Correction

OPINION

Correction for "Opinion: Governing the recreational dimension of global fisheries," by Robert Arlinghaus, Joshua K. Abbott, Eli P. Fenichel, Stephen R. Carpenter, Len M. Hunt, Josep Alós, Thomas Klefoth, Steven J. Cooke, Ray Hilborn, Olaf P. Jensen, Michael J. Wilberg, John R. Post, and Michael J. Manfredo, which was first published March 19, 2019; 10.1073/pnas.1902796116 (*Proc. Natl. Acad. Sci. U.S.A.* **116**, 5209–5213).

The authors note that, on page 5210, left column, Fig. 1, the estimate of recreational anglers for China, suggested to be roughly 90 million, is an underestimate. The number of recreational anglers in China is closer to 220 million based on statistics reported in ref. 1. The authors note further, however, that the updated number does not affect the assertions or conclusions in the Opinion piece.

1. China Society of Fisheries, The development report of China's recreational fishery. *China Fishery* **12,** 20–30 (2018).

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Governing the recreational dimension of global fisheries

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Fisheries provide food. In industrialized nations, the overwhelming portion of seafood comes from a small number of commercial fishers and increasingly aquaculture (1). Fisheries also contribute to leisure and recreation. In developed nations, 1 in 10 people fishes for pleasure, amounting to at least 220 million recreational fishers worldwide (2, 3)—more than 5 times the number of commercial capture fishers (1). This means that the vast majority of people fishing today do so recreationally (Fig. 1).

And yet, for too long, the considerable importance and impacts of recreational fisheries have been ignored. Policymakers and managers need to acknowledge and address the recreational fisheries sector, rethink management objectives and schemes, involve recreational fishers in decision-making processes, incentivize sustainable angler behavior, and improve data collection and monitoring. Recreational fisheries deserve to be considered on equal footing with commercial fisheries, particularly in mixed coastal fisheries.

For too long, the considerable importance and impacts of recreational fisheries have been ignored. Image credit: Florian Möllers (photographer).

Although commercial capture fisheries globally harvest about 8 times the fish biomass caught by recreational fisheries (4), in many localities recreational landings now rival or even exceed the biomass removals by commercial fisheries. In inland waters in the temperate zone, recreational anglers are now the predominant users of wild fish stocks (5), and recreational fishers have become prevalent in many coastal and marine fisheries (6, 7). Globally, recreational fishers catch about 47 billion individual fish per year, of which more than half are released alive (4), either because of harvest regulations or in response to personal ethics (8). Despite high release rates, fishing for food is a strong motive and justification for recreational fisheries (9). Beyond nutritional benefits, recreational fisheries provide a range of psychological, social, educational, and economic benefits to fishers and society that are not associated with commercial fisheries (5). Recreational fishers are also important for conservation by generating revenue for aquatic resource management and maintaining a connection of millions of people with nature and ecological processes (2, 3, 5) (Fig. 1).

A common belief is that recreational fishers, most of whom are anglers, have lower impacts on fish stocks and ecosystems than do industrial fishers (10). This might be

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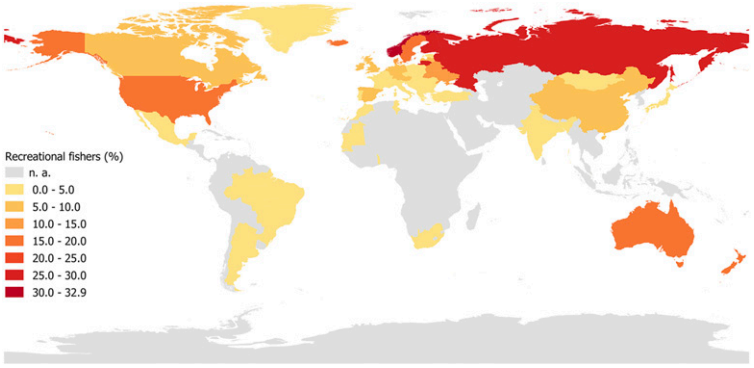

Fig. 1. Participation rates in recreational fishing vary across the globe. Data from ref. 3, updated.

true on a global scale and for certain types of impacts, such as habitat destruction caused by gear types used in commercial fisheries (e.g., bottom trawling). Yet conservation concerns are increasing in recreational fisheries (10–12). Modern anglers and other types of recreational fishers (e.g., spearfishers, household gill netters in Scandinavia) are well equipped, efficient at finding and catching fish, and mobile—linking regional and international ecosystems through tourism (13). Collectively, recreational fishers take a substantial fraction of fish from local fisheries, as well as from coastal areas traditionally dominated by commercial landings (6, 7), thereby contributing to a reduction in fish abundance and size to levels that are considered collapsed in some localities (11, 12).

Recreational fishers can also alter food webs through the selective harvest of predators, cause fishery-induced evolution, and contribute to habitat and wildlife disturbance (11). And they may facilitate the spread of nonnative organisms through stocking, introductions, bait release, and vessel movements among ecosystems (10, 11). These impacts augment other pervasive ecosystem pressures, such as habitat loss and climate change that threaten aquatic ecosystems, affect biodiversity, and reduce productivity (14). Social, political, and ethical conflicts within the angler community and among recreational and commercial fishers and other stakeholders (e.g., conservation groups, animal-rights activists) are increasingly common (15). For all these reasons, policymakers and managers worldwide must pay more attention to the often-ignored recreational fisheries sector.

Scarcity in Recreational Fisheries

Most recreational fisheries have no limit on the total effort that a fishery attracts; they are open access. This can result in high fishing mortality locally, as well as traffic and congestion problems. To avoid these outcomes, anglers' actions must be constrained and coordinated through regulations or collective action. Setting size-based harvest limits, season closures, or daily limits on what can be taken home for dinner—sometimes supplemented with more controversial strategies, such as stocking—are widespread management responses. These actions demonstrate that the benefits recreational fishers demand from fish stocks are often scarce. Otherwise, no management intervention would be needed nor demanded.

Scarcity in economic terms is not confined to fish. It extends to at least two other common-pool resources. The first is availability of fishing sites needed for a satisfying fishing experience. The second is fish catchability because the prevalence of catch-and-release angling and the preferential removal of bold, aggressive, or stress-resistant behavioral types select for timid fish, reducing the reactivity of fish to the gear (16) and further exacerbating the competition for the catch.

Common management actions used in recreational fisheries, such as setting of minimum-length limits or harvest slots, may succeed at avoiding recruitment overfishing (17) but do not necessarily foster broader notions of sustainability, solve stakeholder conflicts, or optimize angler well-being (18). In some mixed commercial-recreational marine fisheries, scarcity coupled with poor management has led to highly polarized resource management conflicts. For example, in the Gulf of Mexico red snapper (*Lutjanus campechanus*) fishery, demand for snapper trips outpaces their availability under the rebuilding quotas prescribed by managers (18).

Paradoxically, even as the fish population rebuilds, increasingly strict harvest regulations are required to keep the recreational catch below management targets because the influx of angling effort in response to a higher quality fishing experience outpaces improvements in the fish stock itself. This has led to a spiral of declining season lengths to a minimum of just a few days, strongly jeopardizing angler well-being by forcing diverse anglers to shift their preferred timing of fishing to a homogenous season—thereby increasing congestion—whereas other more time-constrained anglers may miss out on fishing entirely. This narrowing of access favors certain angler groups over others (e.g., summer tourists over locals) and constrains one of the most important factors of angler well-being: freedom of choice. In turn, this stokes sociopolitical conflict (18).

Relaxing harvest regulations may please many current anglers but at the cost of reduced opportunities for future anglers and possibly commercial fishers. Abbott et al. (18) suggest that improving recreational-fisheries management on a global scale could generate substantial social benefits of the same scale as reforming commercial fisheries.

Decision makers must determine how best to allocate access to fish and space among current users and between current and future users because quality fishing opportunities, and the fish stocks on which these are based, are often scarce. Yet, the currently used tools and procedures are often insufficient and demand reform, tailored to specific local and regional conditions.

Successful commercial fishery management paradigms, such as maximum sustained yield (MSY), cannot be directly transferred to recreational contexts (17). The reason is that anglers are more numerous, diverse, and diffuse than commercial fisheries. Importantly, recreational fishers are driven by a complex

set of catch- and non–catch-related motivations, many of which have nothing to do with a desire to reap maximum biological yield (17).

What constitutes a high-quality recreational fishing experience is personally defined and, thus, highly variable among people (17). Some anglers value the quantity of catch very highly, others care more about the opportunity to catch a single large trophy or they do not take any fish at all whereas still others prioritize non-fish attributes, such as solitude or experiencing nature (17). Thus, many anglers will continue fishing even on small stock sizes because a range of non-fish attributes maintains the attractiveness of fishing as a pastime (12, 17). Therefore, managing for MSY, as is typical in commercial fisheries, cannot be optimal for a large pool of highly diverse recreational fishers (17).

The diffuseness and large regional mobility of recreational fishers also create daunting challenges for the monitoring of catch and stock status, which is logistically and financially impossible in hundreds if not thousands of individual lakes and rivers in a landscape (12). Consequently, there is a widespread lack of data in recreational fisheries, necessitating management innovations that induce self-reinforcing feedbacks that demand little control and enforcement by agencies and do not necessarily rely on expensive stock assessments common to large-scale marine fisheries (13, 19).

Policy Reform for Sustainability

Tough allocation decisions cannot be avoided in recreational fisheries. These tradeoffs relate to (*i*) fish, (*ii*) fishing time, and (*iii*) site access. They extend further to the need to develop fishery-specific management responses to create diverse fishing opportunities from which a regionally mobile, highly diffuse, and heterogeneous group of anglers can choose based on personal preferences (13, 20). Experience from commercial fisheries suggests an effective, efficient, and equitable management is achieved by implementing management approaches that are robust to the behavioral feedbacks of fishers, relay signals of scarcity to harvesters, and provide incentive structures that align fishers' interests with fishery sustainability (19).

Current management systems often fail to create incentives for sustainable management of recreational fisheries. Individual anglers that buy the typical annual license do not experience constraints on individual effort or harvest. They thus receive little to no immediate benefit from limiting their personal take of fish because these resource investments may be quickly harvested by fellow anglers or commercial fishers. Moreover, under open access, anglers that induce more mortality, crowd more sites, or hook and release more fish do not bear higher costs than less impactful anglers. These powerful negative incentives are inconsistent with the scarcity of harvestable fish, the lack of vulnerable fish in catch-and-release fishing, and the often insufficient number of fishing sites needed to maintain high quality fishing for all.

The challenge for recreational fisheries is to shift away from the poor incentives created by one-size-fits-all harvest regulations, annual licensing, and widespread stocking in inland fisheries to policies and regulations that unleash virtuous incentives among a vastly more numerous population of highly diverse people. We offer five pragmatic steps for policy reform (Fig. 2), bearing in mind that it is impossible to address the full diversity of recreational fishing contexts. Nevertheless, our list offers general principles that are broadly applicable and, importantly, are substantially different from common practice.

First, policymakers and managers need to acknowledge the overriding recreational nature of most recreational fishing—fish are part of a multifaceted leisure experience, not primarily a source of food or personal income as in commercial fisheries. There is a need to move beyond dated paradigms, such as MSY, to manage recreational fisheries (5, 17). Countries such as the United States, however, continue to manage federal marine fisheries involving large recreational fishing sectors for MSY. A focus on bioeconomic management targets and models that measure the impact of policies on fishing opportunities and their quality as valued by anglers themselves provide a much-needed step in the right direction (17, 21).

Second, anglers must be better organized and involved in management processes. Although governance systems for recreational fisheries are in place in many developed nations, even wealthy countries struggle to integrate recreational fisheries effectively into the fishery policy and assessment system. For example, the European Union continues to keep recreational

Fig. 2. There are five essential tenets of policy reform for sustainable recreational fisheries (outer ring). And there are several supposed impacts on angler and manager incentives (inner ring). Recreational fisheries are quite diverse in terms of their motives, habitats, and impacts (center image). Image credit: Sign Art Studio.

fisheries largely unregulated and unmonitored within its Common Fisheries Policy. This leads to inefficient allocations, loss of human welfare, and heightened conflict. Angler organizations are key to the promotion of improved participation in management processes and monitoring. Incentives for involvement increase when angler interests are considered on equal footing with other stakeholders, such as commercial fishers. This promises to shift the incentive structure of angler organizations from defensive—mainly about securing access rights—to proactive, forward-looking, and cooperative attitudes to fisheries management and conservation.

In all cases, to be effective the quantity of recreational fishing privileges needs to be limited and consistent with biological management targets. This ensures that individual anglers directly pay for the public resources they consume.

For example, in freshwater fisheries, agencies could establish or support local-level angler organizations and proactively involve them in co-management schemes to design regulations that are tailored to local needs. We encourage decision makers to grant local angler organizations some level of management sovereignty (e.g., the right to decide about which harvest regulations to set), thereby increasing accountability and responsibility for management decisions (22). The experiences from the private fishing-rights systems in freshwater fisheries in Europe show that incentivizing anglers to get involved in local management can pay large conservation dividends at limited costs to the public (13, 22).

Third, a single fishery typically cannot satisfy the often-conflicting objectives of a heterogeneous group of recreational fishers (17, 20, 21). In lake-rich freshwater landscapes, independent populations of fish thriving in different ecosystems enable management for a diversity of fishing opportunities. Managers can strategically develop areas (e.g., different lakes) for particular fishing experiences by varying harvest regulations, access, stocking rates, size of stocked fish, etc. (13). Similar approaches are conceivable in coastal and reef fisheries focused on species with confined home ranges. Anglers can sort in space and seek those opportunities best matching their preferences (20), promoting a self-regulating system. Although some agencies have implicitly used this lakescape/seascape approach (23), this is seldom the explicit policy. The potential for a stabilizing portfolio effect of a diversified management scheme is, however, substantial.

Fourth, decision makers need to clearly signal to anglers, through the management system, that (*i*) the anglers are using a common-pool resource, which is depletable by the anglers' use and (*ii*) fish are a resource that must be invested in to safeguard sustainability. This applies particularly to fisheries that are under high pressure or are overfished, like the red snapper example shows (18, 24). Decision makers may want to use strategies that send unambiguous signals to individual anglers about the value of the fish they land or about the recreational experience itself. The signals may involve monetary or nonmonetary costs. For example, managers could limit access opportunities (e.g., caps on total licenses for a given water body, provision of restricted access points, or release of fishing day passes) or sell harvest privileges (e.g., harvest tags [24]) rather than continue to release annual licenses permitting individually unlimited effort/landings. Scarcity signals are especially clear when opportunities are tradeable with other potential users (e.g., access rights or harvest tags). The harvest tag option is well suited to quota-regulated or otherwise overfished environments with low discard mortality and where the primary impacts of fishing are through harvest. Rights to fish a specified amount of time (e.g., a fishing day or week pass) may be better attuned to fisheries with significant discard mortality or where regulating nonharvest fishing impacts (e.g., congestion or impacts on catch rates through fish-gear–avoidance learning) are important.

In all cases, to be effective the quantity of recreational fishing privileges needs to be limited and consistent with biological management targets. This ensures that individual anglers directly pay for the public resources they consume. These cost signals have two effects. First, anglers who are willing to invest enjoy the benefits, supporting economically efficient allocation. Second, those anglers that have a disproportionate impact on the stock pay the greater costs, internalizing the environmental costs of increased scarcity.

Although economic efficiency tends to favor price-based methods of allocation (i.e., auctions, retail sales of tags or passes, or resale of tags or passes), decision makers will also need to consider distributional aspects of new policies. Other means of allocation (e.g., allocation of harvest tags by lottery) may be judged more equitable but will likely come at the cost of reduced efficiency. Importantly, fishing day passes or harvest tags must not be so expensive to curtail access to the poor. The essential point is that tags or passes are limited (to safeguard biological sustainability where needed) and are allocated to those that benefit more. Clearly, harvest or catch tags are not a panacea, and alternative management tools may also lead to economic efficiency, which constitutes an important empirical research question.

Fifth, data collection and monitoring must be able to assess the status of recreational fisheries in hundreds to thousands of ecosystems and be used in communication with stakeholders and for assessment of policy effectiveness and social-ecological outcomes. Although complete and up-to-date monitoring information is an illusion given the diversity and number of fisheries, data-poor stock-assessment methods can provide suitable approximations (25). Mandatory catch and effort reporting in recreational fisheries complemented by scientific surveys and

assisted by novel technology, such as digital smartphone applications of logbooks and diaries to monitor catches and effort, would have the dual benefits of providing data and sending a signal to anglers that monitoring is also their responsibility to improve stock assessments and avoid invisible collapses (12).

Sustainable fisheries policy must consider recreational fisheries on equal footing with commercial fisheries. Recreational fisheries are a relevant and valuable component of regional, national, and global fisheries and in many areas need better governance and management. Existing or developing conflicts within and between fisheries sectors, as well as conflicts with conservation interests, must be acknowledged and addressed through better management. To that end, careful consideration and implementation of the five steps of policy reform (Fig. 2) can help put recreational fisheries on a trajectory that generates substantial benefits to recreational fishers and society more broadly while fostering ecological sustainability and minimizing conflict.

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