Marine Policy 53 (2015) 165–170

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Are world fisheries a global panarchy?☆

Peter J. Jacques*

Department of Political Science, University of Central Florida, 4297 Andromeda Loop N, Howard Phillips Hall 302, Orlando, FL 32816, United States

ARTICLE INFO

Article history:
Received 13 August 2014
Received in revised form
26 November 2014
Accepted 26 November 2014
Available online 31 December 2014

Keywords:
Global fisheries
Panarchy
Adaptive cycle
Adaptive management
Fisheries collapse

ABSTRACT

Problems of overfishing and other stresses to fish populations have continued to grow in scale, from smaller to more global pressures. These pressures are found in changes in the water column, such as through warming, as well as pollution and fishing effort and practices. Single stock collapses have been common, and pressures are building across marine regions. This paper questions whether or not it makes sense from a policy perspective to think of fisheries as a hierarchical global integrated adaptive system, or panarchy. From a policy perspective rules and institutional procedure, actors, and ecosystem dynamics all provide a foundation for many fishery stresses, and casting policy at the wrong scale can provide problems of institutional fitness, as well as set fishing and fishery based social–economic systems up for unexpected crisis. If it makes sense to think of global fisheries as a panarchy, it is plausible that fisheries can collapse at this scale, and policy makers around the world should use measures to build resilience at this level, primarily through reducing slow persistent disturbances while preparing for surprises. This review concludes that certainly fisheries can be viewed at the global scale and a planetary mindset should be included in international fishery policy making that should assert the value of an interconnected ocean and planet beyond simple fish commodities.

1. Introduction: global fisheries and human interaction

In the final report of the Global Ocean Commission [1], the authors warn in their introductory letter:

> Our ocean is in decline. Habitat destruction, biodiversity loss, overfishing, pollution, climate change and ocean acidification are pushing the ocean system to the point of collapse. Governance is woefully inadequate, and on the high seas, anarchy rules the waves. Technological advance, combined with a lack of regulation, is widening the gap between rich and poor as those countries that can, exploit dwindling resources while those that can't experience the consequences of those actions. Regional stability, food security, climate resilience, and our children's future are all under threat (p. 3).

Fishery scientists have disagreed about the exact nature of the status of world fisheries, but typically these disagreements are about "just how bad is it?" and few voices of reason point to any systematic improvements in marine ecosystems, even though there are many papers identifying where rebuilding could occur. Still, it is fair to say that global fisheries experts continue to call attention to growing problems that threaten ecosystem services, food security, livelihoods, cultural meaning, and economic welfare as the world's stocks continue to decline.

Litzow et al. [2, p. 1476] warn, "Anthropogenic stress has increased the global risk of ecological regime shifts: abrupt, difficult-to-reverse reorganizations stemming from multiple stable-state dynamics". Miles [3, p. 29] argues that the earlier smaller stresses, such as oil pollution, have now been joined synergistically by "megastressors" that include a burgeoning world population, ocean warming, and ocean acidification that are changing the *structure* of the World Ocean System (WOS) non-linearly and that now a, "…threshold has been crossed in the second half of the twentieth century".

Clearly, marine environmental changes are "scaling-up" from smaller to larger time and spatial commitments and this paper questions whether or not it makes sense to conceptualize *global* fisheries as a *global* complex system. Specifically, are global fisheries a nested, hierarchical complex adaptive system, or a panarchy [4]? Does it make sense to think of fisheries as part of a global panarchy for policy making purposes? The answer to whether fisheries form a global panarchy is important because if fisheries are plausibly a globally interconnected complex system, it is theoretically plausible, even if it is unlikely, for a global collapse event that could unfold quickly, such as over a decadal time period and management of fisheries should proceed with this in mind.

The stakes are high because fish provide a very important source of food, but the wild fish catch is not expected to keep up with demand, specifically threatening food security for the world's

☆This research has been funded by an internal grant at by the University of Central Florida's Department of Political Science.

* Tel.: +1 407 823 2608; fax: +1 407 823 0051.

http://dx.doi.org/10.1016/j.marpol.2014.11.024

poorest peoples [5–8]. One analysis in *ICES Journal of Marine Science*, explains that the production of fish must increase by 50% to meet expected demands for food [9], though affluent countries have been able to and will continue to be able to—to lesser and lesser degrees—substitute lost local fisheries for imports [7,10]. Of course, fish are also a vital source of revenue and jobs in direct landings that value between $80 and $85 billion annually [11]; and, economic impact beyond just landings including indirect and induced economic impact, world fisheries produce $225–240 billion annually [12]—even though over half of the landed value is lost due to mismanagement [13]. Finally, fish and fishing play a crucial role in human meaning and culture and have done so since the very old coastal cultures [14].

Complex systems are sometimes related to the idea of chaos, where there are so many variables that relationships and cause and effect are hard to predict, and if fisheries are complex systems, global or not, then it will take prudence and unusual foresight to ensure the inevitable changes to the system are experienced as surprises instead of crises [15–19].

This essay is organized as follows: first the heuristic theory of the adaptive cycle and panarchy will be explained. Then the essay explores whether or not panarchy is an appropriate model for smaller scale fisheries, as well as problems with applying panarchy to the global scale. Then important consequences to a global fisheries panarchy are explored, followed by policy-related conclusions.

2. Theory

Panarchies are nested, hierarchical adaptive cycles. The adaptive cycle is a theory proposed first by Hollings [20] regarding the resilience and vulnerability of, at first, ecosystems. The theory has since been extensively expanded and developed mainly by the Resilience Alliance and is known to apply to varied social–ecological systems [4,17,21].

The adaptive cycle moves through four phases: growth, conservation, release, and reorganization. Marten [72] refers to these same cycles as "growth," "equilibrium," "dissolution (or collapse)," and "reorganization." Walker et al. [19] explain that the first phase, growth (r), occurs with abundant resources, increasing structure, and is highly resilient; however, over time the system moves to equilibrium (K) as growth declines and the system becomes more tightly bound up by its own structure, losing flexibility and increasing vulnerability. This is what Holling refers to as the "foreloop" of sustainability that is the development mode of ecosystems and societies. The backloop of collapse (Ω) and reorganization (α) follow increasing disturbances to the system where the resources and structure collapse and new alternatives are possible. A large volume of research indicates that ecosystems, social systems, and social–ecological systems "appear to move through these four phases" [19, online].

Resource exploitation within an adaptive cycle would be experienced as a disturbance to that system, and if policy makers do not see exploitation as a cumulative process, shifts to subsequent phases like equilibrium may go unnoticed—setting the system up for collapse. In fisheries, there is a danger that policy makers may confuse, "trends in total landings [that] might provide a false sense of security when the development phase is not taken into account" [23, p. 296]. One way to see this cumulative effect is in the pattern of depleted fisheries where in 1950 only 5 percent of the world's fisheries were overexploited, but over time this number has risen an order of magnitude: in 1974 it was 10 percent, 1989 it was 26 percent, and in 2012 30 percent of the world's fisheries were overexploited—this growth in overexploited stocks matches apace the growth in world fisheries themselves [24–26].

One sign of an adaptive cycle is that exploitation becomes more difficult and less efficient requiring more energy for every unit of resource, indicating a move from the first relatively easy and efficient growth to a more fragile equilibrium. Continued disturbance to the resource will, at some unpredictable time, overwhelm the system and equilibrium will cross a threshold of change and the system moves into dissolution. Further, the disturbance is not necessarily contained locally if the dissolution affects the larger nesting systems. Hollings writes, "When a level in the panarchy enters its Ω phase of creative destruction, the collapse can cascade to the next larger and slower level by triggering a crisis. Such an event is most likely if the slower level is at its K phase, because at this point the resilience is low and the level is particularly vulnerable" [21, 398]. If smaller systems collapse, this can travel as a disturbance to larger systems and act as part of the phases of that larger system, and, therefore, can make those larger systems more vulnerable to their own dissolution. Fisheries collapse has been a regularity of the industrial system, so the question is, can these disturbances be connected to a larger, planetary, structure?

If fisheries follow the adaptive cycle, it is possible that increasing collapses of local or regional fisheries can act as increasing disturbances to large marine ecosystems (LMEs). If LMEs operate as a panarchy of nested adaptive cycles, LMEs also follow the growth, equilibrium, collapse, and reorganization phases. If the global oceanic system is also a panarchy of adaptive cycles, stress to the LMEs can be a factor for phase transition.

2.1. Panarchy, chaos, and fisheries

Panarchy has been applied to fisheries and marine ecosystems using more or less similar language and concepts for some time now. For example, since the 1980s, fishery experts have described well-worn phases of fishery exploitation, where fisheries are first in "predevelopment" phase, growth, full exploitation, overexploitation and collapse, then "hopefully" recovery [see for example [23,27]]. For example, the California abalone followed the following trend:

> Period A (1942–1951) was characterized by increasing landings. Period B (l952–1968) reflected apparent stability in landings. During period C (1969–1982) landings declined relatively rapidly, Finally, period D (1983–1996) reflects a gradual, but steady decline that ended in complete fishery closure in 1997 [28, p. 12] .

Further, fisheries are regularly referred to as complex systems, made up of innumerous parts and relationships characterized by non-linear changes [29,30]. One of the more well-known publications on this is Acheson and Wilson [31] who described the parametric management of old coastal cultures who did not attempt to quantify surplus fish population but used broader parameters to understand how and what to fish, to what extent, and when. These coastal cultures saw the ocean and its inhabitants as non-human persons and having their own will [see [14,32]], and they expected chaos. This meant that rather than attempting to control the ocean and fish they expected sudden changes and adapted their political economic systems to a non-linear sea. For example, a common adaptation for preparing for lean times was a prohibition on certain species until a crisis, so that those fish would be abundant and available when the availability of staple fish changed. One interesting benefit of this approach is that it is not data intensive, and offers a grounded set of rough guidelines that, in the past, have been successful avoiding major and serial depletions but under smaller global human populations and a smaller and less connected global economy. Setting broad parameters for fishing rather than setting a total allowable catch (TAC) seemed to work for these societies, and Acheson and Wilson argue that fisheries policy should take this history of success seriously.

Beyond single cases, are there fishery panarchies at larger scales, such LMEs, which are $>150{,}000\ km^2$? Some evidence comes from Worm et al. [33, p. 790]—which headlined with projections of the "global collapse of all taxa currently fished by the mid-21st century (based on the extrapolation of regression … to 100% in the year 2048)" . This ominous finding led to important cooperation between more pessimistic and optimistic camps (namely between Worm, Hilborn, and Branch)—but that headline is not the important contribution from Worm et al. for this analysis. Worm et al.'s central research goal was to measure the *role of biodiversity in marine ecosystem services across scales*, and not surprisingly, they showed that declining marine biodiversity deeply undercut marine ecosystem services based on local experimental, long-term regional time series data as well as global fishery data. A meta-analysis of local experimental data indicated "robust positive linkages between biodiversity, productivity, and stability across trophic levels in marine ecosystems" [33, p. 788] . At the regional scale in coastal and estuarine ecosystems, records across the last thousand years, "revealed a rapid decline of native species diversity since the onset of Industrialization," but systems with more species richness were more stable and had "lower rates of collapse and extinction of commercially important fish and invertebrate taxa over time" [33, p. 788]. At the regional scale, species richness is an important signal for vulnerable fisheries, and higher biodiversity in most if not all ecosystems is known to increase ecosystem stability [34]. Regional biodiversity losses disrupted "the number of viable (noncollapsed) fisheries (−33%); provision of nursery habitats such as oyster reefs, seagrass beds, and wetlands (−69%); and filtering and detoxification services provided by suspension feeders, submerged vegetation, and wetlands (−63%)"[33, p. 788]. At the scale of LMEs, Worm et al. analyzed fishery data from 1950–2003 in all 64 LMEs worldwide. Again, looking at rate of catch decline, collapsed fisheries, which they defined as fisheries that fall below 10% or less of their recorded maximum, and found that 29% of species fished currently are collapsed and that cumulatively over time, and 65% of the recorded taxa collapsed. Species richness provided an important mechanism of resilience against collapse, where, "… the proportion of collapsed fisheries decayed exponentially with increasing species richness. Furthermore, the average catches of noncollapsed fisheries were higher in species-rich systems," and more diverse fisheries were more capable of recovery after collapse [33, p. 798]. Other work has also found important connections to species richness and biomass accumulation and restoration of disturbed ecosystems, where biodiversity has a strong effect on the productivity of marine systems, particularly in longer term experiments [35,36]. Further, Chassot et al. [37] showed that primary production was a limiting factor across LMEs and affected global fisheries systemically, and, that current fisheries consume more primary production than sustainable fisheries, meanwhile marine primary production is declining in some areas, perhaps due to climatic variability. Biodiversity and ecosystem services like nutrient cycling, ecosystem stability, fisheries, nursery functions are inextricably linked and the evidence indicates that fisheries *can* be described as a complex adaptive system in LMEs. As biodiversity is lost, ecosystems services are also lost, and risks to coastal residents compound: beach closures, dead zones, harmful algae blooms and other threats increase.

What about beyond LMEs? The work of Blanchard et al. [38] found integrated systems of fisheries affected by climate change linked to primary production *across* LMEs showing that indeed there are systemic links above the LME scale. Further, at the global level beyond LMEs, Garcia and Charles [39] write that, "Supplementing a detailed analysis by Garcia [40], the long-term evolution of world fisheries might be described using the cross-loop 'figure of eight' model," citing Gunderson and Holling's [4] edited volume, *Panarchy* (emphasis added). From Garcia and Charles, Fig. 1 illustrates a conceptualize global panarchy.

Specifically, Garcia and Charles describe the stages of the (r) phase as fisheries moved from artisanal to industrial fishing (1900–1945) (WWII provided a well-known respite for Atlantic fisheries), with development growing 1945–1960, and steep expansion from 1960–1985. They indicate that the "global fisheries crisis" had been building up the entire century, and they posit that world fisheries

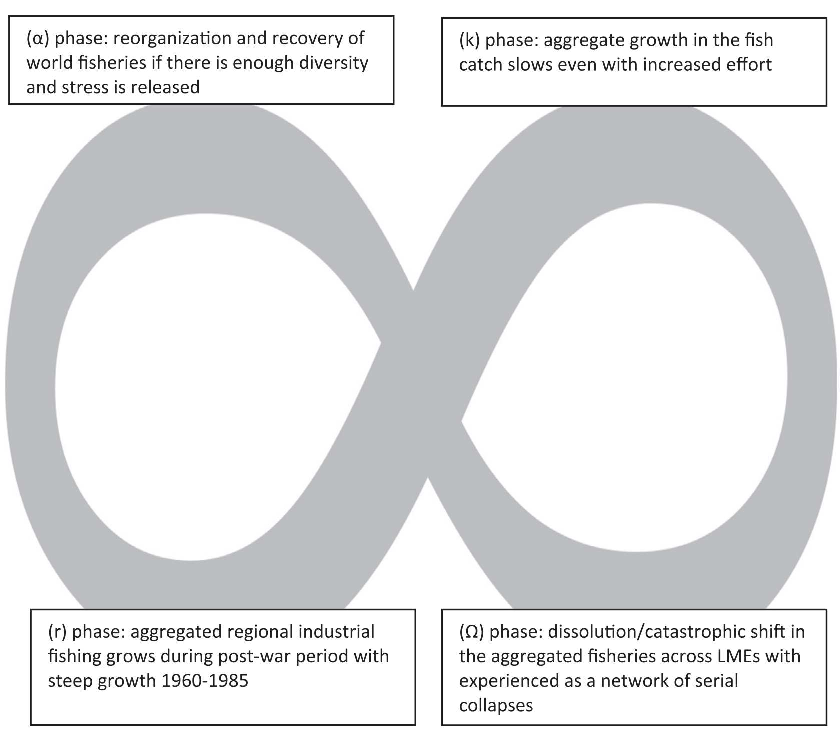

Fig. 1. Conceptualized global fishery panarchy.

entered into the K phase at this point, as in Fig. 1. Thus, evidence from the literature indicates that fisheries theoretically exist within a nested hierarchy of complex adaptive systems from local, LME, and global scales.

3. The planetary future of fisheries

Fig. 2 shows the well-known, but overly optimistic [see [41]], global fish catch pattern, but the question that Fig. 2 makes apparent, is “where is this curve going?” There are only three options: it can plateau, increase, or decrease as it has done probably since the 1980s. If fisheries are complex systems, changes in populations will likely occur through non-linear shifts between stable states [20], but the shape of the curve can take several forms. Holt [42], in a critique of a World Bank [11] report, comments on the expected growth curves of the “*total biomass of all exploited species*” (emphasis in original, p. 4). Here he notes that many fisheries studies have arbitrarily used a simple logarithmic curve, which:

> …is achieved by assuming that the maximum sustainable yield (MSY), by weight, of all commercial exploited fish stocks, lumped together, is somewhat more than the average recent annual reported catch taken to be 85.7 million tonnes in the ‘base year’…by an amount taking some account of estimates of Illegal, Unregulated and Unreported (IUU) catches and of fish discarded at sea for one reason or another; the MSY is assumed to be 95 million tonnes. Given the logistic curve this would be obtained when the total biomass was one half of the carrying capacity (the pre-exploited equilibrium level), which is taken to be 453 million tonnes (Holt, p. 4).

Holt calls these actual numbers into question, arguing that the pristine populations would be much larger than assumed, and that MSY thresholds are themselves arbitrary. He doubts that logistic or Fox curves, also called Pella–Tomlinson curves, accurately represent MSY, and if MSY can be inferred from catch data against projected models of pristine biomass as is done in the World Bank report and elsewhere.

Policy makers should think of Figs. 1 and 2 as heuristics to support a general proposition: the last of the fisheries that are fished below MSY (~15%) are small, global catch effort has been steadily rising, but global catch is gradually receding and the graph in the long run (decades) will likely go down. The resulting proposition is that that global fisheries are in the equilibrium phase of the cycle and is experiencing multiple synergistic disturbances in addition to fishing [3,43]. While this analysis cannot determine the likelihood, it is plausible to conclude that over the coming decades, *global* fisheries are in danger of moving through a catastrophic shift—that is, to a rapid and consequential new state where LMEs and the connections between LMEs are defined by new features than abundant extant fish.

None of this means that all hope is lost, because clearly many stocks can be rebuilt to produce more. Particularly older industrialized fisheries in North America, Europe, and Oceana have potential for rebuilding [44], but the *political* reality of rebuilding globally is grim. Indeed, “other parts of the world probably harbors higher but declining fish biomass on average, less control on exploitation rate, and less ability to set meaningful management capacity” [44]. Further, increased coastal fish scarcity has driven fishing to deeper and deeper waters [45] where some of these fish, such as deepwater demersal fish, are inherently more susceptible to depletion given life histories that include a long maturity time that allow for serial depletions [46] and the sustainability of these highly valuable fish is in question [47]. We are fishing harder and harder, deeper and deeper, expanding energy and building economic complexity that cannot possibly last indefinitely.

Thus, the literature appears to support the proposition that 1) fisheries exist as a series of nested adaptive cycles and 2) that the disturbance to the world oceanic systems continues to intensify and scale-up across LMEs. If the world fisheries can be plausible described as a panarchy, then it is theoretically possible that the world fisheries can and will follow the cycle phases. If world fisheries have entered the K phase, and if exploitation of the system continues unabated then the global fisheries system can cross a threshold or tipping point and enter rapidly into the collapse phase, Ω. This tipping point would be a point at which there is no return to the old system, and the current world fishery system would enter into a “catastrophic shift” or state change [18]. The defining features of alternative states are unpredictable, but it is implausible that it would be one of richer and more abundant

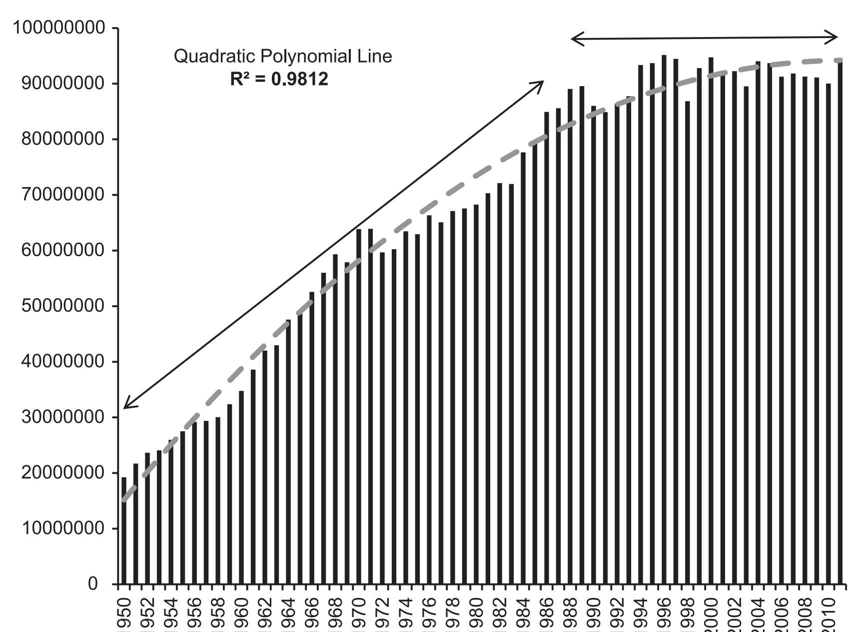

Fig. 2. Global fishery panarchy growth–equilibrium curve.

fisheries, at least at first until new speciation was able to be realized over thousands of years.

4. Discussion

What is known about the potential for global fishery collapse? First, it is plausible that world fisheries are a global panarchy. This single global panarchy is made of subsidiary adaptive cycles that include fish populations and the marine ecosystems up to the planetary level, where stress on the ocean continues to scale up by moving up and across larger and larger scales to the point where stress across LMEs has been observed. For regional fisheries, Litzow et al. [2] show that spatial variability in fish catch may portend a looming collapse within four years. Catastrophic shifts may be predicted, if not precisely, by variability in basic conditions [48], which means global variability of basic marine conditions is a matter of critical future research. However, we cannot wait for more information to act prudently to protect the planetary fishery and World Ocean. We already know that most if not all the indicators of ocean health are going the wrong direction[e.g., [3]], and that the entire marine world is bending toward more and more vulnerability [see [49] for a good discussion]. These indications are ominous for the future of the World Ocean regardless of the immediacy, practicality, or likelihood of a global fishery collapse. Productivity in the oceans clearly *can* be rebuilt and has been rebuilt in areas [50], but the facts on the ground indicate an increasing set of synergistic pressures that are everywhere increasing making the WOS more vulnerable to ecosystem and population collapses at various scales. Ecosystem services of the WOS system are clearly in jeopardy [51], and these threats are increasing in scale. Global fishery collapse is plausible, and the trends of important variables in the ocean continue to make something so heretofore unthinkable more, rather than less, likely.

5. Conclusions: policy making and international action

The most important conclusions for policy makers, then, have been made before [see for example [1]]. For example, stressors that make fisheries more vulnerable across scales must be scaled back through strategic reductions in fishing effort and all the forms of pollution, but heat and acidification in particular. Just how obvious these points are indicates just how robust and entrenched the problems of making these changes have been, or as Miles calls them "malign" problems—which are synergistic, nonlinear, problems for which cooperation is difficult to arrange [52]. Political economic forces, world political and international relations, increasing population, and scientific information problems have all increased the connectivity of these problems making them less resilient and less flexible. However, if increasing stress on global fisheries does not scale back, we can expect that the fish themselves may force the issue.

There is a good reason to contextualize fishery decisions into a global context using the framework of adaptive management, first discussed by Beverton and Holt [53], but has now been iterated and supported by many scholars [54–56]. Adaptive management operates under the condition of admitted uncertainty, multiple resources pressures, shifting resource dynamics using flexible decision making, learning, sensible monitoring, and collaboration [57]. Adaptive management has been used to varying degrees of success in fisheries, but what has not been done to date is to use a planetary model for fisheries and fisheries decisions. What this ultimately means that the consequences of fishery decisions in one place must be made with other fisheries and places in mind.

This could have several social and ecological benefits. Ecologically, important local stresses are connected to the functioning of distant ecosystem processes. Pollution is no longer simply a problem for the Gulf of Mexico, but one that is situated within a larger region of the Atlantic, and collapse of one species is understood to have cascading effects across the trophic scale—not just a local depletion of cod or mackerel or tuna.

Socially, if we think of fisheries as a planetary system, we are no longer confused why serial depletions in exploited areas push fishers to expand to deeper or more remote or otherwise historically less-exploited areas. From a policy perspective, were decision makers to be organized at varied scales, systemic action could stem the loss of livelihoods, resource exhaustion, and the social–ecological misery created for Ghanaians who no longer have fish because industrial trawlers simply moved from another area to their area as a matter of serial expansion [58]. Indeed, 80 percent of the world's fish production has moved to the global South, with much of this fish exported to wealthy nations of the North, endangering the South's food security and cultural integrity but organized through nearly impenetrable capitalist relations [see [10,59,60]]. If fisheries were organized under planetary priorities, the justice of fishing could more practically be addressed, whereas now the fisheries of the poor are essentially being looted by the rich countries, their subsidies, and the unaccountable fleets of roaming corporations looking to penetrate valuable areas that have yet to be simplified [61].

Fisheries are logically managed by geographic region typically as single stocks. This approach has the benefit of focus on small-scale changes. At the international level, regional fishery management organizations (RFMOs) manage high seas fisheries, as well as transboundary and highly migratory fisheries and fisheries that are outside the auspices of any single national authority. These organizations have had various successes, but sustainable fishery management does not appear to be one of them [62]. Cullis-Suzuki and Pauly [63] measured RFMO effectiveness across 26 criteria with the average RFMO receiving failing scores—but more importantly, two-thirds of RFMO-managed stocks are depleted or overexploited. It is under these conditions that integrated goals for *global* fishery resilience make sense, and in this case it may make sense to take the propositions of a globally coordinated fishery governance regime proposed by Barkin and DeSombre seriously [22,64].

Further, fisheries already exist and are part of global commodity chains that are partly controlled by transnational corporations with global reach, a radical departure from the largely sustainable fisheries in the preindustrial period. All oceans are now being fished, with 10 × the effort (power) as in the 1950s, but fleets are only catching half the fish per effort of that time [65]. Lam and Pitcher [66] argue compellingly that this commodification, reaching back to the Roman Empire but severely intensifying in the industrial period, has transferred the value of living fish from the "value of relationships" embedded in ecosystems to the "value of things." This wholly instrumental and shortsighted type of value concretely encourages and reproduces unaccountable exploitation [67], and *this value system* has driven maladaptive and increasingly unsustainable fisheries. One problem, then, is that exploitation and commodification occur at the global level, but governance does not direct that scale. Thus, integrated goals for global fishery resilience would make sense, and in this case it may make sense to think of a globally coordinated fishery governance regime proposed and advocated by Barkin and DeSombre [22,64]. A global governing system for fish will not automatically replace the value of live fish in ecosystems, but it is an opportunity to insert these ecosystem relationships because the point is to view fish as part of a larger integrated oceanic whole—the oceanic circle that Borgese [68] long argued was necessary for sustaining a living ocean, and therefore a living planet. Clearly, we have the institutional capacity to develop a global governance structure by developing a protocol based on the authority of the Law of the Sea. And, on a final but important note—it is my personal hope that such a protocol would include Indigenous leaders and groups as equals to States, because Indigenous groups around the world could really add a forceful voice that would be effective in placing limits on commodification [32,69–71].

References

[1] Global Ocean Commission. From decline to recovery—a rescue package for the global ocean. Oxford: Global Ocean Commission; 2014.
[2] Litzow MA, Mueter FJ, Urban JD. Rising catch variability preceded historical fisheries collapses in Alaska. Ecol Appl 2013;23:1475–87.
[3] Miles EL. On the increasing vulnerability of the world ocean to multiple stresses. Ann Rev Environ Resour 2009;34:17–41.
[4] Gunderson LH, Holling CS. Panarchy: understanding transformations in human and natural systems. Washington, D.C: Island Press; 2002.
[5] Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food security: the challenge of feeding 9 billion people. Science 2010;327:812–8.
[6] Kent G. Fisheries, food security, and the poor. Food Policy 1997;22:393–404.
[7] Pauly D, Watson R, Alder J. Global trends in world fisheries: impacts on marine ecosystems and food security. Philos Trans R Soc B: Biol Sci 2005;360:5–12.
[8] Coulthard S, Johnson D, McGregor JA. Poverty, sustainability and human wellbeing: a social wellbeing approach to the global fisheries crisis. Glob Environ Change 2011;21:453–63.
[9] Pauly D, Palomares M-L. Fishing down marine food web: it is far more pervasive than we thought. Bull Mar Sci 2005;76:197–212.
[10] Jacques PJ. Globalization and the world ocean. Lanham: MD: AltaMira/ Rowman and Littlefield; 2006.
[11] Willman R, Kelleher K, Arnason R, Franz N. The sunken billions: the economic justification for fisheries reform. Washington, D.C.: World Bank/United Nations Food and Agriculture Organization; 2008.
[12] Dyck A, Sumaila UR. Economic impact of ocean fish populations in the global fishery. J Bioecon 2010;12:227–43.
[13] Arnason R. Loss of economic rents in the global fishery. J Bioecon 2011;13:213–32.
[14] Jacques P. The power and death of the sea. In: Kütting G, Lipschutz RD, editors. Environmental governance: power and knowledge in a local–global world. New York: Routledge; 2009. p. 60–77.
[15] Berkes F, Kislalioglu M, Folke C, Gadgil M. Exploring the basic ecological unit: ecosystem-like concepts in traditional societies. Ecosystems 1998;1:409–15.
[16] Folke C. Resilience: the emergence of a perspective for social–ecological systems analyses. Glob Environ Change 2006;16:253–67.
[17] Folke C, Carpenter SR, Walker BH, Scheffer M, Elmqvist T, Gunderson LH, et al. Regime shifts, resilience and biodiversity in ecosystem management. Annu Rev Ecol Evol Syst 2004;35:557–81.
[18] Scheffer M, Carpenter S, Foley J, Folke C, Walker B. Castrophic shifts in ecosystems. Nature 2001;413:591–6.
[19] Walker B, Gunderson L, Kinzig A, Folke C, Carpenter S, Schultz L. A handful of heuristics and some propositions for understanding resilience in social–ecological systems. Ecol Soc 2006:11.
[20] Holling CS. Resilience and stability of ecological systems. Annu Rev Ecol Syst 1973;265:1547–51.
[21] Holling CS. Understanding the complexity of economic, ecological, and social systems. Ecosystems 2001;4:390–405.
[22] Barkin JS, DeSombre ER. Do we need a global fisheries management organization? J Environ Stud Sci 2013;3(2):232–42.
[23] Kleisner K, Zeller D, Froese R, Pauly D. Using global catch data for inferences on the world's marine fisheries. Fish Fish 2013;14:293–311.
[24] FAO. State of the world fisheries and aquaculture. Rome: Food and Agriculture Organization of the United Nations; 2012.
[25] FAO. State of the World Fisheries and Aquaculture. Rome, Italy: Food and Agriculture Organization of the United Nations; 2006.
[26] Jacques PJ. International regulation of ocean pollution and ocean fisheries. In: Denemark B, editor. International Studies Encyclopedia; 2010. p. 4437–56.
[27] Hilborn R, Walters CJ. Quantitative fisheries stock assessment: choice, dynamics and uncertainty/book and disk. Norwell, MA: Kluwer Academic Publishers; 1992.
[28] Karpov K, Haaker P, Taniguchi I, Rogers-Bennett L. Serial depletion and the collapse of the California abalone (Haliotis spp.) fishery. (Canadian Special Publication of Fisheries and Aquatic Sciences) (1). 2000; 11–24.
[29] Wilson J. Matching social and ecological systems in complex ocean fisheries. Ecol Soc 2006;11(1):9 URL:http://www.ecologyandsociety.org/vol11/iss1/art9/.
[30] Milich L. Resource management versus sustainable livelihoods: the collapse of the newfoundland cod fishery. Soc Nat Resour 1999;12:625–42.
[31] Acheson JM, Wilson JA. Order out of chaos: the case for parametric fisheries management. Am Anthropol 1996;98:579 (59).
[32] Jackson M. Indigenous law and the sea. Washington, DC: Island Press; 1993.
[33] Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, et al. Impacts of biodiversity loss on ocean ecosystem services. Science 2006;314:787–90.
[34] Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, et al. Biodiversity loss and its impact on humanity. Nature 2012;486:59–67.
[35] Stachowicz JJ, Best RJ, Bracken MES, Graham MH. Complementarity in marine biodiversity manipulations: reconciling divergent evidence from field and mesocosm experiments. Proc Natl Acad Sci 2008;105:18842–7.
[36] Reynolds LK, McGlathery KJ, Waycott M. Genetic diversity enhances restoration success by augmenting ecosystem services. PLoS One 2012;7:e38397.
[37] Chassot E, Bonhommeau S, Dulvy NK, Mélin F, Watson R, Gascuel D, et al. Global marine primary production constrains fisheries catches. Ecol Lett 2010;13:495–505.
[38] Blanchard JL, Jennings S, Holmes R, Harle J, Merino G, Allen JI, et al. Potential consequences of climate change for primary production and fish production in large marine ecosystems. Philos Trans R Soc B: Biol Sci 2012;367:2979–89.
[39] Garcia SM, Charles AT. Fishery systems and linkages: from clockworks to soft watches. ICES J Mar Sci: J Cons 2007;64:580–7.
[40] Garcia S. Ocean fisheries management: the FAO programme. In: Fabbri P, editor. Ocean management in global change. Amsterdam: Elsevier Applied Science; 1992. p. 381–418.
[41] Watson R, Pauly D. Systematic distortions in world fisheries catch trends. Nature 2001;414:534–6.
[42] Holt S. Sunken Billions—But how many? Fish Res 2009;97:3–10.
[43] Rogers AD, Laffoley D. Introduction to the special issue: the global state of the ocean; interactions between stresses, impacts and some potential solutions. Synthesis papers from the international programme on the state of the ocean 2011 and 2012 workshops. Mar Pollut Bull 2013;74:491–4.
[44] Worm B, Branch TA. The future of fish. Trends Ecol Evol 2012;27(11):594–9. http://dx.doi.org/10.1016/j.tree.2012.07.005.
[45] Morato T, Watson R, Pitcher TJ, Pauly D. Fishing down the deep. Fish Fish 2006;7:24–34.
[46] Cheung WW, Watson R, Morato T, Pitcher TJ, Pauly D. Intrinsic vulnerability in the global fish catch. Mar Ecol: Prog Ser 2007;333:1.
[47] Norse EA, Brooke S, Cheung WWL, Clark MR, Ekeland I, Froese R, et al. Sustainability of deep-sea fisheries. Mar Policy 2012;36:307–20.
[48] Carpenter S, Cole J, Pace M, Batt R, Brock W, Cline T, et al. Early warnings of regime shifts: a whole-ecosystem experiment. Science 2011;332:1079–82.
[49] Pitcher TJ, Cheung WWL. Fisheries: hope or despair? Mar Pollut Bull 2013;74:506–16.
[50] Worm B, Hilborn R, Baum JK, Branch TA, Collie JS, Costello C, et al. Rebuilding global fisheries. Science 2009;325:578–85.
[51] Millennium Ecosystem Assessment. Living beyond our means: natural assets and human well-being. Washington, D.C.: Island Press; 2005.
[52] Miles E. International regimes effectiveness: confronting theory with evidence. Cambridge, MA: MIT Press; 2002.
[53] Beverton RJ, Holt SJ. On the dynamics of exploited fish populations. Fishery Investigations Series 2: sea fisheries. London: MAFF; 1–533.
[54] Walters C. Adaptive management of renewable resources 9. New York: Macmillan; 1986.
[55] Walters CJ, Hilborn R. Ecological optimization and adaptive management. Annu Rev Ecol Syst 1978;9:157–88.
[56] Williams BK. Adaptive management of natural resources—framework and issues. J Environ Manag 2011;92:1346–53.
[57] Armitage DR, Plummer R, Berkes F, Arthur RI, Charles AT, Davidson-Hunt IJ, et al. Adaptive co-management for social–ecological complexity. Front Ecol Environ 2008;7:95–102.
[58] Sumaila UR, Pauly D. The "march of folly" in global fisheries. In: Jackson J, Alexander K, Sala E, editors. Shifting baselines: the past and the future of ocean fisheries. Washington, D.C: Island Press/ /Center for Resource Economics; 2011. p. 21–32.
[59] Campling L, Havice E, Howard PM. The political economy and ecology of capture fisheries: market dynamics, resource access and relations of exploitation and resistance. J Agrar Change 2012;12:177–203.
[60] Alder J, Sumaila UR. Western Africa: a fish basket of Europe past and present. J Environ Dev 2004;13:156–78.
[61] Hipwell WT. The industria hypothesis: 'the globalization of what?' Peace Rev 2007;19:305–13.
[62] Gjerde KM, Currie D, Wowk K, Sack K. Ocean in peril: reforming the management of global ocean living resources in areas beyond national jurisdiction. Mar Pollut Bull 2013;74:540–51.
[63] Cullis-Suzuki S, Pauly D. Failing the high seas: a global evaluation of regional fisheries management organizations. Mar Policy 2010;34:1036–42.
[64] Barkin JS, DeSombre ER. Saving global fisheries: reducing fishing capacity to promote sustainability. Cambridge, MA: MIT Press; 2013.
[65] Watson RA, Cheung WWL, Anticamara JA, Sumaila RU, Zeller D, Pauly D. Global marine yield halved as fishing intensity redoubles. Fish 2013;14 (4):493–503. http://dx.doi.org/10.1111/j.1467-2979.2012.00483.x.
[66] Lam ME, Pitcher TJ. Fish commoditization: sustainability strategies to protect living fish. Bull Sci Technol Soc 2012;32:31–40.
[67] Plumwood V. Environmental culture: the ecological crisis of reason. New York: Routledge; 2002.
[68] Borgese EM. The oceanic circle: governing the seas as a global resource. New York: United Nations University Press; 1998.
[69] Johannes R. Traditional marine conservation methods in oceania and their demise. Annu Rev Ecol Syst 1978;9:349–64.
[70] Lam ME, Borch T. Cultural valuing of fishery resources by the Norwegian Saami. Glob Ecol Integr Sci Int Law 2011;361:16.
[71] Ridgeway S, Jacques P. The power of the talking stick: indigenous politics and the world ecological crisis. Boulder, CO: Paradigm Publishers; 2013.
[72] Marten Gerald G. Human ecology: Basic concepts for sustainable development. London: Earthscan; 2001.