Opinion

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The future of fish

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Recently, the global state of marine fisheries and its effects on ecosystems have received much scientific (and public) scrutiny. There is little doubt that global limits to exploitation have been reached and that recovery of depleted stocks must become a cornerstone of fisheries management. Yet, current trends appear to be diverging between well-assessed regions showing stabilization of fish biomass and other regions continuing to decline. This divergence can be explained by improved controls on exploitation rates in several wealthy countries, but low management capacity elsewhere. Here, we identify an urgent need to direct priorities towards 'fisheries-conservation hotspots' of increasing exploitation rates, high biodiversity, and poor management capacity, and conclude that the future of fish depends, at least in part, on redoubling science, co-management and conservation efforts in those regions.

Fish for the future?

The sustainability (or not) of fisheries has been an important and controversial issue for more than a century [1]. The past 20 years, in particular, saw this debate move to a global level, because fisheries were recognized as a major driver of ecological [2–4] and evolutionary change [5–7] in all oceans. By the late 1980s, the global limits to exploitation were reached and possibly exceeded, with catches peaking at approximately 100–120 Mt, including unreported removals and discards [8–10]. A global fish production limit of 100 Mt had already been projected during the late 1960s, when catches were only approximately half of that level [11,12]. In recent years, a new debate has erupted over the direction of current trends in fish abundance and the prospects for recovery or collapse, given present exploitation regimes [13]. This debate is not merely academic, because it relates to global food security and biodiversity conservation issues. A key question is how to maintain fish production while ending overfishing and recovering depleted populations (or 'stocks' in fisheries parlance) and supporting ecosystems. Here, we examine the global state and future prospects of fisheries through the lens of different data sources. We analyze geographical differences in fishing trends, management capacity, and biodiversity, and highlight diverging trajectories between well-assessed and other regions. We also discuss management solutions that have been shown to help achieve sustainable fisheries.

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The current state of fisheries

Stock assessments

Part of the ongoing controversy around current trends in fisheries is explained by reliance on different data sources, specifically biomass estimates, stock status reports, and inference from catch data [14,15]. These data types can give different impressions about the status of fisheries, in part because they represent different stocks and emphasize different regional patterns. Several recent analyses of biomass trends were based on a new database of 331 formal fish stock assessments, the RAM Legacy (in honor of the late Ransom A. Myers) database [16]. Although this is the most comprehensive database on fish biomass trends in the world, there is an inherent spatial bias, in that 90% of those assessments currently come from North America, Europe, and Oceania, and only account for 20–25% of global catch. As of 2006, these data indicate stabilization of fish biomass at an average of approximately 32% of calculated 'virgin' biomass without fishing (B_0); this corresponds to approximately 92% of the average biomass level that would support maximum sustainable yield (B_{MSY}; Figure 1a) [14–16]. This pattern of low but stable biomass is explained by a long history of industrial fishing in the developed world, followed by declining exploitation rates in many regions as managers address a growing mandate towards long-term recovery, or 'rebuilding' in fisheries terminology [14,17]. Although declining exploitation rates have not yet shifted biomass from stabilization to recovery, approximately half of biomass-depleted fish stocks are expected to rebuild at least to the biomass that supports maximum yield, given present levels of fishing [14]. However, rebuilding prospects are more uncertain for expanding invertebrate fisheries, which tend to be poorly assessed [18], and for coastal and estuarine species, which face multiple pressures from fishing, pollution, and habitat degradation [19].

Stock status reports

A broader global viewpoint comes from average stock status trends of 445 large fish stocks monitored by the Food and Agriculture Organisation (FAO) of the United Nations (UN) [20], which we have translated into relative biomass units in Figure 1a. Taken together, these stocks currently produce approximately 80% of global catches. The FAO reports are more representative of the global picture, because they encompass a larger and more balanced sample of fisheries from both developing and developed countries. By contrast, they are less precise than are stock assessments because they rely on expert judgment for some regions. Although average biomass derived from

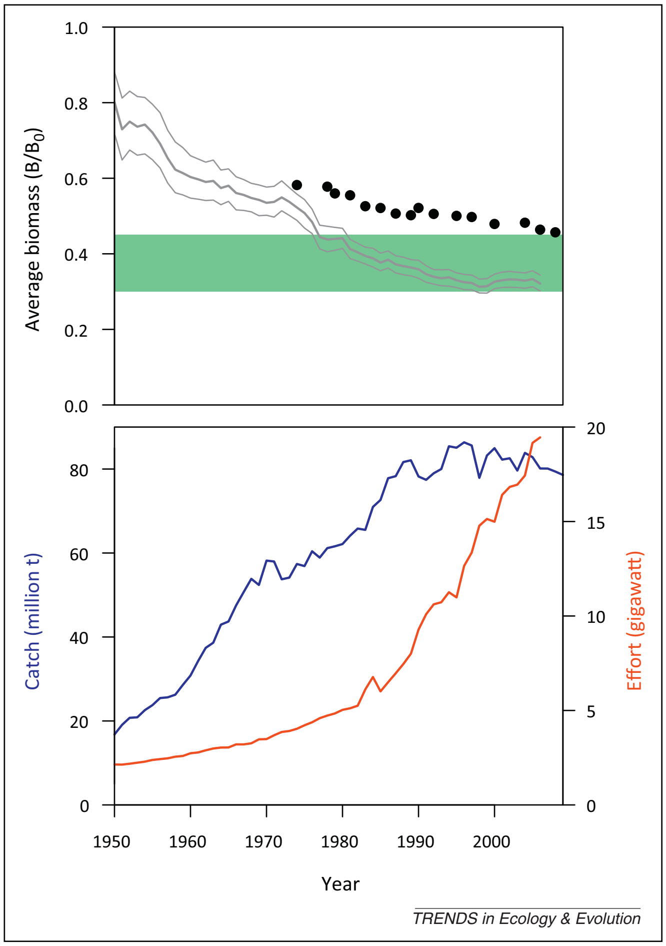

Figure 1. Global fisheries trends. **(a)** Estimated relative biomass of exploited fish and invertebrate stocks from available stock assessments (median and 95% intervals) and Food and Agriculture Organisation (FAO) status reports (circles, 95% intervals subsumed within). Biomass (*B*) is expressed relative to the calculated 'virgin' biomass without fishing (B_0) and the region of biomass typically associated with maximum sustainable yield B_{MSY} (0.30–0.45 of B_0, green-shaded area). **(b)** Increases in global catches (blue line, reported tonnage to FAO) and fishing effort (red line, total engine power in gigawatts, 10^9 watts, expended per year). Redrawn and combined from data in [15,20,21]. Stock assessment values in (a) were originally reported as biomass relative to B_{MSY}, and were converted to values relative to B_0 by assuming that $B_{MSY}/B_0 \cong U$ (0.24, 0.460) for spawning biomass estimates and that $B_{MSY}/B_0 \cong U$ (0.27, 0.56) for total biomass estimates, based on stock assessments for which this information was available. FAO stock status information was converted to biomass according to informal FAO criteria, that is, underexploited (0.8–1.0 B_0), moderately exploited (0.6–0.8 B_0), fully exploited (0.4–0.6 B_0), overexploited (0.15–0.4 B_0), depleted (0–0.15 B_0), and recovering from depletion (0–0.4 B_0). Conversions involved running 1000 Monte Carlo simulations, drawing values from these ranges for each stock, and calculating the overall mean and 95% intervals.

FAO status reports is higher than the average from stock assessments, it displays a continuous declining trend, rather than stabilization (Figure 1a). Using these data, the FAO estimates that only 15% of monitored fish stocks are low or moderately exploited, with the remainder being fully exploited (53%), overexploited (28%), depleted (3%), or recovering from depletion (1%) [20].

Global catch data

Analyses of global catch data (covering all species and regions) lead to more pessimistic conclusions (Figure 1b), as catches peaked during the mid-1990s and have since declined 9% below that level [9,20]. This occurred despite increasing fishing effort over the same time period [21]. Both the catch and effort data are subject to underreporting and data gaps [10,21]. Between 13% and 32% of global catch is unreported [10], and 8% is discarded [22], and effort data do not yet fully account for increases in fishing efficiency due to technology gains over time. Nevertheless, it seems probable that there has been a global decline in catch-per-effort that is also reflected in the declining FAO stock status trends. This suggests that the global situation is still worsening, on average, despite the stabilization in many assessed stocks and the regional rebuilding efforts discussed above. It also means that there is little room for future expansion of fisheries, both from an ecological and economical perspective. This view is reinforced by additional studies. Recent modeling work suggests that fisheries already harness more than 10% of primary production in most accessible areas [23], and economic analyses suggest that new fisheries will contribute little to global catch or value in the future [24].

Synthesis

Hence, the emerging global picture is one of increasing contrast between different parts of the world. In much of Europe, North America, and Oceania, fish biomass is currently stabilizing below sustainable levels, but reduced exploitation rates should promote rebuilding of biomass in the long term. The current status of these fisheries is poor, but future prospects are hopeful (with much variation across different stocks and management regimes [14]). The rest of the world probably harbors higher but declining fish biomass on average, less control on exploitation rate, and less ability to set meaningful management targets due to lower scientific and management capacity [25]. Many of these fisheries may still be productive, but future prospects are poor (except where comprehensive management solutions exist [26,27]).

This geographically diverging state of fisheries is not unlike what is observed on land. There, we see forest cover increases in heavily deforested regions across North America and Europe, driven both by rural-to-urban population shifts and increasing environmental concerns around land use [28]. Conversely, developing countries such as Brazil still have major forests (64% of land cover), but these are dwindling over time [28], although this trend is recently slowing due to a changing political and economic landscape [29]. Likewise, in the ocean, changing economic incentives and increasing environmental concerns may contribute to the rebuilding of previously depleted resources where appropriate governance systems are in place [14,30].

Capacity for science and management

A key problem in global fisheries is that much of the world catch, and a large fraction of its biodiversity, resides in regions that urgently require increased food production and employment, but that have little capacity for scientific assessment and management controls (Figure 2 shows this at the scale of large marine ecosystems, or LMEs [31]). For example, only one of the top ten fishing nations by volume (the USA) has comprehensive stock assessments available in the RAM Legacy Database [32] (others will hopefully be added over time). Although management capacity is good to fair for many industrial fisheries in Europe, North America, and Oceania, management capacity is lower on

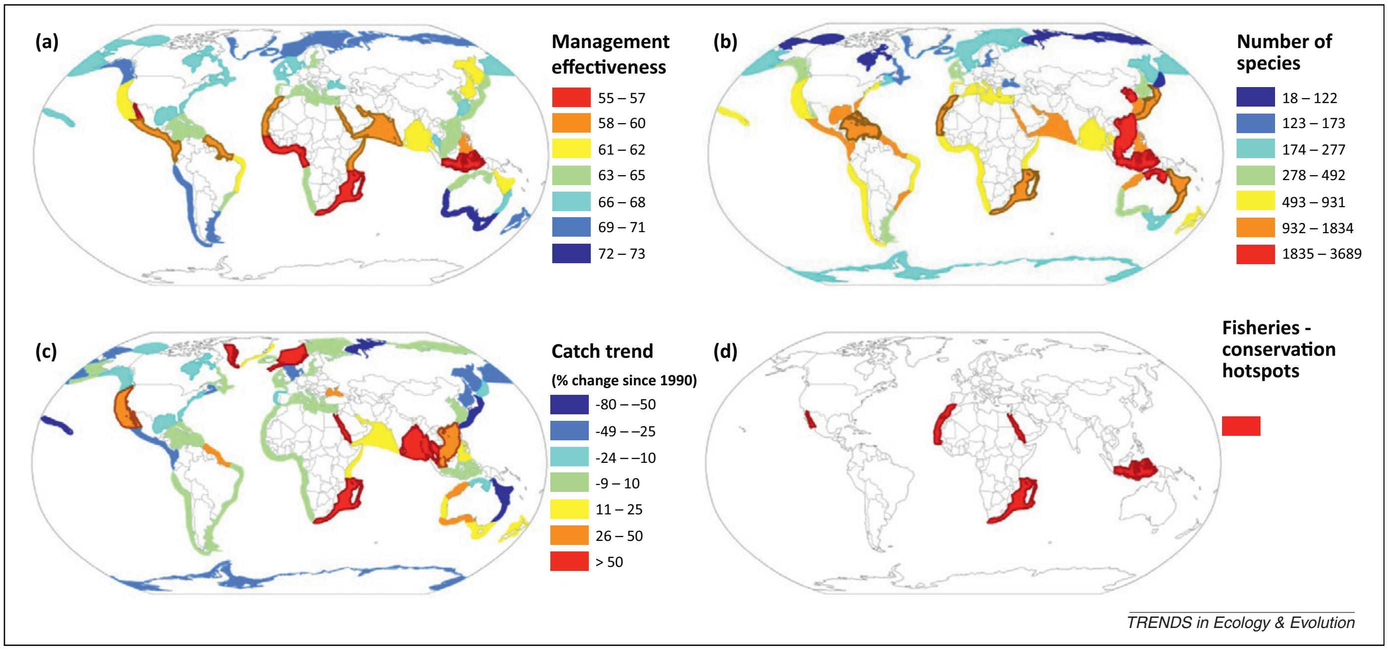

Figure 2. Fisheries-conservation hotspots across the large marine ecosystems (LMEs) of the world. **(a)** Average management effectiveness assessed from interviews with local fisheries scientists and managers (after [25], averaged across countries for each LME, ten lowest-ranking LMEs outlined in bold, note that LME-averaged results may not reflect well the management practices in individual countries). **(b)** Fish species richness (data from [51], top-ten cells outlined), **(c)** Regional catch trends 1990–2006 (catch data from the Sea Around Us Project website as described in [52], percent change from 1990–1994 to 2001–2006, ten fastest-growing cells outlined). Note that higher catches could reflect increasing fishing pressure or increases in abundance (particularly of small pelagic species that can fluctuate greatly). **(d)** Fisheries-conservation hotspots, here identified as LMEs with low average management effectiveness and simultaneously high richness or rapidly increasing catches, resulting in possible overexploitation of large numbers of species (this is for illustration; other variables could be used to identify hotspots).

average in much of Africa, Asia, and Latin America (Figure 2a). These regions also harbor most of the marine fish species richness (Figure 2b), and are hotspots of marine biodiversity in general [33]. It is also notable that many regions with poor management capacity report increasing catches (Figure 2c), and so deviate from the global average of slowly declining catches (Figure 1b). This supports the notion that some of these ecosystems are still productive, but exploitation rates are probably increasing and will lead to lower biomass over time, particularly in regions where the capacity to manage these fisheries is low. Conversely, declining catches in some regions (e.g., the northwest Atlantic and northwest Pacific, Figure 2c) may represent the effects of both lower productivity due to overfishing and reduced harvests to promote rebuilding [14]. One pressing concern is that improved management in parts of the developed world may not reduce global fishing pressure, but instead lead to a redistribution of excess fishing effort into other countries, where it is less well controlled [34]. Illegal fishing further exacerbates this contrast, because it is concentrated in the developing world and tends to be significantly correlated with low governance scores [10]. Hence, it appears that historical differences in fishing capacity and exploitation rates (high in industrialized countries and low in developing countries) are increasingly being reversed.

Importantly, in both developed and developing fisheries, good management does not require perfect science if precautionary measures are taken, and the goal of maximizing yields is abandoned [35]. A management strategy that aims at retaining higher biomass than what would be required for maximum yield ($B>B_{\text{MSY}}$) is more robust to scientific uncertainty, and has substantial ecological (more natural ecosystems and fewer species collapses) and economic benefits (higher catch-per-unit-effort and lower costs) [14,36,37].

A new focus

Based on the emerging global picture discussed above, we suggest that the future focus of fishery science and marine conservation might shift away from the already data-rich regions of North America, Europe, and Oceania. In our opinion, a pressing challenge lies in obtaining stock status and ecosystem-scale information for developing countries (for example, through local scientific surveys, better integration of existing databases, or via novel approaches of interpreting those data [38,39]), and in contributing to effective management solutions in places that we call 'fisheries-conservation hotspots' (Figure 2d). These hotspots are here defined as LMEs with low management capacity (for illustration, we chose the ten LMEs with lowest management scores, Figure 2a) combined with high biodiversity (Canary Current, Gulf of California, and Indonesian Sea LMEs) or large increases in catch levels (Red Sea LME) or both (Agulhas Current LME). These ecosystems also typically harbor rapidly increasing populations with high dependence on fishing for food and livelihoods [20]. Such conditions can promote so-called 'Malthusian Overfishing' [40], where immediate needs for food and income override long-term sustainability and the conservation of biodiversity. Another common factor among these hotspots is the prevalence of highly mobile foreign fleets, which may in part be driving increasing catches and exploitation rates [34].

Box 1. Solutions for fishing-conservation hotspots

There is now widespread recognition that successful management and conservation rely upon a combination of tools, and that these vary between large-scale industrial fisheries (often reasonably data-rich) and small-scale artisanal fisheries (often data-poor) [14,42]. Although industrial fisheries often rely on science-based management measures that require strong enforcement (typically a combination of catch, effort, and area restrictions), artisanal fisheries cannot be controlled the same way, due to lack of data, enforcement capacity, and a different social fabric. Here, natural resource users are often engaged in collaborative management arrangements, referred to as community-based co-management [26,27]. Although industrial and artisanal fisheries require different management approaches, they are often not independent, because they may pursue the same species, possibly at different life stages, or using different fishing gears. Competition between these fleets is common and needs to be incorporated into an overarching management strategy.

Many regulators, including the FAO, are now favoring an EAF, which explicitly recognizes such ecological and socioeconomic linkages at the ecosystem scale [47]; sometimes this involves reviving pre-existing (precolonial) management approaches that may already involve adaptive management measures and an ecosystem approach [48,49]. Although there is no universal formula for success, the establishment of some form of local fishing rights is often a key element, for example through so-called 'TURFs' (Territorial Use Rights in Fisheries) implemented across hundreds of fishing communities (Figure Ia) on the coast of Chile [50]. Access to benthic shellfish resources including a high-value gastropod, *Concholepas concholepas*, was partitioned spatially; this replaced an ineffective system of individual quotas, and allowed a previously collapsed resource to recover in many (but not all) areas. Another aspect of spatial management includes protected areas (Figure Ib), which combined with the banning of unselective fishing gear, helped rebuild reef fish populations in parts of Kenya [41]. These two measures, combined with limited access to fisheries, reversed 'Malthusian overfishing', led to recovery of fish populations, and improved livelihoods for fishermen [41]. A key prerequisite of co-management initiatives is the engagement of the local community in management and conservation efforts [26,42], starting with the youngest stakeholders, for whom the future of fisheries is most important (Figure Ic).

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Figure I. Case studies. **(a)** Establishing local fishing rights across 14 000 fishermen engaged in the Chilean *Concholepas concholepas* fishery. **(b)** Peacock grouper (*Cephalopholis argus*) thriving in a Kenyan protected area. **(c)** Childhood education forms part of a community-based management initiative in Raja Ampat (Indonesia), which includes some of the most biodiverse reef systems in the world. Images reproduced, with permission, from Ana Parma (a), Tim McClanahan (b), and Sterling Zumbrunn (c).

Solutions to the fishery crisis

How can the fishery crisis be solved in the hotspot regions that we identified? At present, a small but growing number of fisheries scientists and ecologists work in these hotspots; those who do often report surprising successes, albeit typically at local scales and using locally adapted management approaches (Box 1). These solutions often include community co-management [27,41], promotion of local fishing rights [42], and protected areas [35,41], among others. Co-management is a cooperative management process shared by fishers, regulators, and scientists. Recently, there have been several efforts to identify common features among successful (or unsuccessful) co-management schemes; these had to overcome the poor quality of the available data and the idiosyncrasies of individual management regimes [43]. Yet, despite these limitations, two global analyses of such local governance schemes recently concluded that co-management can be successful in safeguarding biological resources, while improving fishers' livelihoods and compliance [26,27]. One study that included both tropical and temperate regions found that strong leadership and social cohesion, combined with a system of fishing quotas and protected areas, was most likely to improve management success [27]. Another study that focused on tropical reef fisheries concluded that the exploitation status of co-managed fisheries is most strongly affected by access to markets and levels of dependence on marine resources [26]. Realistically, it can be difficult to implement management measures in regions that suffer from severe poverty and lack of alternative livelihoods, because these conditions can create sociological 'traps' that minimize long-term sustainability [44]. Therefore, poverty alleviation measures (such as microcredits [45]) that help reduce dependence on marine resources and enable alternative livelihoods can be important in transforming fisheries in these regions [26]. In addition, the control of foreign and illegal fishing is also necessary to limit exploitation rates, and to allow local people to benefit from their own management and rebuilding efforts [34].

Concluding remarks

Here, we have argued that the current state and future prospects of global fisheries diverge among different parts of the world, and that these trends should inform scientific priorities. In our opinion, fisheries science and marine conservation currently face two important frontiers. One is the study of recovery dynamics in regions with long histories of industrial fishing, some of which have recently reduced exploitation rates [30]. It will be interesting to see how depleted populations and communities respond to this perturbation; time lags and non-linear transition dynamics have been observed in some systems, and may alter the recovery trajectory of target stocks [30,46]. Also, ecosystem approaches to fisheries management (EAF) will require additional management measures, for example where non-target stocks and vulnerable habitats require further protection. Second, we argue for a large increase in the scale of research and capacity building in those regions where industrial fishing has had a shorter history, but where the fisheries-ecological crisis is becoming more acute. The particular 'fishing-conservation hotspots' that we identify in Figure 2 only exemplify such areas, clearly there may be others, depending on the specific criteria one might use (species richness, management capacity, catch or biomass trends, reliance on fisheries, poverty, and hunger, among others). However, independently of the exact criteria, we argue that these areas are of dual importance, both to the future of marine biodiversity and the future of fisheries. They harbor a large fraction of global marine biodiversity and many productive fisheries that are of importance to local people and their economies. These critical regions urgently require better data on their ecological status and trends, and the promotion of locally based co-management approaches and enforcement capacity to avert further overfishing and mismanagement.

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