentration is 1.1 million km². There are 38 countries that possess at least 1 000 km² and, of those, 22 countries that have more than 10 000 km². Although the surface areas that are suitable seem very large, there may be competing and conflicting uses for the same space. Furthermore, access in terms of time and distance from shore support facilities to culture sites also limits the area available for development. Both of these considerations will be addressed in future studies. However, these results are speculative because offshore aquaculture potential has been estimated in areas that have yet to be developed. Therefore, opportunities for validation based on locations of existing installations are very limited.

CHALLENGES

A legitimate question is: Despite the many varieties of applications presented herein, why is the use of GIS, remote sensing and mapping in aquaculture not more common and widespread as in other disciplines such as water resources? Part of the answer may be a lack of information about the capabilities of these tools among administrators and managers and a lack of experience among practitioners, especially in developing



countries. This technical paper represents one solution. GISFish (the FAO Internet gateway to GIS, remote sensing and mapping as applied to fisheries and aquaculture)⁴⁸ and an FAO overview on the potential of spatial planning tools to support the ecosystem approach to aquaculture⁴⁹ are complementary resources to this technical paper.

However, other possible constraints on the use of spatial tools need to be considered. One is that there is too little opportunity for formal education in GIS that should accompany undergraduate and graduate studies in all fields of natural resource research and management. Another is lack of access to computer equipment, software and the bandwidth in order to operate on the Internet effectively, especially with regard to communicating and acquiring data, and especially in developing countries. The impediments to more effective and widespread use of spatial tools in aquaculture need to be examined.

Possibilities for next steps in this direction include the formation of an international working group to address specific items such as:

- a review of the aquaculture sector's present and future needs for spatial analyses;
- a critical analysis of why GIS has not taken off;
- the role of GIS, remote sensing and mapping for the management and development of aquaculture and in strategic and operational decision-making.

From the viewpoint of organization and implementation of GIS, it is clear that marine fisheries and marine aquaculture share common needs for environmental and economic data, and many of the species are both cultured and captured. Furthermore, spatial analytical procedures are the same or similar in marine aquaculture and fisheries. Therefore, it would seem that there is much to be gained by cooperation between, or integration of, GIS activities in aquaculture and fisheries at national government levels and among academic institutions.

CONCLUSIONS

To date, the GIS applications in marine aquaculture have been very specific. That is to say, they have usually been aimed at resolving single issues. However, GIS, serving as the backbone of an aquaculture management information system, could help resolve pressing issues. The benefits would accrue in many ways, but perhaps the most important would be that diverse data and different perspectives on a problem would be integrated, a development that could lead to comprehensive solutions to the advantage of all stakeholders.

Global review of aquaculture development 2000–2010

Global aquaculture production (excluding plants) increased from 32.4 million tonnes in 2000 to 52.5 million tonnes in 2008, while the contribution of aquaculture to global food fish consumption rose from 33.8 percent to 45.7 percent in the same period. It is estimated that aquaculture will meet more than 50 percent of global food fish consumption by 2012.

The aquaculture sector has further expanded, intensified and diversified in the past decade. The expansion has mainly been due to research and development breakthroughs, compliance with consumer demands and improvements in aquaculture policy and governance, as identified in the 2000 Bangkok Declaration and Strategy.⁵⁰ Efforts to develop the sector's full potential and increase seafood supplies have been aggressively pursued in recent years, often under regulatory regimes that support industry expansion and growth. Much of the aquaculture sector has developed sustainably in keeping with principles of an ecosystem approach to management and in accordance with the CCRF. However, these trends have not occurred consistently throughout all regions.

The environmental performance of the aquaculture sector has continued to improve as a result of a combination of appropriate legislation and governance, technological

innovations, risk reductions and better management practices. There is also evidence in most regions of efforts to apply the ecosystem approach to aquaculture development. In many countries, sea-farming activities have expanded, as has promotion of multitrophic aquaculture, causing reduced environmental impact. Aquaculture networking has improved and communication has been amplified. Technology has strengthened, several new species have emerged (striped catfish, tuna, cod, etc.) and some have reached production volumes sufficient for stable markets to develop. The quantity and quality of seed and feed have increased globally as producers have responded both to consumers' concerns and to the availability of resources. Significant improvements in feed conversion have been recorded and the reliance on fishmeal has been reduced for several species. In general, aquaculture health management and biosecurity have improved, although sporadic outbreaks of transboundary diseases have occurred in most regions. The use of veterinary drugs and antimicrobials has come under increased scrutiny, and legal frameworks for controlling their use have been established in many countries. However, effective enforcement of such laws is still constrained by a shortage of financial and human resources.

In the past decade, the Asia-Pacific region has witnessed the highest overall growth and development of aquaculture. The small-scale farming sector in Asia has endeavoured to comply with consumer demands in importing countries. Application of a cluster management approach to farming and adoption of better management practices have been evident in many countries. This has meant improved food quality and safety for small-scale farmers' aquaculture products and improved access to markets. However, many countries still do not benefit fully from the opportunities offered by international trade as their aquaculture products have difficulty satisfying the import requirements of some of the leading markets.

The Asia-Pacific region has exhibited two interesting developments in the last decade. Within the space of a few years, an almost complete shift has occurred in marine shrimp production – away from the indigenous black tiger shrimp (*Penaeus monodon*) to the exotic white leg shrimp (*P. vannamei*). There has also been an explosive growth in striped catfish (*Pangasius hypophthalmus*) farming in Viet Nam (the Mekong Delta), where production reached a million tonnes in 2009.

In Europe, research and development achievements in aquaculture have been remarkable, in particular the improvements in the efficiency of production systems and the quality of the fish produced therein, while mitigating environmental impacts. Examples of new technologies include: the development of underwater surveillance to manage feeding and biomass; the upscaling of recirculation systems; the development of cages and nets that can be used in higher energy locations; and the development of integrated multitrophic production systems. However, in spite of undeniable technological progress, Europe remains a net importer of fish, possibly a consequence of increasingly stringent regulations for aquaculture and dwindling access to water resources and land suitable for aquaculture.

In Latin America, aquaculture has advanced well. Brazil, Mexico, Ecuador and Chile, the leading aquaculture producers, have spearheaded this development, producing growing quantities of salmon, trout, tilapia, shrimp and molluscs. Commercial and industrial-scale aquaculture still dominates in Latin America. However, there is significant potential for small-scale aquaculture development. Initiatives to develop such aquaculture are under way in the Amazon Basin, one of the largest aquatic environments in the world and with significant aquaculture potential. However, Latin American aquaculturists have also encountered difficulties. Recently, Chilean aquaculturists have experienced dramatic losses of revenue as almost 50 percent of their Atlantic salmon production has been infected by a virus (infectious salmon anaemia). The recovery from this catastrophe is slow and difficult, demanding more research and better governance. Export markets are becoming less accessible and, therefore, regional and local markets are being promoted, especially as an outlet for small producers.

In North America, aquaculture has evolved into two broad industry types: finfish production and shellfish production. Finfish production is dominated by salmon, catfish



and, to a lesser degree, trout, while aquaculture of shellfish primarily includes oysters, mussels and clams. The finfish industry is still at the forefront of the sector, with salmon taking the lead in Canada and channel catfish in the United States of America.

In Africa, aquaculture production increased by 56 percent in volume and more than 100 percent in value between 2003 and 2007. This growth was due to increasing prices for aquatic products along with the emergence and spread of small and medium enterprises, and to a significant investment in cage culture accompanied by the expansion of larger commercial ventures, some producing high-value commodities for overseas markets. Egypt has continued to dominate production in Africa. In the Near East and North Africa, some countries have invested heavily in capacity building and infrastructure development for aquaculture. Several countries in sub-Saharan Africa, including Angola, Ghana, Mozambique, Nigeria, Uganda and United Republic of Tanzania, have also experienced good growth in aquaculture. In other countries in sub-Saharan Africa, growth has been held back by persistent bottlenecks such as access to good-quality inputs and markets. However, African governments have demonstrated increasing support for aquaculture, presumably anticipating benefits to economic growth, food supply and security as well as in the form of poverty alleviation.

Almost 40 percent (live weight equivalent) of the total annual production of fish (capture fisheries and aquaculture) has entered international trade in the last decade. Farmed shrimp, salmon, trout, tilapia, catfish and bivalves have contributed significantly to this trade. This increase in trade in aquaculture produce has been accompanied by increased concern in the public and private sectors about: (i) environmental impacts of aquaculture; (ii) consumer protection and food safety requirements; (iii) animal health and animal welfare; (iv) social responsibility; and (v) traceability and consumer information along the aquaculture supply chain. Non-governmental organizations have initiated or strengthened these concerns and developed strategies to wield influence over consumers' purchasing decisions and especially over the procurement policies of major buyers and retailers of fish. These developments have resulted in the proliferation of aquaculture standards and certification schemes designed to trace the origin of fish, its quality and its safety, and the environmental and/or social conditions prevailing during aquaculture production, processing and distribution of fish and feed.

Although precise figures on some aspects of the impact of aquaculture are lacking, it seems clear that its contribution to poverty alleviation, food security, employment, trade and gender opportunities has increased in the past decade. In part, this growing contribution has been caused simply by the growth in volume and value of production and by the expanding worldwide presence of aquaculture products in retail trade and as raw material to the processing sector. However, aquaculture's contribution to society has also come about through features such as: ownership by beneficiaries; people-centred approaches; the use of species that feed low on the food chain; sharing benefits and employment among household members; use of methodologies originating in farmer field schools; and technologies that have been developed to fit the local context, and this using local networks.

Unlike many other sectors of the economy worldwide, aquaculture has generally been resilient in the face of the various economic crises of the last decade. However, an extended global crisis could damage the sector's growth, especially by limiting funds available for research and for support to vulnerable groups such as small-scale farmers. Experience during the past decade indicates that governments, especially in developing countries, will have difficulties in finding the necessary funds unless they have sound macroeconomic and public-sector management programmes in place. Governments, perhaps in collaboration with donors, will also need to engage in long-term planning in order to have safety nets in place for vulnerable groups, including those engaged in aquaculture activities, to allow them to adapt to the possible impacts of climate change.

The global aquaculture sector's long-term ability to achieve economic, social and environmental sustainability depends primarily on continued commitment by governments to provide and support a good governance framework for the sector. It is encouraging that the experience of the past decade indicates that many governments remain committed to good governance for the sector and that involving stakeholders, particularly producer associations, in strategic policy decisions is becoming an accepted practice. In the past decade, governments have strengthened their capability to monitor and manage environmental and social consequences of aquaculture, and they have made conscious efforts to address these in a transparent manner, backed by scientific evidence. One of the main difficulties has been not to overreact at the expense of aquaculture producers, particularly small-scale farmers, for example by framing legislation that would be costly, time-consuming and difficult to implement.

Although aquaculturists have scored many successes in the past decade, there is no room for complacency. Increasingly strict market and environmental standards continuously challenge the sector to achieve its full potential. However, as the new decade unfolds, it would appear that a stronger and more confident aquaculture sector stands ready to face and overcome these challenges and move further along the sustainability path.

Using the Internet for fisheries policy and management advice

INTRODUCTION

In the early 2000s, the EAF and the ecosystem approach to fisheries management (EAFM) received global recognition and endorsement. Broadening the objectives of, and constraints to, management, the approaches increased the amount of data and the related analytical capabilities needed by those providing policy and management advice in fisheries. Because of the need to broaden the types and sources of information and to compare knowledge on similar ecosystems in different regions, the practice of sharing information via the Internet has grown in importance. Nonetheless, the formidable potential offered by the Internet for enhancing the implementation of the EAF (including through capacity building) is still only partially and unevenly used, suggesting that more regional and global initiatives are needed.

A recent FAO study⁵¹ reviews the complexity of the EAF and the information needed for effective management and describes the types of data and information that can be found under publicly or privately maintained Internet sites. The following sections are taken from the study.

CURRENT SITUATION

Although it is probably impossible to obtain, through a desk-study, a complete picture of the use of the Internet in the formulation and use of fisheries policy and management, essential aspects of that picture will appear from a review of three key areas of information-related needs in relation to science-based decision-making: (i) access to basic or reference data; (ii) availability of tools for data processing; and (iii) diffusion of results beyond the strict decision and publication processes.

Expertise

Finding the expertise needed for assessment and management is a problem. The Web-based registry *OceanExpert*⁵² (of the Intergovernmental Oceanographic Commission [IOC] of the United Nations Educational, Scientific and Cultural Organization [UNESCO]) could potentially be a useful source of information, but the registration of fisheries expertise in this database is still very limited. A database of fisheries expertise would be very helpful.



Bibliographic records

Bibliographic information is available on many commercial sites. However, acquiring information may be very costly, especially for individuals and organizations in developing countries. *Aquatic Sciences and Fisheries Abstracts*, developed with FAO, has the advantage that it offers good economic conditions to users in developing countries. The *Aquatic Commons* repository covers marine, estuarine and freshwater environments as well as the science, technology, management and conservation of these environments and their resources with their economic, sociological and legal aspects. It has the significant advantage that it contains grey literature (e.g. policies, plans, stock assessment reports). The *OceanDocs* system from the IOC is also a free-access library of non-copyrighted material or material whose distribution has been authorized. These efforts are valuable and should be pursued.

Ocean bottom data

Bathymetric data is also available at various resolutions, for example on the *GEBCO* Web site. The *Virtual Ocean* platform allows the online generation of user-defined bathymetric, geological and hydrological maps online. Other bottom-related information of importance to fisheries, such as bottom types or habitats, does not seem to be available. Considering that pressures are highest in the coastal zone, these facilities need to be continued and others developed, improving the availability of high-resolution bathymetry and other information about these areas.

Hydrographical data

The International Oceanographic Data and Information Exchange (*IODE*) programme of the IOC is the centre of a very active global network for the exchange of oceanographic and atmospheric data. For example, the database of the International Comprehensive Ocean-Atmosphere Data Set (*International COADS*) contains 220 years of data, easily accessible and constantly updated. This system is an example and needs to be connected to biological information. This might come with the recent entry of the Ocean Biogeographic Information System (OBIS – see below) into the IODE. In the near future, more oceanographic data will be collected directly by marine animals, equipped for this purpose (see below).

Biological information

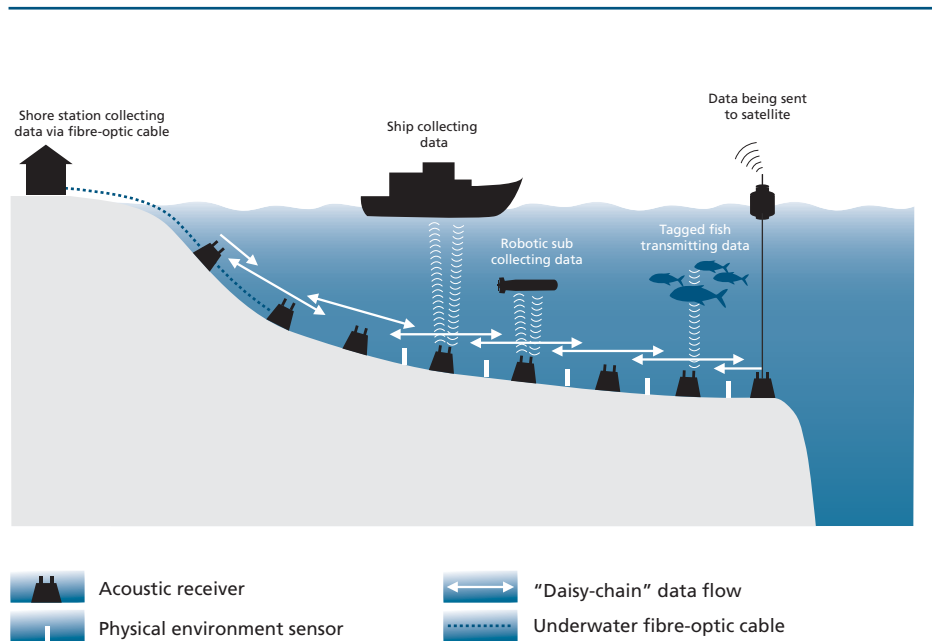
A large amount of information on the biological parameters of fisheries resources is also available through FAO's Fisheries Global Information System (*FIGIS*, *FAO Fisheries and Aquaculture Department*) as well as in other systems such as *FishBase* (with FAO collaboration) and *SeaLifeBase*: images, taxonomy, biology, ecology, distribution, diseases, diet, and life history parameters. Financial support is needed to ensure the survival and updating of these fundamental sources of biological reference data, particularly considering the growing potential impact of climate change on these parameters. At the moment, the life parameters are only accessible by individual species, and the system could usefully be modified to enable transversal access to all biological parameters in order to allow meta-analyses.

As fisheries management moves towards a more ecosystemic approach, biodiversity data become important. A project of the Census of Marine Life, *OBIS* already has more than 20 million records (compiled from almost 100 databases) and is connected to the World Register of Marine Species (*WoRMS*), *Global Biodiversity Information Facility*, *FishBase*, *Encyclopedia of Life (EOL)*, etc. and offers online mapping facilities. The taxonomic records of OBIS need to be enriched with more detailed information on species, probably through more connections with dedicated databases such as *FishBase* and *FIGIS*. With its network of regional nodes, OBIS is a good example of the types of Web infrastructures that would be useful to support an enlarged fishery community in the future.

Information on the distribution and migration of marine animals and on the environment they cross during those migrations is being collected and made available on maps by the *Ocean Tracking Network (OTN)* (Figure 41). Fish and marine mammals

Figure 41

Listening array of the Ocean Tracking Network



Source: R.K. O'Dor, M. Stokesbury and G.D. Jackson. 2007. Tracking marine species: taking the next steps. In J.M. Lyle, D.M. Furlani and C.D. Buxton, eds. *Cutting edge technologies in fish and fisheries science*, pp. 6–12. Workshop Proceedings, Hobart, Tasmania, August 2006. Australian Society for Fish Biology (available at www.asfb.org.au).

(from 20 g to 20 tonnes) and other marine animals are tagged with acoustic and archival electronic devices, which collect geolocated information on the oceanic environment, and in some cases, on other tagged fish they meet on the way. The tagged animals are passively or actively tracked as they travel, and the information collected is downloaded either to satellites (when the animal comes to the surface), fish aggregating devices (FADs), underwater vehicles, or large-scale telemetry arrays of radio-listening devices installed on the bottom of the continental shelf in many places around the world. The information allows the analysis of the oceanographic conditions under which migration takes place, as well as the mapping of fish movements. This sort of information (which can be made accessible to the public through *Google Ocean*) may soon become more easily available and therefore more usable to provide information for management, particularly on highly migratory species like tuna, salmon, sharks and marine mammals.

Fishery statistics

FAO statistics are available at the national, regional and global levels with different degrees of accessibility and practically no interoperability between systems. Global statistics since 1950 are available and are accessible through the statistics section of the *FAO Fisheries and Aquaculture Department*. The database can be queried online and the outputs can be graphed but not yet mapped. This limitation might be overcome in the future by the D4Science-II *Integrated Capture Information System* project. In general, however, access to fishery statistics at the national and subnational levels (including at fishery level) remains problematic except when RFMOs have established relevant databases. A facility to upload the national statistics into regional and global systems through the World Wide Web, in a semi-automatic manner, would be a major improvement and an effective incentive to data providers.



Financed by the European Union (EU) in Northwest Africa, the Improve Scientific and Technical Advices for Fisheries Management project (with its regional Web platform, *ISTAM*) organizes regional fisheries monitoring. It improves national statistical systems, develops common standards and sharing protocols, validates datasets and provides assessment methods and training with a view to improving stock assessment and management practices (particularly of shared stocks) as well as general diffusion of scientific assessments on the Internet. Such systems are probably part of the solution to improve national systems and global accessibility to statistics as well as capacity building.

The *Fishery Resources Monitoring System* (FIRMS) launched by FAO has expanded that approach to the whole world. It aims at a global systematic inventory of the world stocks, fisheries and management systems developed by FIRMS partners with FAO support. FIRMS is powered by FIGIS, and the information contained in its database is published in the form of standardized fact sheets. This system provides the various data owners with tools to ensure controlled dissemination of high-quality and updated information. As for FishBase, the system could be usefully modified to allow transversal access to all parameters for meta-analyses of stocks or fisheries. It could also be completed by a system of reference data on the characteristics and performance of fishing vessels.

Data processing platforms

A number of fishery modellers and analysts use *The R Project for Statistical Computing* (also called GNU) for analysis and visualization of data, and it is a good example of the sort of open-source software development platform that is needed in fishery science. The fishery community has already reacted positively to the opportunity that the R platform represents:

- The FLR library (*FLR*) is the result of an open collaborative effort by researchers from a number of laboratories and universities in various countries (under the leadership of the International Council for the Exploration of the Sea) to develop a collection of tools in the R statistical language. It is a generic toolbox specifically suited for the construction of simulation models, such as bioeconomic or ecosystem models and other models usable, for example, for fisheries management strategies evaluations (MSEs).
- Similarly, the AD Model Builder (*ADMB*) is a high-level software suite. It is an environment for non-linear statistical modelling, enabling rapid model development, numerical stability, fast and efficient computation, and high-accuracy parameter estimates. The *ADMB* Project promotes wider application of the *ADMB* to practical fishery problems and assists *ADMB* users to become more proficient.

Much more effort in this direction is needed, particularly to enhance the capacity of the developing world to use these tools and, for example, to test the robustness of the simpler, less demanding models. There is also a need to develop tools better suited to data-poor and low-capacity conditions.

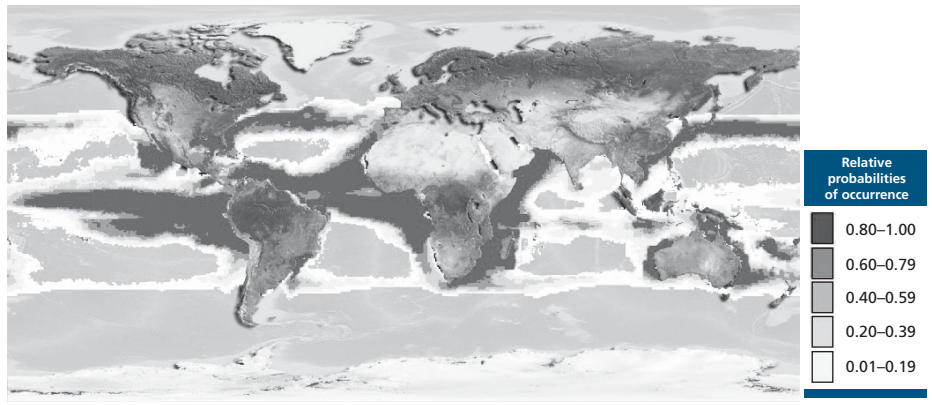
Interactive mapping

The capacity of online interactive mapping is rapidly improving. The United Nations Environment Programme–World Conservation Monitoring Centre (UNEP–WCMC) has developed interactive mapping services, and the Interactive Map Service (*IMapS*) is an authoritative source of environmental data that can freely be accessed, downloaded if needed, and mapped online to user requirements. It can be used for environmental impact assessment. A number of thematic or regional applications exist on the UNEP–WCMC Web site (e.g. on the Caspian Sea watershed). Jointly developed by FishBase and SeaLifeBase, *AquaMaps* is another example of the substantial progress made in online interactive mapping (Figure 42). The facility has been used to generate model-based probability distributions of species based on their ecological requirements and known distribution.

Regional data integration is a crucial level of collaboration for the development of any global system and should be a priority for systems development. Such platforms could very usefully improve the work of regional fishery bodies (RFBs).

Figure 42

An example of AquaMap output for distribution of the whale shark (*Rhincodon typus*)



Source: Based on a screenshot from AquaMaps (available at www.aquamaps.org).

Global communication

The pressure and incentives are growing to make the information on fisheries and their resources more widely available to the actors and the public. This is usually done through conventional institutional portals offered by institutions and projects focused on core business. The Web sites of FAO (*FAO*) and The WorldFish Center (*WorldFish*) are extremely rich examples. Some portals are rather specific. For example, that of the Global Ocean Ecosystem Dynamics project (*GLOBEC*) deals with the impact of climate change on recruitment, abundance, diversity and productivity of marine populations. *GLOBEFISH* (see below) is an international network of regional institutions established by or with the assistance of FAO and specialized in fish trade. The Web site of the FAO FishCode project (*FishCode*), aiming at supporting numerous aspects of the implementation of the CCRF in the bioecological as well as socio-economic arenas is more diversified. Such portals are now routinely offered, and numerous ones deal with marine resources and fisheries. However, they are usually static and one-way, with little or no interaction with the users yet.

The *UN Atlas of the Oceans* is a more dynamic and interactive portal developed by FAO on behalf of its sister UN Agencies competent in ocean matters and their partner institutions. It is an excellent example of collaborative effort in coordinated information diffusion. *OneFish* is another fisheries information portal maintained by FAO. Both *OneFish* and the *UN Atlas of the Oceans* offer users the possibility to establish virtual offices, i.e. specific sub-Web sites that can be used as platforms to organize collaboration, working groups, etc. Once established, such interactive Web sites (whose contents are controlled and published directly by the content producers in a decentralized manner) can be maintained at low cost.

Google Ocean (see above) is a unique publication platform in which large quantities of data can be made freely available to a large potential audience in the form of images, videos, sound files, connection to specific sites, etc. The OBIS, OTN and other Census of Marine Life projects already use *Google Ocean* for information diffusion. Another important knowledge-federating output is the emerging *EOL* (see above). These global platforms should probably always be used in the future to make selected information available to the public.

The contribution of industry

Missing from the above panorama of Web usage by the world fishery community is the industry "voice", taken here in the broad sense of the private sector, in large-



scale and small-scale fisheries. The role of the sector in modern, inclusive, participative governance is essential. However, the Internet is still not the channel most used by industry to communicate its concerns or policy or management proposals. Confidentiality of data is the default rule in this arena. A variety of Web sites are found when using the search term "fishing industry websites": (i) numerous sport fishing sites; (ii) single company or consortium sites advertising fishing technology or fishery products; (iii) private companies offering a range of services (e.g. consultancies, training, general information);⁵³ and (iv) sites from industry NGOs (fishers associations) delivering information of relevance to their constituency. The latter tend to be the ones dealing more frequently with management issues.

Of the many Web sites available, *GLOBEFISH* and *FISHINFOnetwork* warrant special mention. *GLOBEFISH* is an international collaborative effort of the fishing industry, fostered by FAO to collect, store, organize, share and distribute fish trade information. It coordinates and is an integral part of the *FISHINFOnetwork*, consisting of seven independent intergovernmental and governmental organizations.⁵⁴ Created to assist the fishery sector, particularly in developing countries and countries in transition, the network provides services to private industry and to governments. *FISHINFOnetwork* executes multilateral and bilateral projects, produces and distributes a number of publications, and organizes conferences, workshops and training seminars. It has more than 70 full-time staff members and works with more than 100 additional international consultants in all fields of fisheries. Fifty national governments have signed international agreements with the different *FISHINFOnetwork* services and are using the expertise of these services to develop the fishery sector worldwide.

The New Zealand seafood industry Web site (*New Zealand Seafood Industry Gateway*) provides a wide range of information to its members. A section on this site deals specifically with global aspects of sustainability issues put in a local perspective. This seems to stimulate debate on local "burning" issues. The Web site of the New Zealand Seafood Industry Council (*Seafood Industry Council*) has a science group and a policy group and offers contributions to the policy debate. The Web site of the Queensland Seafood Industry Association (*Queensland Seafood*) has debates on partnerships with management institutions on the issue of climate change, showing that the industry is concerned about long-term environmental issues and open to debate on them.

A few sites may indicate a movement towards more interaction among the actors of the sector. For example, the Northwest Atlantic Marine Alliance (*NAMA*), created in 1995 in New England (United States of America) is an independent, non-profit organization dedicated to pursuing community-based management to restore and enhance more resilient, diverse and abundant resources and uses. Advocating self-organization and self-governance, the institution also tries to provide an interface between scientists and fishers. That cooperation is also one of the key aims of *FishResearch.org*.

Numerous governmental sites exist whose purpose seems to be to inform and/or educate fishers and the industry about the issues, the decisions and their implications, reaching out from the state to the industry. For example, the Web site of the New South Wales Department of Primary Industries (*Fishing and Aquaculture*) offers considerable information on protected species, threatened habitats, fishery science and management issues. However, the level of interaction possible with the site is minimal. Government sites are not discussion platforms, as this form of interaction takes place through other more conventional channels involving the government, scientists and fishers associations.

There are also a few hybrid sites, such as *Seafish*, independent but supported by the Government of the United Kingdom. It provides information on a responsible fishing scheme and is financed by a levy paid by industry. It intends to prepare the constituency for a fishery world in which ecolabelling and accreditation will be the rule. The critiques seem to indicate that the interaction between fishers and the fishery management authority is still unsatisfactory.

The EU's seven newly established Regional Advisory Councils (RACs)⁵⁵ provide a strong and structured interface between the industry and the European Commission and European Parliament. Their present role is only advisory, but an evolution towards more involvement in decision-making is to be expected.

An Internet search on small-scale fisheries reveals that many Web sites deal with small-scale fisheries in one way or another. These sites may be connected to other sites belonging to developed countries' aid programmes, international organizations, environmental NGOs, etc. However, the number of sites exclusively dedicated to small-scale fisheries seems to be limited. The International Collective in Support of Fishworkers (ICSF) is an important exception. This aims of this NGO are to: (i) monitor issues that relate to the life, livelihood and living conditions of fishworkers around the world; (ii) disseminate information on these issues, particularly among fisherfolk; (iii) prepare guidelines for policy-makers that stress fisheries development and management of a just, participatory and sustainable nature; and (iv) help create the space and momentum for the development of alternatives in the small-scale fisheries sector. The ICSF is very active in the international fisheries management processes and publishes in multiple national and local languages. Established by commercial fishers in New Delhi, in 1997, the *World Forum of Fish Harvesters and Fishworkers*, also focuses on small-scale and medium-scale fishing, coastal sustainable fishing, coastal fishery livelihoods and relations with the WTO. Its degree of activity is hard to evaluate. The Web site of the Confederación Nacional de Pescadores Artesanales de Chile (CONAPACH), is an example of a national Web site dedicated to small-scale fisheries. Established in 1990 by all the small-scale fisheries unions of Chile, CONAPACH aims to represent the interests of the small-scale fishers regarding their rights and their living conditions. It also provides services such as training materials and information. *Collectif Pêche et Développement* is an NGO under French law that also seeks to connect artisanal fishers of the world to promote solidarity and sustainability in the fishery sector.

A few other sites offer services. *The Courier* is an online magazine established by EuropeAid of the European Commission, acting on behalf of the African, Caribbean and Pacific (ACP) countries. It offers information and communication on management and development issues in small-scale fisheries in the ACP countries. The *Safety for Fishermen* Web site is a gateway to information and material related to safety at sea, hosted by FAO and managed by a selected group of experts contributing information and material on safety at sea in the fisheries sector with a focus on small-scale fisheries.

CONCLUSIONS

The World Wide Web is developing at an accelerating rate, offering potential for progressively more powerful and effective global collaborations. Scientists are embracing the opportunity. Fishers are joining in only slowly, but with time more and more are likely to use the Internet, at least in communities that have the infrastructure and capacity and where the practice is common in other areas of economic and social life.

The above sections indicate that a substantial amount of information and some tools of high relevance to the implementation of the EAF are already available on the World Wide Web. However, these elements are still little used by fishery analysts, and some very interesting examples of use are limited to a few experts in a very few countries. The reasons have not been studied but may include all or some of the following: (i) the sites are not known; (ii) the scale of information provided is not detailed enough; (iii) the coverage is too incomplete; (iv) Internet access is too limited; and (v) the competence needed to use these systems properly is not available. In any case, an effort is needed to upgrade the capacity to use the World Wide Web to facilitate the emergence of a global and interactive fishery science.

The brief and probably partial overview of the industry Web sites provided above offers no clue as to how active or effective the Web sites are or what their audience really is. Some are very active (e.g. that of the ICSF), others seem to be



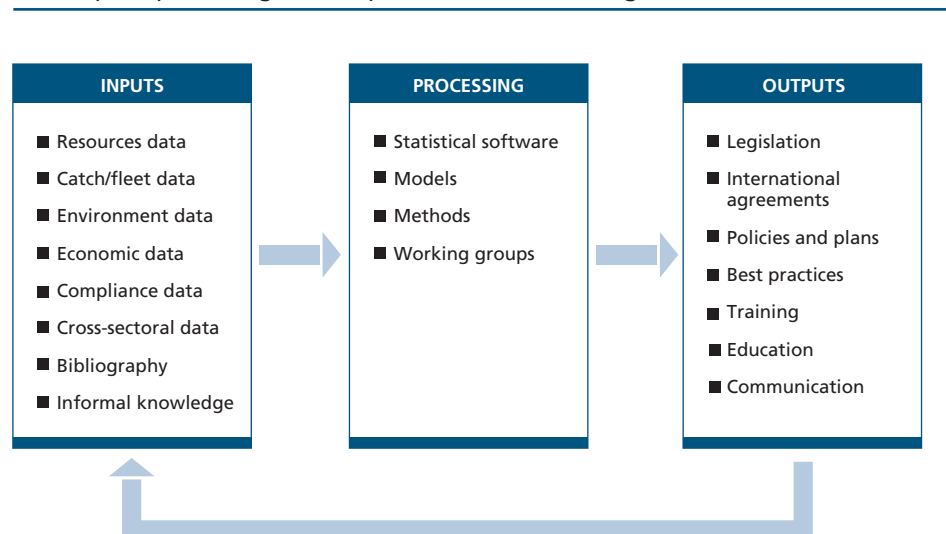
more confidential. Most are a one-way channel of communication trying to reach out to fishers who have access to and use the World Wide Web, governments and other NGOs. The degree of interactivity between the Web sites and the fishers and the extent to which the sites represent the fishers' views are also not clear. The Web culture is only developing now⁵⁶ and extending progressively from advertisement and provision of corporate services to policy and management issues and the collaborative defence of fishers' livelihoods. In the process of integrating the World Wide Web into communication strategies, large-scale fishers seem better equipped than small-scale ones, and associations better positioned than individuals. The situation is evolving more rapidly in countries where Internet usage is common (e.g. Australia, Iceland, New Zealand) and the industry is eager to receive more information via the Internet and keen to be effectively involved in the decision process regarding resource allocation, taxation schemes, subsidies, protected areas, etc. However, it is likely that the voice of the small-scale fishers will only be sufficiently heard if efforts are made by governments and NGOs to catalyse their communication. Important efforts are already ongoing in this direction.

More focused and more interactive portals are needed to support regional or global communities of practice on fisheries assessment, policy and management. There is also a need to better interconnect or federate the scattered initiatives currently on the World Wide Web. In order to function effectively, the recurrent process of assessment and decision for adaptive management needs a wide range of formal and informal inputs regarding resources, fleets, fisherfolk, environment, economic performance, compliance, interaction with other sectors, etc. The process results in a range of outputs such as new legislation, policies, plans, best practices, training, education and communication material. Indeed, many of these outputs are cross-checked and recycled as knowledge inputs in the successive assessment and decision loops (Figure 43).

The wide range of information needed should ideally be further organized in interoperable databases and knowledge bases, ontologies,⁵⁷ glossaries, open bibliographic libraries (with as free access as possible) and information repositories. For data processing, scientists should have access to analytical tools such as statistical and modelling software and other assessment tool boxes, and to open-source platforms to develop these tools. Facilities are also necessary to organize the assessment-and-decision process, including e-meeting facilities, "wikis",⁵⁸ catalogues of contacts and

Figure 43

Data inputs, processing and outputs for fisheries management



expertise (for joint reporting), and e-training for on-the-job competence building. Much of this information can be organized in interactive and dynamic portals.

As stated above, many facilities exist but they tend to be scattered, non-comprehensive, not interoperational and weakly interactive. More use of dedicated social network services⁵⁹ would facilitate the emergence of more effective regional or global epistemic communities. Depending on the context, the expectations⁶⁰ of fishery communities range from very basic to very sophisticated. They include:

- improved access to authoritative, federated regional data systems;
- generalization of georeferencing of fishery data, starting with FAO statistics;
- access to three-dimensional displays, as depth is essential in oceans;
- tools visualizing uncertainty, particularly on maps and charts;
- more dynamic representations;
- more Google Ocean applications;
- platforms for collaborative development of multidisciplinary atlases;
- standardized publication platforms for a federated and federating publication process;
- case studies and catalogues of best practices;
- availability of e-training, particularly for assessment, modelling and management.

Future information systems in support of science-based policy-making should ideally have the following properties:

- multisource, harvesting data from multiple providers;
- multipurpose, allowing use by many different types of users;
- multidisciplinary, integrating various types of knowledge;
- multicultural and multilingual, accessible to users with different national and social backgrounds;
- multi-output and multimedia, producing statistics, maps, graphs, briefs and fact sheets as well as videos, sound bites, etc.;
- multiscale in space and time, scalable up and down depending on the decision level;
- interactive, i.e. piloted both by users and providers;
- interoperable, to federate efforts and data and facilitate the crossing of information from different sources using common standards;
- nested, e.g. connecting local, national, regional and global systems;
- evolutive, with the capacity to adapt to changing demands and changing technology;
- authoritative, providing verified information with traceable pedigree;
- affordable, with low maintenance cost;
- flexible, e.g. allowing on-line processing as well as downloading for offline work;
- providing capacity building, training, repositories of best practices, mentoring, etc.;
- action-oriented, i.e. built, maintained and connected to decision-making;
- end-user-oriented as opposed to technology-driven or supply-oriented;
- ethical, acknowledging the complex web of data providers and system developers and respecting confidentiality requirements.

The need to involve fishers more directly in the assessment and advisory process calls for better connection between the sites developed by scientists and by industry, and major efforts are needed in this direction. For example, the RACs might provide the opportunity and incentive to do so in Europe.

A development that possibly would encapsulate most needs is if information and communication technologies were used to foster the development of a global *community of practice* around fishery science and management, with perhaps many interconnected smaller (possibly regional) and more specialized communities around subsectors (e.g. artisanal fisheries) or themes (e.g. ecosystem simulation or ecosystem-based management). Within such efforts, the development of open source platforms is needed to accelerate the collaborative development and diffusion of interdisciplinary bioeconomic, behavioural and ecosystem models as well as participatory role games in which the industry must be called to participate. A global community of practice might also allow the development of the collaborative *cloud computing* capacity needed to run large, complete-fishery system models.



This review indicates that a significant increase in collaboration for fisheries management is possible with little additional cost through increased and more effective use of the World Wide Web. FAO, and other international organizations, could help in the effort to link the international fishery community's expectations and the potential offered by the Internet.⁶¹ This would help avoid a digital divide in fisheries science developing between nations.

List of Web sites mentioned in this article

ADMB www.admb-project.org/	Integrated Capture Information System www.d4science.eu/icis
AquaMaps www.aquamaps.org	International COADS icoads.noaa.gov/
Aquatic Commons aquacomm.fcla.edu/	IODE www.iode.org/
Aquatic Sciences and Fisheries Abstracts www.fao.org/fishery/asfa/en	ISTAM www.projet-istam.org/
Collectif Pêche et Développement pechedev.free.fr/	NAMA namanet.org/about/about-nama
CONAPACH www.conapach.cl/home/	New Zealand Seafood Industry Gateway www.seafood.co.nz/
EOL www.eol.org/	OBIS www.iobis.org/
FAO www.fao.org	Ocean Tracking Network oceantrackingnetwork.org/news/index.html
FAO Fisheries and Aquaculture Department Fact sheets: www.fao.org/fishery/factsheets/en Statistics: www.fao.org/fishery/statistics/en	OceanDocs www.oceandocs.org/
FishBase www.fishbase.org	OceanExpert www.oceanexpert.net/
FishCode www.fao.org/fishery/fishcode/en	OneFish www.onefish.org/global/index.jsp
Fishery Resources Monitoring System firms.fao.org/firms/en	Queensland Seafood www.qsia.com.au/future-proofing-industry.html
FISHINFOnetwork www.fishinfonet.com/	Safety for Fishermen www.safety-for-fishermen.org/en/
Fishing and Aquaculture www.dpi.nsw.gov.au/fisheries	Seafish www.seafish.org/indexns.asp
FishResearch.org www.fishresearch.org/default.asp	Seafood Industry Council www.seafoodindustry.co.nz/n392,67.html
FLR www.flr-project.org/	SeaLifeBase www.sealifebase.org/
GEBCO www.gebco.net/	The Courier www.acp-eucourier.info/Partners.14.0.html
Global Biodiversity Information Facility www.gbif.org/	The R Project for Statistical Computing www.r-project.org/
GLOBEC www.globec.org	UN Atlas of the Oceans www.oceansatlas.org/index.jsp
GLOBEFISH www.globefish.org/	Virtual Ocean www.virtualocean.org/
Google Ocean earth.google.com/ocean/	World Forum of Fish Harvesters and Fishworkers www.pcffa.org/wff.htm
ICSF www.icsf.net/icsf2006/jspFiles/icsfMain/	WorldFish www.worldfishcenter.org
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- 36 By volume, the principal species are shrimp, milkfish, Nile tilapia, common carp and rohu. By value, shrimp and milkfish top the list, followed by rohu, common carp and tilapia.
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- 41 The term “institutional framework” refers to both the set of rules governing fisheries resources use and the specific organizational arrangements involved in the formulation and implementation of fisheries resources laws, policies, strategies and programmes.
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- 48 The Web site for GISFish is www.fao.org/fi/gisfish.
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- 50 NACA and FAO. 2000. *Aquaculture Development Beyond 2000: the Bangkok Declaration and Strategy*. Conference on Aquaculture in the Third Millennium, 20–25 February 2000, Bangkok, Thailand. Bangkok, NACA, and Rome, FAO. 27 pp.
- 51 S.M. Garcia. (forthcoming). *Fisheries science and policy: connecting information and decision-making. Enhancing the use of the Internet for fisheries policy and management advice*. Paper presented at the Fishery Dependent Information Conference, 23–26 August 2010, NUI Galway, Ireland. Rome, FAO.
- 52 The Web sites indicated in italics are listed together at the end of this article.
- 53 For example, the Southern Fish Industry Training Association (www.sfita.co.uk/) offers courses in sea survival, firefighting, first aid, fishing practice, food hygiene, fish trade, fish processing, etc.
- 54 EUROFISH (Eastern and Central Europe), INFOFISH (Asia and Pacific region), INFOPECHE (Africa), INFOPESCA (South and Central America), INFOSA (Southern Africa), INFOSAMAK (Arab countries) and INFOYU (China).
- 55 The seven RACs are: Baltic Sea Regional Advisory Council (www.bsrac.org/mod_inc/?P=itemmodule&kind=front), Mediterranean Regional Advisory Council, North Sea Regional Advisory Council (www.nsrac.org/), North Western Waters Regional Advisory Council (www.nwwrac.org/), South Western Waters Regional Advisory Council (www.ccr-s.eu/EN/index.asp), Pelagic Regional Advisory Council (www.pelagic-rac.org/), and Long Distance Fleet Regional Advisory Council (www.ldrac.eu/content/view/12/29/lang,en/).



- 56 An example of the developing Web culture is the growing use of the Internet by fishing captains for formal transmission of data about their fishing activity.
- 57 An ontology is a system that contains terms and the definitions of those terms, and the specification of relationships among those terms. It can be thought of as an enhanced thesaurus – it provides all the basic relationships inherent in a thesaurus, plus it defines and enables the creation of more formal and more specific relationships. It is designed to serve as a central focal point for the vocabulary of a particular domain, and to codify and standardize the knowledge within that domain. It enables better communication within and across domains, and structures meaning contained in the domain. (Agricultural Ontology Service Workshop, Rome, November 2001).
- 58 A “wiki” is a Web site (or a function in a site) that facilitates joint creation and editing of interlinked Web pages, usually under some system of authorities. Wikis are often used in collaborative Web sites.
- 59 The social network services referred to here can be used to build a social network and enhance social relations among people who share fishery management interests and/or activities. They consist of a representation of each user (often a profile), his/her social links, and a variety of additional services. They provide means to interact over the Internet, such as e-mail and instant messaging as well as common information resources and tools, and facilities to organize electronic meetings and jointly write or edit documents. They may empower groups of experts, e.g. in modelling, reef assessment or marine protected areas.
- 60 Obtained from a selection of 19 very experienced fishery scientists with a strong background in modelling and information systems.
- 61 An example of such collaboration is the EU’s D4Science-II project, with which the FAO Fisheries and Aquaculture Department collaborates.