International Fisheries: How do we get there from here?

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The oceans are being emptied and, while there is no shortage of ideal solutions to the problem of overfishing (i.e. Collie et al. 2005 and Crowder et al. 2006), the reality is that fisheries management fails much more often than it succeeds (Worm et al. 2009). The recent nomination of nine large marine predators for endangered species status—including several species of shark and the exceptionally valuable bluefin tuna—highlights the severity of the situation (Stokstad 2010). The rejection or delay of all of these nominations highlights the nature of the problem: fisheries management is a matter of political strategy rather than either biological or economic science. Given the critical nature of the problem, we believe that it is time to examine the potential for success in the current system and explore possible steps to a better system; one that combines ideals and incentives.

1. Introduction

Over the last half-century, people have gotten really good at catching fish. Due to technological advances, fishers can now target stocks across the breadth and depth of the oceans. Similarly, through freezing and canning techniques, processors can provide a much wider range of products to fish-hungry consumers. As a result, the supply of fish has increased phenomenally. By the year 2000, world capture production of fish reached more than 86 million metric tons. That is five times the marine harvest in 1950 (see Figure 1.1; FAO 2010a).[1] Furthermore, the total value of fisheries exports and imports more than doubled in real terms from 1976 to 2000 (FAO 2010b) and by 2006 the total value of global capture production reached about $91.2 billion (FAO 2009, 7).[2] For comparison, this is less that meat and dairy production combined ($142.6 billion in 2006) but more than staples like wheat ($72.2 billion) and soy beans ($44.8 billion; FAO 2010c).

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[1] Aggregate all countries, species, Group Area by Marine Areas

[2] Aggregate all countries and commodities, determine real values using US CPI (2005=100) from (World Bank 2010).

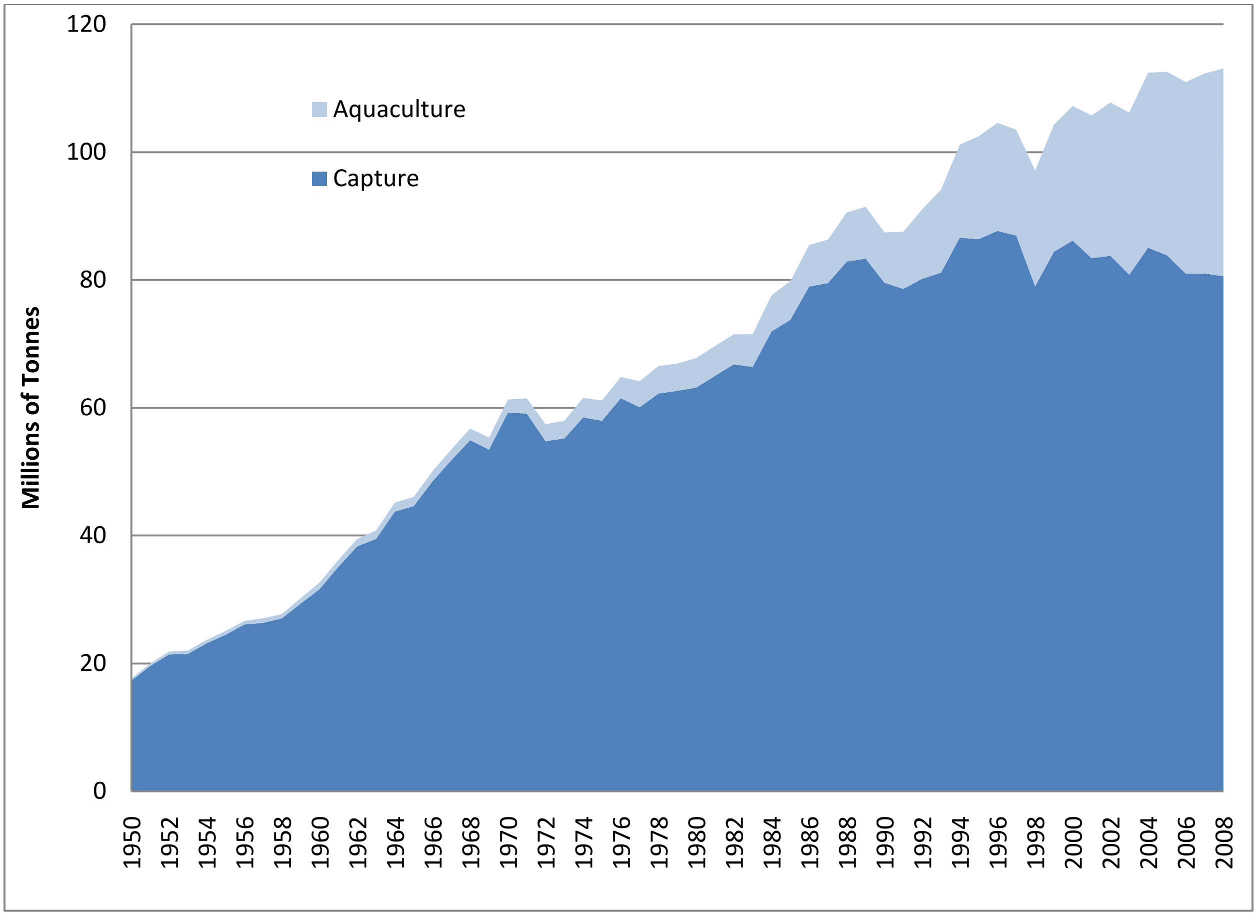

Figure 1. 1 Global fisheries production 1950-2008 (FAO Fishstat Plus Databases)

However, recent data suggest that we may have reached or even surpassed the limits of the oceans' productive capacity. As Figure 1.1 shows clearly, marine capture production roughly leveled out in the 1990s and the majority of increased production since then is only through aquaculture practices, which may not be sustainable (Burke and Naylor 2005). More direct evidence of the decline in fisheries resources can be found in a recent survey by Worm et al. (2009). They found that 6 of 10 major fisheries ecosystems and 63% of single-stock fisheries for which data were available have been overfished at some time since the 1990s. In addition, some of the most valuable fisheries in the world have collapsed in the last few decades (North Atlantic groudfish) or are on the brink of collapse (Antarctic toothfish and Atlantic bluefin tuna).

To grapple with these problems, we need science—sustainability science—that can tackle the complexity of marine fisheries in a transdisciplinary way. As Ostrom et al. (2007) point out, we need to be able to explore the interactions between physical, biological, economic, social, and political drivers of global fisheries in order to truly understand the range of potential human impacts on this system. As part of this drive, social scientists need to provide a more nuanced view of human decision making at all levels. This entails a synthesis of behavioral psychology/economics, and aggregate approaches ranging from organizational theory to international relations (part of what Ostrom et al. refer to as a nested, multitier framework).

While it would be valuable, full meta-analysis of international fisheries management using Ostrom et al.'s approach is beyond the scope of this paper. Instead, we begin the process by examining several core problems in international fisheries and answering a simplified version of the three questions posed by Ostrom et al. (p. 15182):

1. What patterns and outcomes are associated with the current resource system?
2. What endogenous sources of change exist within the system?
3. How robust or sustainable is the system?

In answering these questions, we start by describing the sources of stability and drivers of change in the current system. Section 2 covers core limits, drivers, and signals in a generic fisheries system, fisher responses to those signals (Section 2.1), and additional drivers (Section 2.2) and limits (2.3). We then go on to evaluate the sustainability of the current system in Section 3, including its resilience (3.1), adaptability (3.2), and tranformability (3.3). Finally, in Section 4 we propose that simulations—informed by stakeholders and experts but performed through computational techniques—can be used to better explain the human role in international fisheries, to explore the geo-bio-socio-political-economic interactions of such systems, and to search through a broad array of possible solutions for those that are both appealing to a majority of users and robust across multiple possible futures.

2. Sources of stability, drivers of change

Like many governance regimes, regional fisheries organizations frequently exhibit responsive rather than proactive behavior (Webster 2009). That is, they respond to problems, rather than preventing them. Sometimes these responses prove sufficient and lasting. At other times, RFMOs fail to respond in time, resulting in fishery collapse. In order to understand this responsive behavior, we need to make the connections between forces that drive the expansion of fishing effort and controlling feedback mechanisms that limit that effort.

For instance, Figure 2.1 shows the basic elements of a common pool resource (CPR) system. The main driver in this system is the combination of open access and rivalness, which leads to a "race for the fish" as fishers seek to capture as much of the resource as possible before it is taken by others. This competition leads to increasing quantity supplied (Q_S) and decreasing stock biomass (B). All else equal, price (P) should decline as quantity supply increases and costs (C) should increase as biomass is depleted. Thus there are both biological and economic limits on the exploitation of the fishery. Furthermore, these limits are expressed through the signal of declining net revenue (R; otherwise known as scarcity rent for the economists). In a closed system, this signal would tell fishers to stop increasing effort, effectively nullifying the CPR driver where total revenue is equal to total costs and no one can benefit from additional entry into the fishery.

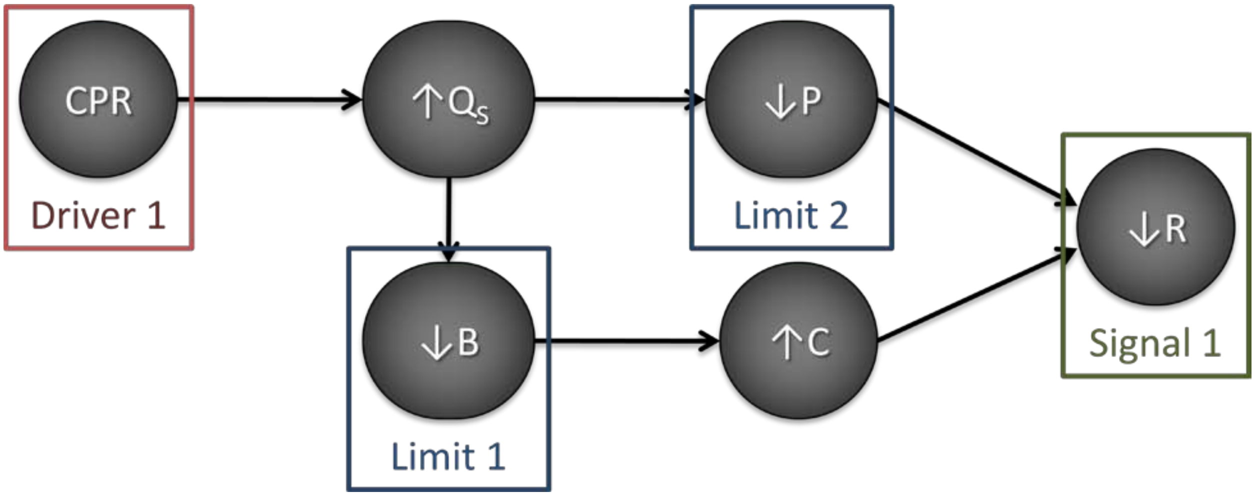

Figure 2. 1 Basic model of a common pool resource (CPR) system

Few fisheries are so remote that they could really be considered closed systems. Certainly, international fisheries, which include the high seas, are open systems in many ways and therefore require further elaboration. We will review additional drivers of and limits on international fisheries in three subsections. First, we describe fisher responses to Signal 1. It is important to remember that fishers can do much more than simply compete or die in response to declining net revenues. Sometime these responses act as limiting factors in the system but often fishers make economic or political choices that lead to the expansion of fishing effort.

2.1 Responses to rent dissipation

Figure 2.2 shows some of the most common documented fisher responses to Signal 1. These include: 1) exclusion of some fishers or limiting entry into the fishery (Exclude), 2) catch or effort limits (Limit), 3) exploration to find new fishing grounds or species to exploit (Explore), 4) investment in better technologies to reduce costs (Invest), and 5) lobbying to get government protections such as subsidies or trade barriers (Lobby). Although numbered for reference, the actual order or weight given to each response depends much on individual fishers, social institutions, and government characteristics.

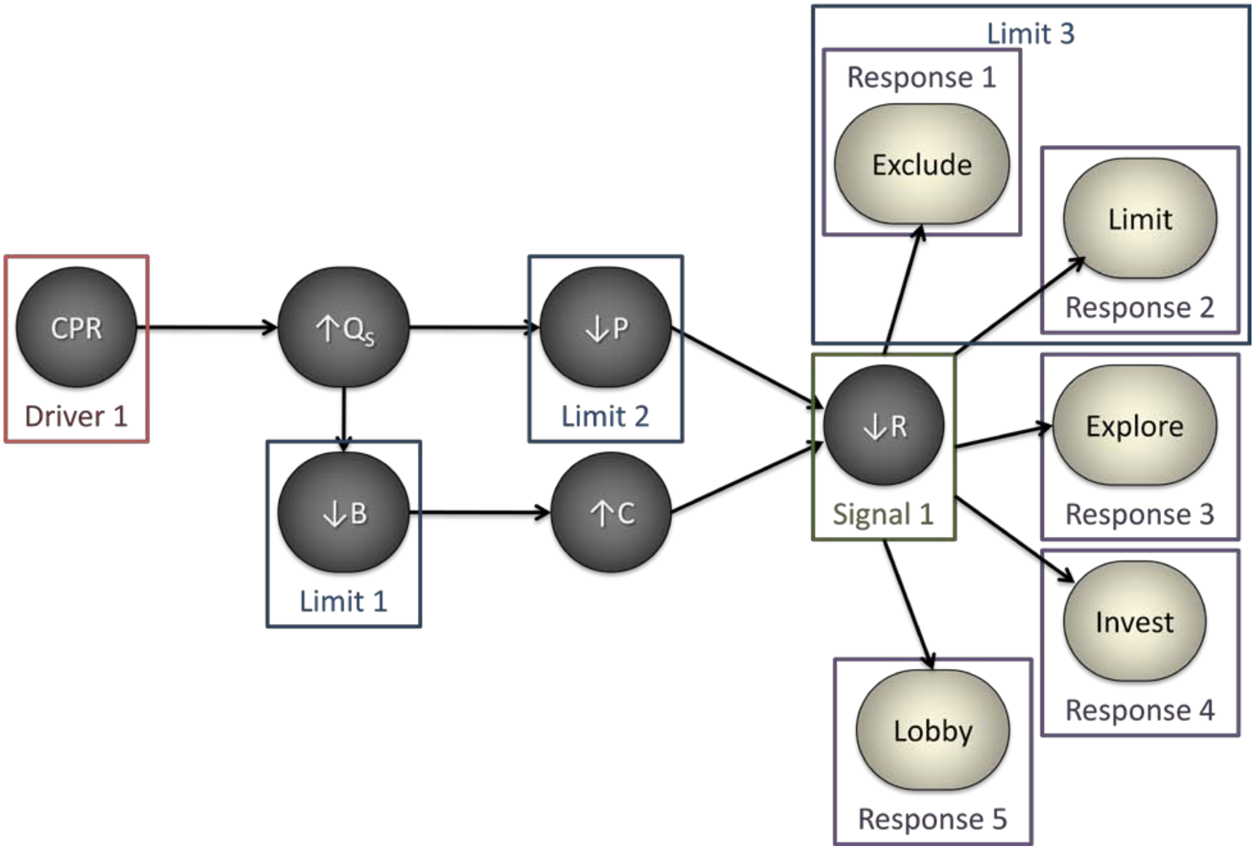

Figure 2. 2 Multiple responses to declining net revenues

As the figure shows, the first two possible responses are also limiting factors. That is, when fishers chose to reduce access (Exclude) and control harvests (Limit), this serves as an institutional rather than economic or biological limit on the system. Historically, governance of fisheries resources has been about rights of access, either establishing who may fish or settling disputes between fishers with contesting claims to a given stock. Most of the communal sharing arrangements that have been studied deal more with the distribution of benefits than actual limitation on effort. Indeed, many traditional arrangements define who gets to fish when and where, rather than how much they are allowed to take all together. Whether it is the guild-based system of ancient Samaria, the territorial systems that still survive in Northern Brazil and Southern Australia or the vaunted harbor gangs of Maine, almost every non-state system of fisheries management we know of today has had two main goals: exclude outsiders and distribute the resource among insiders.[3]

In modern times, however, Responses 3-5 are much more common among fishers themselves (as opposed to governments; the distinction will be explained in Section 2.3). In the past few centuries, fishers have spread from coastal areas and are now active throughout the oceans. Fishing intensity has increased as well, due to improvements vessel size, range, gear effectiveness, and guidance technology. These changes are most visible in harvests of highly migratory species like tunas and billfish. Figure 2.3 shows how catches of highly migratory species expanded from mainly coastal areas and the tropical

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[3] See Berkes (1992), Cordell and McKean (1992), Ostrom (1990), Acheson (1988), etc.

Atlantic in 1960 to global distribution throughout the major oceans by 2000. Increases in intensity are also shown in the figure; there are more areas with dense catch rates and the maximum value for the total catch per graticule is almost 4 times larger in 2000 than it was in 1960.

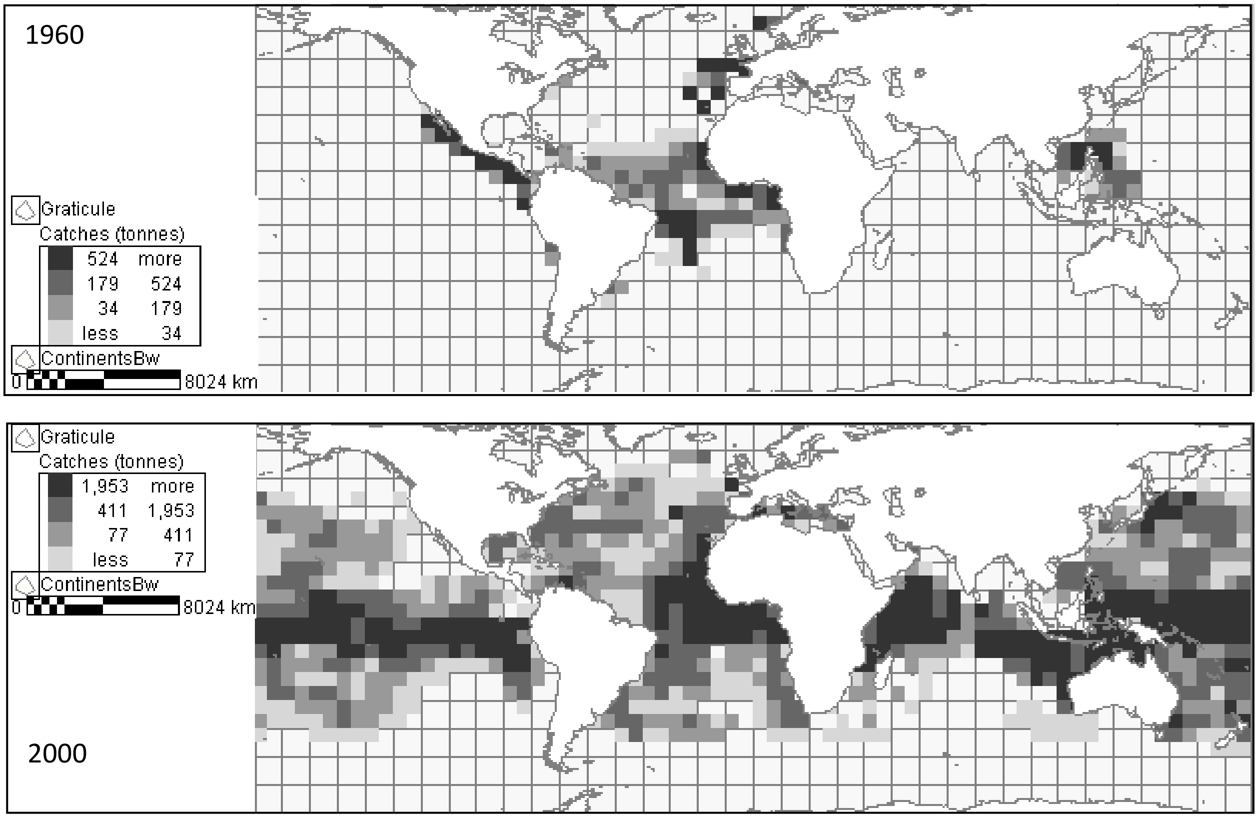

Figure 2. 3 Geographic dispersion and intensity of global tuna harvests (FAO 2010)

Fishers may also choose to lobby their governments for protection against declining net revenues (Lobby in Figure 2.2). Such interventions can be limiting but often facilitate the expansion of a fishery or the fishing industry generally. Fishers usually lobby to protect their way of life, which can mean provision of subsidies to substitute for net revenues dissipated under the CPR regime or exclusion of one type of fisher to benefit those who remain in the fishery. Although fishers are politically powerful in many countries, their lobbying efforts may have additional unintended effects. For example, because accusations of overfishing were used as fodder in a domestic controversy between traditional longline fishers and new trap fishers, the U.S. government created the first federal agency devoted to fisheries science and management (Webber 2002, 6; Juda 1996, 23). In fact, the politics of distribution has been a central motivator for government involvement in fisheries management around the world.

2.2 Additional drivers of fishery expansion

Figure 2.4 shows four additional drivers of fishery expansion: 1) subsidies (Subs), 2) better technology (↑Tech), 3) globalization (Globalize), and 4) growing demand (↑ D). When lobbying results in subsidies (Subs), it can create a feedback loop that actually drives additional entry into the fishery as individuals pursue political as well as resource rents. This is no trivial effect. In one of the most recent analyses, (

Dyck et al. 2010) estimate that global fisheries subsidies ranged between 25 to 29 billion USD in 2003.[4] The authors also broke down their data into three categories: beneficial (subsidies that enhance management), capacity building (subsidies that increase fishing capacity), and ambiguous (subsidies like buy-back programs that should reduce capacity but frequently do not). They estimated that about USD 16.2 billion was spent on capacity building subsidies in 2003. An additional USD 3 billion went to ambiguous subsidies, so as much as 70% of annual support for fisheries could be contributing to expansion of effort.

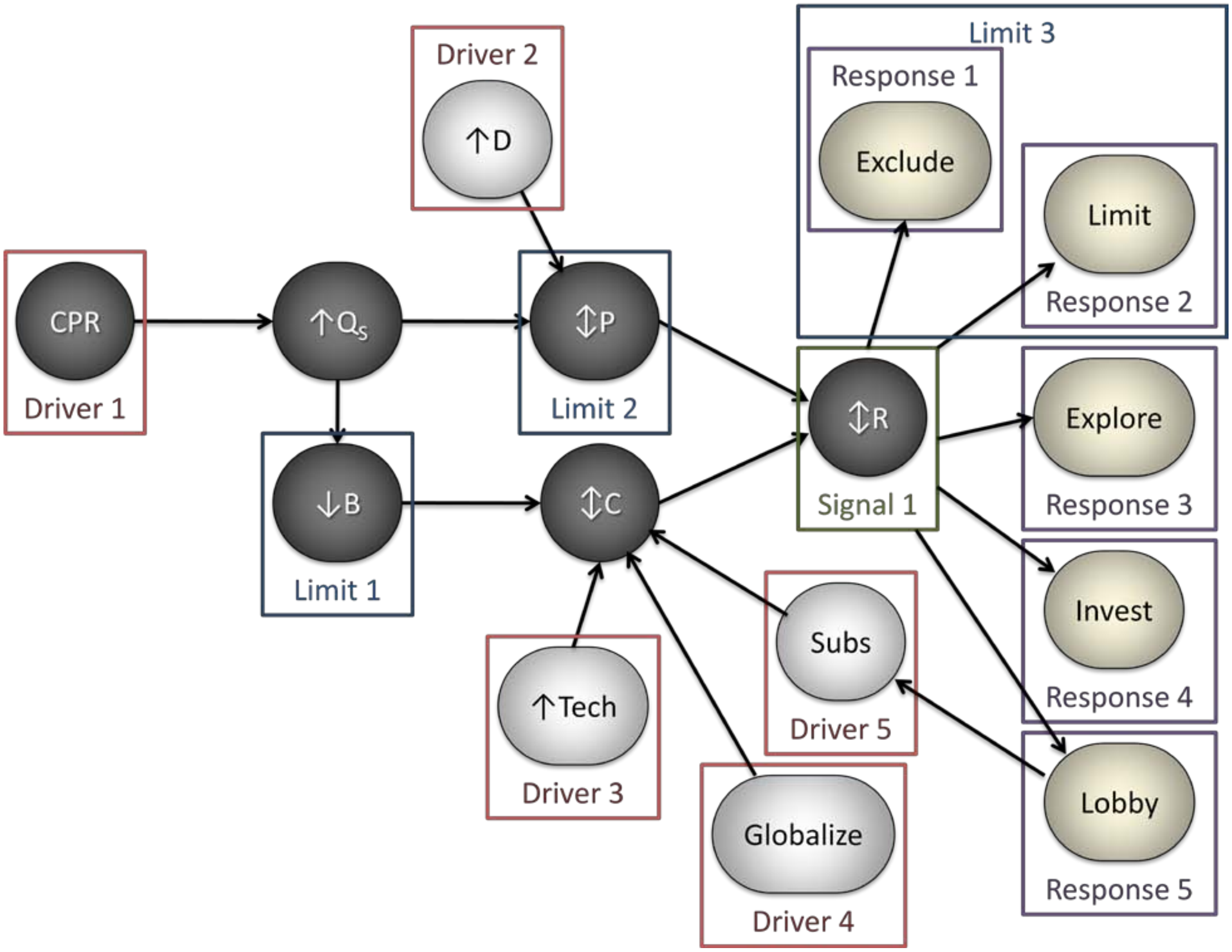

Figure 2. 4 Additional drivers of fishing effort

Like lobbying, which leads to subsidies, exploration and investment could be considered drivers as well as responses but it is more useful to separate fishers' pursuit of new stocks and better technologies from their ability to actually access those items. (Andersen et al. 2007, 192-209) point out that technological changes in fisheries can either be made through big investments that alter productivity

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[4] This is considerably higher than some estimates, like Greboval and Munro (1999; USD 8-10 billion) or Milazzo et al. (1998; USD 14-20 billion), but lower than others such as Sumaila and Pauly (2006; USD 30-34 billion) or FAO (1993; USD 54 billion). Generally, lower estimates exclude "beneficial" subsidies like the cost of management and higher estimates use less conservative extrapolation techniques for missing data or are based on a smaller dataset. To date there is no way to rigorously track changes in global fisheries subsidies over time.

substantially or through “technology creep”, in which many small advancements add up over time. Big investment items include switching to motorized vessels, mechanized gear, and computerized fish-finding technologies. All of these improvements involve adapting existing technologies to fishing activities. Technology creep is more difficult to describe, but may result from new gear configurations, better use of fish-finding technologies, and other small improvements in fishing effectiveness or vessel capacity. Again, we see fishers largely improving existing technologies, albeit those developed originally for fishing.[5] Therefore, even though fishers can be highly entrepreneurial, their ability to develop new technologies is limited by existing technologies and may even include path dependence or “lock in” to particular gear types or practices.

As Salvanes et al. (2010) show, access to capital is also an important determinant of fishers’ ability to increase their productivity, whether through exploitation of new stocks or appropriation of new technologies. They also point out that the availability of capital for investment in fisheries often depends on the health of the wider economy, not just the value generated in the fishery itself. In fact, world-wide investment in fishing effort is driven by global economic growth (Globalize) much more than internal fisheries resources. Globalization has also driven the geographic expansion of fleets as fishers from developed countries seek cheaper operating costs in addition to new stocks of fish and governments in developing countries subsidize fisheries as a new source of foreign exchange (Royce 1987; Dyck et al. 2010). Indeed, between 1985 and 1995, the export value of fish eclipsed coffee and other major cash crops (see Figure 2.5).

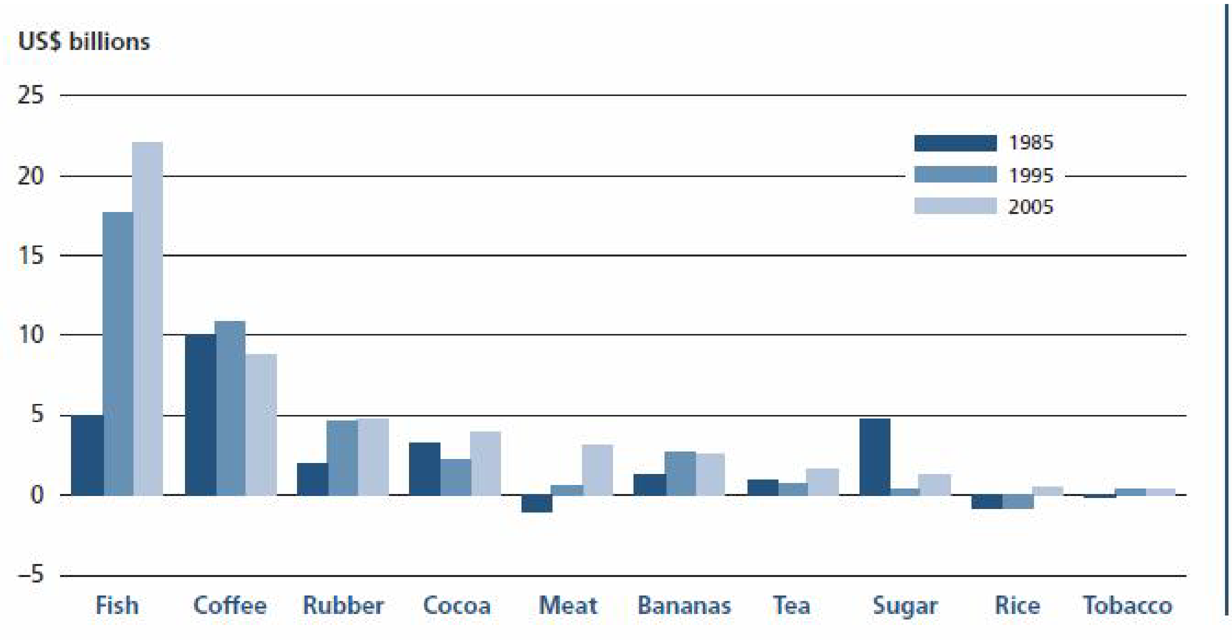

Figure 2. 5 Net exports of selected agricultural commodities by developing countries ((FAO 2009, 1-176), 28, Figure 32)

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[5] For quantitative estimates of the impact of technology change on specific fisheries, see i.e. Prellezo and Escapa (2003), Salvanes et al. (2010), Andersen et al. (2007), and Squires (1994). For descriptive narratives regarding the historical development of fisheries see i.e. Ellis (2003), Johnston (1965), Juda (1996), and Royce (1987), among others.

The last major driver of fishing expansion shown in Figure 2.4 is increasing demand for fish products (↑D). People are buying more fish and they are paying more for it. Figure 2.6 shows clearly that, even in real terms, the value of fisheries exports (our best approximation for global production value) almost tripled from 1976 to 2007, even as the quantity of exports did the same. This trend is connected to globalization but is also fueled by population growth.[6] As income increase globally, people demand more protein and also are willing to pay for better protein. Globalization further facilitates the dispersion of national cuisines like sushi, creating new demand for fish and fish products (Bestor 2000). Lastly, population growth is a major cause of increasing demand for fish products globally. Even though total fish production has increased 7 fold since 1950, the per capita supply of fish remains almost the same because there are so many more people on the planet (FAO 2009). Thus, even without economic growth, demand could keep pace with supply due to population growth.

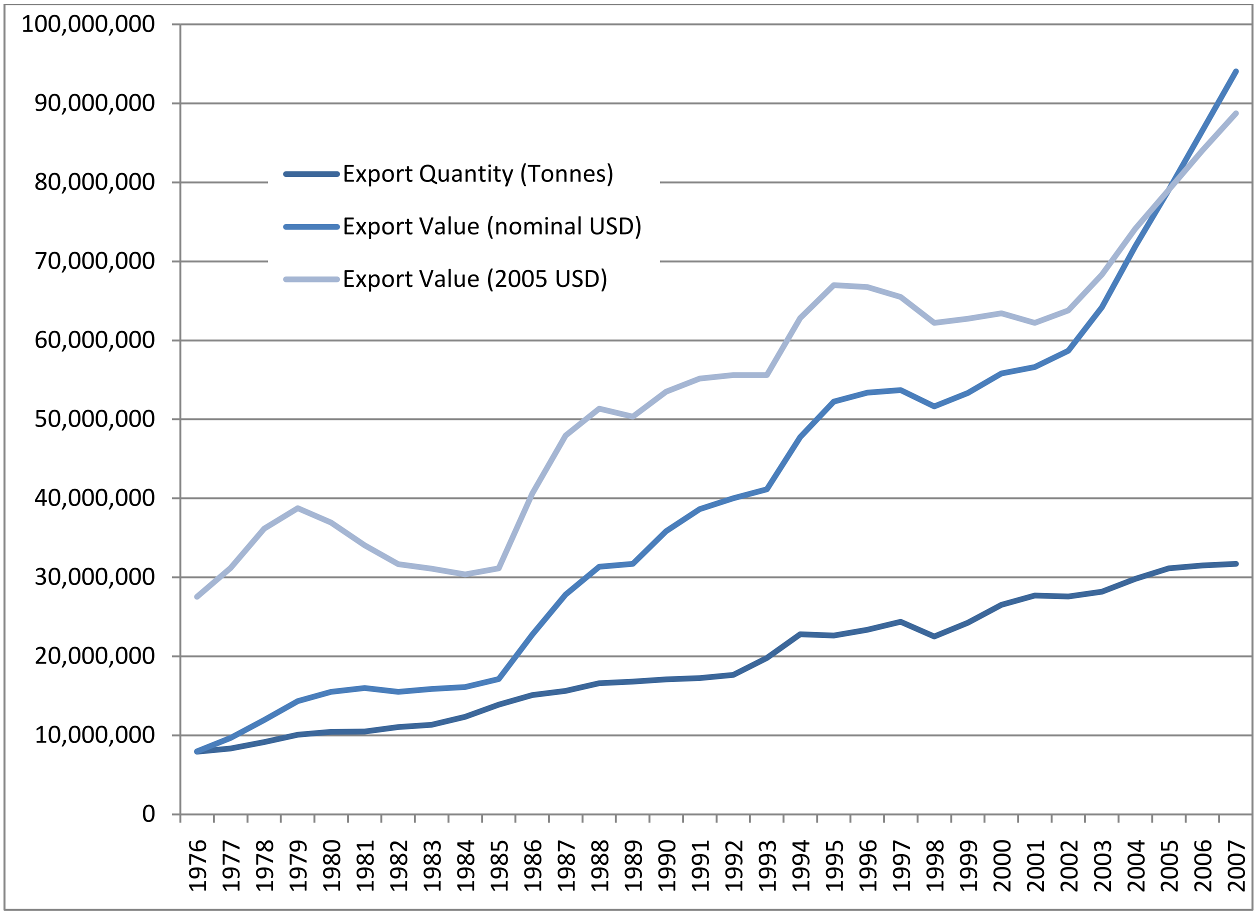

Figure 2. 6 Quantity and value of exports of fishery products globally (FAO 2010b)**, real values computed using CPIs from World Development Indicators).**

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[6] Measures of global fish production, value, and trade are notoriously inaccurate due to difficulties with data collection and standardization. However, the FAO's Fishstat Plus databases are generally thought to provide at least a good indication of the orders of magnitude on these parameters. Also, because these are just export values, the value of total production is probably much higher overall and there is no reason to believe that the trends reflected in the graph would not also be observed for domestic consumption.

All of these additional drivers exacerbate the CPR problem in fisheries by dampening Signal 1 (declining net revenues). Driver 2 (increasing demand) ensures that prices actually increase with growing supply, rather than declining as they would in a closed system. Drivers 3-5 reduce the costs of production so that fishing remains cost effective even as stocks are depleted globally. Yet none of these drivers actually counteract Limit 1 (biomass). Certainly, geographic expansion and switching to new species prolongs the life of the fishing industry, but ultimately there are still only so many fish in the seas. Before we move on to discuss the implications of this limit for the sustainability of the system as a whole, we need to cover a few additional system limits and drivers.

2.3 Additional limits on fishery expansion

There are three more elements that need to be covered before moving on to consider the resilience of this system. All three can act as limits but two of these have also been observed to drive increases in fishing effort. These three factors are governments (Gov), noncommercial interest groups (NCo), and the oceans ecosystem itself (Eco).

Noncommercial interest groups can vary widely but generally include recreational fishers and conservationists/preservationists. Their most effective tools are popular grass-roots movements like those that lead to International Whaling Commission's moratorium on commercial whaling and the creation of the Agreement on International Dolphin Conservation Program. These groups have had smaller victories as well, including the widespread adoption of by-catch avoidance mechanisms for endangered sea turtles and sea birds, as well as the proliferation of sustainable seafood lists and labels (Barkin and DeSombre 2000). Recreational fishers have worked to establish a "catch-and-release" ethos within their own ranks and have lobbied around the world to protect game fish like salmon and billfish.

At times these groups join forces with each other and even with commercial fishers (DeSombre 2005), but, unless a species is particularly charismatic, they usually they don't take strong action until it is severely depleted. For instance, Atlantic bluefin tuna has been in decline for more than a decade, but has only received serious attention from conservation organizations in recent years (see Webster 2011) and still hasn't ignited any grass-roots fires. Focus on charismatic species can also undermine broader ecosystem health. For example, "dolphin-safe" tuna may be better for dolphins but the controversy itself initiated the use of fish aggregating devices, which expanded tuna fishing generally and increased incidental catches of juvenile tuna and other species (Menard et al. 2000; Bromhead et al. 2003).

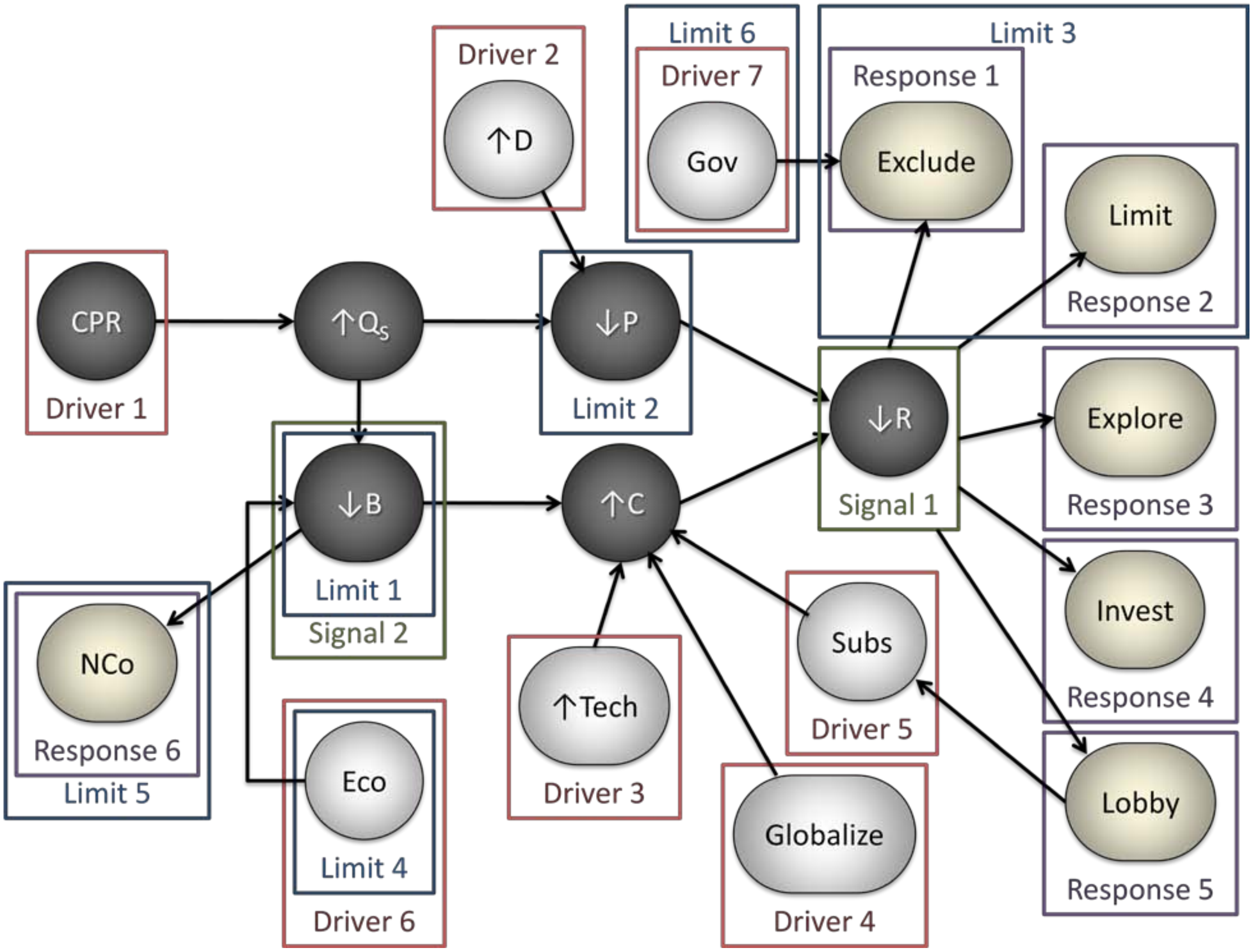

Figure 2. 7 Full fisheries system diagram

Public focus on charismatic species has not prevented scientists and other interest groups from recognizing the importance of the oceans as ecosystems, rather than simply sources of specific benefits (be they commercial or noncommercial). Yet, as Figure 2.7 shows, this complexity plays a rather ambiguous role in the full fisheries system. In the short run, ecosystem effects (Eco) can drive fishery expansion by obscuring the effect of fishing on stock biomass. In some cases, such as Pacific anchoveta, recruitment (the volume of juveniles who make it to the adult stage) is almost entirely determined by environmental factors, which makes it very difficult to determine the overall effect of fishing effort on the stock (Chavez 2003). Many other fisheries often experience “good years”, in which recruitment is very high, even when stocks have been overfished for a long time. This undermines fisher confidence in scientific advice and, by restoring profitability in a fishery, encourages expansion of effort, which then exacerbates collapse when “bad years” come along.

In the long run, ecosystem effects limit extraction in more complex ways. In some cases, feedback effects magnify stock depletion. For instance, in his review of the literature (Roberts 1995) describes how even low levels of fishing can alter the species composition around coral reefs, including drastic reductions in keystone species like sea urchins, which leads to severe damage to the entire ecosystem. The establishment of marine protected areas can help to reverse these trends, but the rebuilding of coral reefs is a dynamic process and reefs do not always rebound as expected (Hoegh-Guldberg 2006).Other irreversible fishing-induced ecosystem shifts have been documented. The most famous example is the collapse and continued low populations of groundfish in the north west Atlantic. In spite of a long-standing moratorium on fishing, these stocks have not rebounded, largely because of trophic shifts within the ecosystem (Morissette et al. 2009).

The dual role of governments (Gov) has already been discussed briefly. Governments can respond to fisher lobbying through 1) subsidies, which drive fishery expansion, 2) exclusion, which temporarily limits catch, or 3) some type of catch or effort limits that reduce harvests in the long run. However, governments are more than just the pawns of domestic fishing interests. They also represent the public interest or at least the interests of their political power base. As such, governments may choose to subsidize fisheries as part of a development program as shown previously in Figure 2.5. They may also choose to reduce subsidies or place limits on domestic fishing activities in order to protect national resources. Such steps are often taken in response to lobbying by non-commercial interests but may also occur in response to pressures from commercial fishers when they observe a decline in stock abundance (Peterson 1995, 272).

Given that this paper addresses international fisheries specifically, this last point deserves elaboration. As (Litfin 1998) and others have pointed out, states' concern with sovereignty—particularly legal sovereignty—shapes international environmental agreements and visa versa. This is true in fisheries as well, but states are also very interested in the appropriation of the resource and, by extension, jurisdiction or some other formal claim to rights of access. This drive originally lead to the expansion of national power from the "cannon shot rule" of 3 miles in the late 1600s to the present day system of 200-mile exclusive economic zones (EEZs; Juda 1996). Defining rights of access has also been a major factor in the management of highly migratory species, but its affect on the system as a whole is difficult to parse out.

For one thing, government focus on rights of access can drive the expansion of fishing effort as fishers, often encouraged by government policies, compete not only over the present stock of the resource but also over rights to future access. This additional competition occurs in part because of a carefully established norm that past catches should be used as a benchmark to allocate quota shares in international negotiations. Clearly, this norm favors countries like the U.S., Japan, France, and Spain, whose distant water fleets have been actively fishing on the high seas for more than half a century. In response, developing countries have successfully negotiated to include coastal developing status as a new norm for allocation (see FAO HMS agreement). With both norms in place, new entrants can drive up fishing effort just as predicted by (Munro, Houtte, and Willmann 2004).

As (Peterson 1995) points out in her exhaustive study of international fisheries management, conflict over the allocation of access rights can also undermine attempts to collectively limit fishing mortality. Even if members agree that such limits are needed, they may fail to identify a sharing arrangement that will satisfy all parties. When this occurs, the RFMO either takes no action or limits itself to less effective measures, which generally allows further depletion of the fishery.[7] However, as (Webster 2009) shows, agreement over allocation may be eventually be reached if politically powerful countries are also economically vulnerable. This is usually a delayed response—since it takes time for fishers and fishing states to recognize how much they are losing out under open competition—but it does help to counteract the inertia associated with disagreements over access rights.

Note that this vulnerability response dynamic differs qualitatively from the traditional tragedy of the commons problem, since the concern is not free-riders but rather conflict over allocation. In fact, over the last 30 years, RFMOs have actively worked to reduce free-riding through increasingly stringent monitoring and enforcement mechanisms. Monitoring measures undertaken by many RFMOs include on-board and regional observer programs, vessel monitoring systems, positive and negative vessel lists, statistical document programs, and even port-state inspections. Many RFMOs still rely on flag states to penalize their fishers, but an increasing number are also undertaking trade restrictive measures, which are essentially sanctions on imports of a species from a country whose fleets are acting in contravention of the RFMO's management measures (DeSombre 2005). Figure 2.8 shows the number of RFMOs employing each of these measures for at least one of the stocks in their jurisdiction as of 2010.

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[7] Examples would be requesting additional scientific analysis, establishing vague effort restrictions with multiple reference years, or setting a TAC that is higher than scientific advice in order to accommodate all demands.

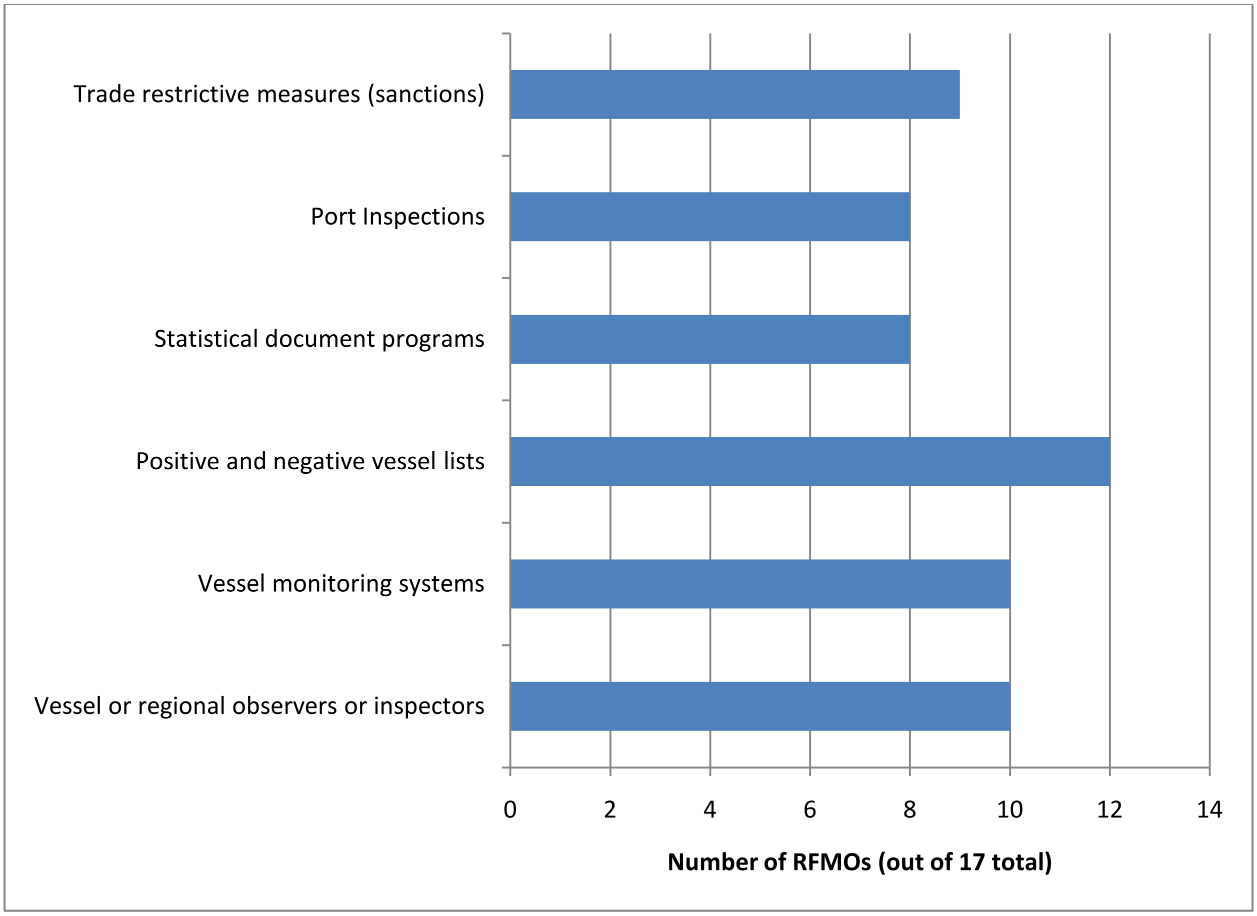

Figure 2. 8 Count of marine RFMOs employing each monitoring or enforcement mechanism for at least one stock (data collected directly from respective RFMO websites).

In spite of all these new measures, illegal, unregulated, and unreported (IUU) fishing remains rampant, especially targeting valuable species like southern and Atlantic bluefin tuna or Antarctic toothfish (a.k.a. Chilean seabass). Moreover, RFMOs continue to adapt weak or insufficient management measures for many stocks. That is, they either fail to enforce their regulations or they enact regulations that fall well short of scientific advice. A deeper problem is the institution of maximum sustainable yield, which dominates international fishery management, causing RFMOs to neglect the ecosystem effects described above (Finley 2009). This will be discussed more as we look at the sustainability of the system in the next section.

3. Sustainability of the System

With so many complex elements, it is difficult to gage the sustainability of the global fisheries system. However, we will make some general observations here before moving on to explain how computational techniques can provide detailed projections for specific fisheries. Our analysis will be guided by (Carpenter et al. 2004), who posit that stability and change in social-ecological systems like global fisheries can be defined by the interactions between their resilience, adaptability, and transformability. Carpenter et al.'s definitions of these three factors are quoted in Table 3.1. The next three subsections cover each factor in turn, focusing on the global fisheries system described above but also acknowledging two major exogenous forces: climate change and oil scarcity. Specifically, we will consider the potential impact of climate change on ecosystem resilience and the effect of increasing oil prices on fisher adaptability.

Resilience	…the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (5).
Adaptability	…the capacity of actors in a system to influence resilience (6).
Transformability	The capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable (6).

Table 3. 1 Factors affecting the future of complex social-ecological systems as per Walker et al. (2004; page numbers in parentheses)

3.1 Resilience

Resilience is a tricky concept. As Hughes et al. (2006) point out, when dealing with social-ecological systems one must ask not only, "how resilient is the system?" but also "how resilient is the system to what and for whom." Within the scope of this paper, our concern is largely the resilience of the oceans ecosystem to human activities and visa versa. Furthermore, although there are many human activities that impact oceans ecosystems, we focus on two: the endogenous factor of fishing effort and the exogenous factor of climate change. Other factors, such as nutrient loading, coastal hardening, and invasive species are more important in coastal fisheries but will be briefly discussed as they affect anadromous fisheries.[8] As for the "for whom", we recognize that marine living resources are critical sources of income and protein around the world and therefore mainly consider commercial fisheries but remain mindful of other values as well as the interconnectedness of the system as a whole.

Carpenter et al. (2004) propose four elements of resilience: latitude, resistance, precariousness, and panarchy. Latitude refers to the amount of change that a system can handle before crossing a threshold into a new regime. Resistance is a measure of the system's resistance to change. Both latitude and resistance describe the overall potential of the system for change, but precariousness is a means of relating the current state of the system to that potential. It quantifies the proximity of the system at a given point in time to known thresholds. Panarchy is a more diffuse idea. It requires a description of cross-scale interactions within the system and with exogenous but still connected elements. Ultimately, panarchy is a means of identifying surprises that come from system connections rather than the state of the system itself (i.e. elements outside of latitude, resistance, and precariousness).

Based on this approach, the first step to understanding the resilience of global fisheries is to identify major thresholds in what Carpenter et al. call the "state space"—basically all the possible variants of the system. Several such states have already been described in the discussion of ecological limits and drivers in Section 2.3. There are thriving fisheries and collapsed fisheries; healthy coral reef systems and overgrazed coral reef systems; benethic systems dominated by cod and benthic systems dominated by seals. In each of these examples, a system crossed a threshold from one state to another, sometimes

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[8] Technically, two of the RFMOs covered here, the Pacific Salmon Commission and the North Atlantic Salmon Conservation Organization, were established for salmon, a group of anadromous species that migrate between fresh water and marine environments.

less desirable state. Below we outline a range of general thresholds that can exist in international fisheries systems.

Fishery collapse	Economic	Cost of fishing exceeds benefits, most fishers exit
	Biological	Stock of fish becomes too scarce to exploit profitably
Ecological imbalance	Keystone species	Removal of one or more species decimates an ecosystem
	Trophic transformation	One or more species replaced by competitors
Environmental shifts	Natural cycles	Normal changes in the oceans system (i.e. ENSO)
	Climate change	Ocean temperatures, possibly currents shift
	Pollution	Reduces survivability of most species
	Habitat removal	Reduces survivability of most species
	Invasive species	Similar to ecological imbalance

Table 3. 2: Thresholds in International Fisheries Systems

From the traditional single-stock perspective, fishery collapse is one of the most common thresholds. Collapse can be economic, when it simply becomes too expensive to continue exploiting the fishery. Usually small stock size is a major contributor to economic collapse, but other factors like change in consumer demand, government regulation, or costs of production can also generate economic collapse. Biological collapse has a similar effect—the decimation of a fishery—but the cause is specifically that there are too few fish to harvest profitably. These collapses may be due to overfishing but are more often the result of overfishing plus environmental changes such as those described below.

There is already considerable evidence of both types of collapse in the global fisheries systems. Economic collapses are most often regional, such as the shift of US fleets from California to bases in the western Pacific in the 1970s. This was caused by several factors, including escalating competition, high input prices (due to unionized labor as well as the oil price spikes of the 1970s), and the political ramifications of the tuna-dolphin controversy at the time. However, biological depletion is much more common. In 2007, 14% of assessed stocks were categorized as "collapsed", that is, the estimated biomass of these stocks was less than 10% of the level that would support maximum sustainable yield (Worm et al. 2009). As has been noted, these are usually the most valuable of commercially targeted species as well.

Ecological thresholds are more difficult to understand than single-stock thresholds, but are much more important because the effect of an ecological shift is felt more widely and is less likely to be reversible than the collapse of a single stock. That said, the collapse of one stock can trigger an ecological threshold effect, as in the removal of keystone species from otherwise resilient systems. Global fisheries threaten much more than this, though. By systematically extracting certain types of fish (i.e., top predators like tuna, swordfish, and sharks) we may be pushing the system toward a trophic transformation, in which once dominant species are too few to continue to compete successfully.

Section 2.3 covered localized (i.e. disappearance of urchins and coral bleeching) and regional (replacement of groundfish by other predatory species in the north west Atlantic) ecological shifts caused at least in part by fishing. Given the diversity of the oceans, it is difficult to imagine a complete change in all ecosystems. Nevertheless, such shifts have certainly occurred in prehistory and may occur in the future. Currently, scientists are concerned about the growing number and size of jellyfish blooms around the world (Malakoff 2001). This trend began in the 1980s and such blooms are often traced at least in part to the removal of jellyfish predators and/or competitors via fishing (see i.e. Gibbons and Richardson (2009) and Suchman et al. (2008)).

Finally, there are environmental effects that can alter any of the above thresholds but may also be associated with their own tipping-points. For instance, climate change is expected to produce a gradual warming of the world's oceans, which will be beneficial to some ecosystems but detrimental to others, shifting their bioeconomic thresholds in different directions. In fact, climate is another factor contributing to escalation of jellyfish blooms (Purcell 2011). At the same time, if climate change causes the melting of the Greenland ice sheet, it's likely that the oceanic conveyor will collapse, which will cause havoc throughout the oceans (Rahmstorf 2010). This is an extreme example, but we should not neglect the potential for surprises due to natural changes in the ocean systems or shifts driven by human action such as climate change, pollution, habitat destruction, and invasive species.

3.2 Adaptability

Adaptability measures people's ability to alter the resilience of a system. Like resilience, the concept seems simple but is actually hard to implement in a particular setting. One of the most difficult aspects of the analysis is delineating among human behaviors that are a part of system resilience, actions taken to alter system resilience, and attempts to transform the system (which will be discussed in the next subsection). Hypothetically, the adaptive actions taken below could also be considered as additional thresholds within the state-space itself—divergences caused by people who are responding as parts of the system as a whole. However, for clarity, we will consider human responses to be adaptations of rather than additions to the state space.

For our analysis, it will be useful to break adaptability down to economic, biological, political, and ecological components. Economic adaptability has been very high throughout the history of international fisheries. Through exploration and investment, fishers have become more efficient and effective, reducing costs of production even as stock decline should have made fishing more expensive. That said, coastal and artisanal fleets have much less adaptive capacity than distant water fleets, since they are confined to a smaller area. In fact, distant water fleets often adopt a "roving bandits" strategy, moving to a new stock whenever economic or ecological conditions become unfavorable. This makes them more resilient in the short run (Berkes et al. 2006). However, it is part of the panarchy of the system that, as more fishers enter the system and more stocks become overexploited or collapse, the options available to roving bandits dwindle as well. In this sense, economic adaptations are maladaptive—reducing the resilience of the system as a whole.

In fact, most of the economic adaptations undertaken by fishers actually reduce the long-term biological resilience of the stocks that they exploit. That said, people have taken some steps to improve biological resilience for some stocks via seeding programs and mariculture. Seeding involves raising fry in a lab setting and then introducing them into the wild environment. This has been done successfully with white seabass off the California coast, but is not common in international fisheries (Lorenzen et al. 2010). Mariculture is a more widespread adaptive technique in the oceans. For international fisheries, the two most common forms of mariculture are the farming of salmon and the ranching of bluefin tuna. Farming involves raising fish from hatcheries whereas ranching refers to the capture and fattening of adult wild-caught fish. Both can increase the biomass harvested, but ranching may actually reduce overall fecundity, exacerbating stock decline (Volpe 2005).

These mariculture techniques are controversial for several other reasons. First, economically viable species tend to be large, carnivorous fish that require substantial protein input, usually from capture of smaller marine species which would provide more nutritional value if consumed directly. Second, there are concerns about concentrations of effluents around mariculture operations. Third, because of the close proximity of fish in pens, antibiotics are commonly used to reduce disease mortality. This creates several problems, including introduction of antibiotics into the marine environment through effluent and the proliferation of antibiotic-resistant diseases in wild stocks. Fourth, parasites also breed much more successfully in pen environments and can easily transfer to wild stocks. This is particularly problematic for fry and small fish who can easily succumb to just one or two parasites. Finally, recent attempts to introduce transgenic fish in mariculture operations raises the fear that these genetically modified fish could escape and completely alter wild populations through competition or interbreeding (see Burke and Naylor (2005) and Halling et al. (2003) for a good overview of these issues).

Before moving on to other types of adaptability, we should briefly cover the potential for large changes in the underlying economics of the current global fisheries system. As explained in Section 2.2, continued profitability in the sector depends heavily on fishers' ability to access credit for investment and to keep operating costs low through technology and lobbying for favorable policies. Increasing demand for fish products is also important, because it keeps prices high in spite of growth in supply. Because of these factors, many fishers, but especially distant water fleets are vulnerable to exogenous economic changes. Economic recession limits the availability of credit and lowers demand, which lowers prices and profitability. So far, many fleets have weathered these storms, but the increasing cost of oil threatens to cause both exploding costs of production in fisheries and widespread economic recession. If this occurs, the economic adaptability of industrial fishing fleets will be severely tested (see Tyedmers, Pauly, and Watson (2005) for an analysis of fuel use by global fishing fleets).

Governments and conservation groups have also tried to improve the resilience of the global fisheries system. As described in Section 2.3, these organizations can act as limits on the expansion of fishing effort. When governments work, either individually within their EEZs or collectively through an RFMO, to restrict fishing mortality on a particular stock, they can increase both the economic and biological resilience of a fishery. All else equal, reducing mortality should allow for rebuilding of the stock, which means more fish and easier fishing. A lower supply of fish can also lead to higher prices as long as the fishery is substantial relative to the market. Therefore, fishers should make more money and fish should be more plentiful, which should improve their biological resilience.

Another way that governments—usually prodded by conservation groups—seek to improve the resilience of the system is through the establishment of marine protected areas (MPAs). These types of regulations ban fishing and other disruptive human activities around highly productive habitats (i.e. coral reefs or upwelling systems). In theory, MPAs should increase the abundance of all species within a protected area and also improve fishing in adjacent waters as organisms spread outside of the zone (Young et al. 2007). Evidence on inshore MPAs generally supports this view, although there is considerable variation in effectiveness (see i.e. White et al. (2008). Placed within the scheme of RFMOs, MPAs also take on a strategic value; since most fleets stick to specific geographic regions the placement of an MPA could hurt or help national harvests vis a vis international competition. This has already occurred in RFMO negotiations on time-area closures for the protection of juveniles or bycatch species (Webster 2009).

Looking at the historical record, government management often falls short of improving either economic or biological resilience. Reasons for this in domestic fisheries are well documented (see i.e. Clark (2006)). Section 2.3 covers the additional obstructions to successful international fisheries management. These can be reduced to three main problems. First, due to disagreements over the allocation of access rights, RFMOs usually evince a delayed response to the decline of stocks in their jurisdiction. For some species, like bluefin tuna, such disagreements may prevent effective action all together. Second, even when RFMOs agree to scientifically recommended measures and implement international monitoring and enforcement mechanisms, the incentives to fish illegally are still very high while the risk of capture is quite low. This fuels a huge parallel market in valuable fishses like bluefin and toothfish. Third, even if enforcement were perfect, current management approaches only address stocks one at a time and therefore do not account for bycatch mortality, ecosystem effects, or environmental change.

These last two factors are intertwined, in that the single stock approach has long prevented RFMOs from dealing with IUU fleets, which have used the “roving bandit” technique to avoid management as much as to pursue more profitable fishing opportunities. In spite of years of collaborative work to coordinate RFMO enforcement schemes, IUU fishing is still a huge problem. This has led many, including the RFMOs themselves, to call for coordinated reduction of fishing capacity, which would really improve the resilience of the system. However, the same types of disagreements over allocation have stymied these attempts as well. Everyone agrees that capacity should be reduced but too few countries are actually willing to make the necessary cuts themselves.

Furthermore, it is not clear that capacity limits will really be effective. As long as globalization and increasing demand drive prices up faster than costs of production, IUU fishing will be profitable. In fact, with reduced production, prices should increase, which would add to the incentive to “cheat”. In order to stem the effect of increasing prices, several conservation groups have established programs to convince consumers to buy only sustainably harvested seafood. The oldest of these are lists that tell consumers what fish they should or should not eat for various reasons. For instance, the Monterey Bay Aquarium’s Seafood Watch program lists fish in “best”, “good”, and “avoid” categories that cover several concerns ranging from sustainability to by-catch problems to mercury content. These simple systems are easy to use and many are available as pocket guides or phone apps. The Marine Stewardship Council recently introduced a sustainable seafood labeling system as well, so that fishers who fish responsibly can be rewarded even if a particular species is on a “bad” list. While such programs could be helpful, little evidence is available on either changes in consumer preferences or ancillary effects on commercial fishing operations.

Based on this assessment, the adaptability of the global fisheries system is at best precarious and at worst balanced toward maladaptive responses. Some fishers, conservation groups, and government officials are trying to do something about declining stocks and eroding ecosystems, moving the system away from disadvantageous thresholds. Exogenous factors that slow economic growth or otherwise increase the costs of production while reducing demand for fisheries resources could augment management efforts by reducing incentives to overfish; these same forces could also overwhelm global fleets, resulting in the economic collapse of the system. However, if the expansion of fishing effort continues, even at lower rates, then a future crowded with biological collapse and ecological upheaval is likely.

3.3 Transformability

Carpenter et al. (2004) describe transformability as the capacity to completely alter a system that has become untenable, for whatever reason. Transformation totally changes the state space, as new variables and connections replace old ones. Fisheries related examples include a switch from whaling to whale watching or from commercial fishing to recreational fishing and scuba/snorkel trips around coral reefs. The first transformation was a response to the biological and political untenability of whaling after the near-extinction of several species and effective PR by conservation organizations raised whales to the status of charismatic megafauna. The second has taken place in some locations, largely in response to economic and ecological decline associated with overfishing as well as the rise of ecotourism as a popular development tool. Fishing and whaling are not completely absent in either case, but merely eclipsed by alternative use values.

What, then of global fisheries? Is tuna tourism the next big thing? In order to answer these questions we would first need to clarify the nature of the transformation. That is, we must answer two questions:

1. What is/will be untenable about the state of the system prior to transformation?
2. What will this untenable system transform into?

No one has the answers to these questions. Finding answers will be discussed in Section 4. Here, we reiterate the untenable aspects of the system as described above and relate these to possible (not even probable!) transformations.

Take first an economic collapse of commercial fisheries; say oil prices become prohibitive or demand suddenly falls. In the oceans, ecosystems would be left to continue their evolution without fishing pressure. Something similar happened during World Wars I and II. At that time, stocks quickly rebounded and fish were plentiful when fishers returned in times of peace (Juda 1996). Today, oceans ecosystems would still be exposed to climate change and habitat loss and invasive species and pollution, but one could hope that rebuilding would occur. On land, however, fishing communities—millions of people—would be forced to find new work, which is often difficult because the skills associated with fishing are not highly transferable (FAO 2009, 1-176). Some might manage to make the switch to ecotourism, but others would have to be absorbed into the broader economy. In addition, billions of people would need to find new sources of protein or suffer from malnutrition (Srinivasan et al. 2010).

This would place an added burden on already stressed agricultural resources and health care and/or social safety net resources. The transformation to a “no fishing” system could be quite costly.

Alternately, commercial fishers could be pushed out of the market by aquaculture operations. The problems associated with aquaculture have already been described above, but aquaculture production increased by an order of magnitude over the last 40 years and now accounts for almost half of the fish produced for human consumption globally (FAO 2009, 16-17). Aquaculture operations are certainly able to supply a similar product at a much lower price than capture fisheries. Indeed, many people agree with (Halling et al. 2003) that carefully planned and managed aquaculture is the best way to increase fish production to match population growth and other drivers. Therefore, one admittedly far-fetched transformation of the system would be the “farming of the seas”, in which only a few enclaves of wild fish survive as humans appropriate and magnify the productive capacity of the oceans.

A more likely fault in the system would result from the biological collapse of important species or ecological shifts in the oceans. We have already seen that the collapse of a single stock—or even several important stocks—merely displaces effort into other fisheries (though it may also increase political will, see below). Therefore, collapse would have to be widespread to generate a transformative effect on the system. This could result in an ecological shift—that is, the primary structure of oceans ecosystems would change—in which case fishing might continue as long as consumers are willing to adapt their preferences to the new species (the Chinese are already buying up jellyfish). Another possibility, made more likely by the presence of multiple stressors, would be the total biological collapse of marine fisheries. In this case, there would be the same land-based costs as in an economic collapse with the additional effect of a decimated marine system. Fisheries would have to lie dormant for decades or longer and there would be no telling what type of new life would rise up to replace the old.

Hopefully, the political elements of the system will become untenable long before either of the above catastrophes occur. Those biological and economic collapses that have happened certainly raised awareness of the problems associated with overfishing among fishers, conservationists, governments, and the public. So far, this knowledge has led to quite a few innovations in national and international governance as well as consumer activism. In Section 3.2, these changes were discussed as elements of adaptability, but there are two important potential transformations in the politics of the system that should be covered here.

First, we could witness the proliferation of an “oceans ethos” or, more broadly, a “sustainability ethos” throughout mainstream consumer culture. This is in fact what many environmental philosophers call for and what many environmental organizations advocate. Indeed, these ideas have been around for a long time, but it may take more crises, not only in fisheries, but also in other human-ecological systems to substantially change our current consumer culture. One should not discount the costs of these crises, even if the long-run end is a less consumptive society. Nevertheless, if such an ethos were to pervade the system, then premiums on “sustainably harvested stocks” and public demands for sustainable management might alter the balance between political limits and economic drivers. These new consumers would have to account for ecosystem effects, demanding more nutrition from low trophic levels and limiting their overall consumption via both population controls and voluntary restraint.

Second, growing demand for protection of fisheries from many parties, including commercial fishers, could amplify national willingness to pay for successful management so much that countries would acquiesce to a global fisheries government that would replace the current system of RFMOs. This body would supposedly enact management without the wrangling over allocation of costs and benefits that makes agreements in RFMOs so difficult. Presumably, it would also be able to better coordinate among various fisheries and would be given powers to monitor and enforce its regulations on all fleets, irrespective of flag state. One would hope that such a miraculous body would apply the precautionary approach and ecosystem management, imposing marine protected areas and other multi-stock regulations as necessary. However, given the success (or failure) of national management of fisheries within EEZs, it is likely that a global fishery government would fall well short of perfection.

Above, we described several possible futures for this motley system based on concepts of resilience, adaptability, and transformability. Unfortunately, we cannot say which future is most likely without much more detailed analysis. What we can say is that these simple visions—particularly those transformations that might be wrought by political actors—are really visions of panaceas that are untenable in themselves. To truly transform this system we need to move beyond panaceas and to do this we need a new approach to understanding the oceans as social-ecological systems.

4. Beyond Panaceas

What we described above as a single system is really a patchwork of subsystems that exist at different levels and scales but are deeply interconnected, both through human and natural elements. If we are to understand this large system in the present and have any hope of shaping its future, we will need to rigorously explore each subsystem and all of the most important connections between these moving parts. Moreover, such exploration needs to fully integrate the human and natural elements in the system and its component parts. This is no easy task, but it is possible.

Scientists from all disciplines—natural, physical, and social—will need to communicate with each other and with non-scientists in order to build and test both qualitative and quantitative models of specific fisheries systems. This will entail getting fishers to cooperate as well, or at least finding ways to develop testable hypotheses regarding their behavior, in selecting the timing and location of their harvest, the magnitude of their effort, and their political as well as economic response to regulations. It will also require consolidated knowledge of economic interactions, including the relationship between capital investment and fish production as well as the shifting nature of consumer demand over a wide array of available substitutes. Lastly, on the human side, we need to be link up the wealth of knowledge regarding political interactions—between interest groups and governments and among governments at the international level—with the rest of the drivers in the system.

Computational techniques can be very helpful in this endeavor. Already most fisheries biology is undertaken using advanced models that relate data on catch per unit effort to known species dynamics. Temporally explicit geospatial models of international fisheries are already functioning for most oceans, though with difficulty due to lack of data and information on fisher decision-making.[9] Several approaches could be used to transform these programs into real models of coupled human and natural systems. Traditional statistical modeling techniques have been used to integrate economic, biological, and oceanographic systems in some fisheries (see i.e. Siegel et al. (2003)). Another approach would be the use of agent based modeling to incorporate rule-based mechanisms into fisher behavior as has already been undertaken by Wilson, Yan, and Wilson (2007) and Brede, Boschetti, and McDonald (2008). The most important thing, however, would be to ensure comparability across subsystem models and to find ways of capturing emergent properties in order to ultimately model the international fisheries system as a whole.

As part of this research project, computational models would be used to explore a range of possible futures to identify practical ways of increasing the resilience and adaptability of the system that we have and to identify any potential for positive transformations should the system become untenable. Data collection on stakeholder preferences and dissemination of information about oceans systems could be accomplished through scenario visioning processes such as described by (Olabisi et al. 2010) and Tansey, Robinson, and Carmichael (2004). A similar but denser approach is the Robust Decision Making (RDM) framework as articulated in Lempert, Popper, and Bankes (2003) and Lempert and Collins (2007). RDM uses powerful computational techniques to simulate a wide range of possible futures—from thousands to hundreds of thousands—and then search those results for robust outcomes that are associated with a wide array of input parameters and system attributes. It can also be used to search for thresholds and similar nonlinearities in the state space.

We need to undertake such research to move beyond panaceas in international fisheries governance. As March and Simon (1993) pointed out, for big changes to occur, it's not just the solutions that are important but also the opportunities for change and the presence of advocates who are willing to champion those good ideas. We already have a good set of possible solutions. What we need is to understand if, when, and how opportunities and advocates might arise to successfully solve the problems of international fisheries governance. Like the system itself, this processes is likely to be patchy and even precarious, but it is also an unprecedented opportunity to better understand and impact the sustainability of social-ecological systems.

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[9] Much of this work can be traced through the Global Ocean Ecosystem Dynamics (GLOBEC) project (http://www.globec.org/). Although GLOBEC consortiums often include social science working groups, the integration of these groups into the larger research framework is not very good.

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