POLICY PERSPECTIVE

Life below water: Fish spawning aggregations as bright spots for a sustainable ocean

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Abstract
Transient fish spawning aggregations (FSAs) are critical life-cycle events for many commercially important species, in which fish congregate in huge numbers to spawn at predictable times and places. This behavior makes them exceptionally vulnerable to fishing. The “illusion of plenty” and poor access to monitoring tools and techniques has resulted in some FSAs being overfished or unwittingly eliminated. We present a co-conservation network, formally linking site-focused partners who cooperatively monitor and actively manage multispecies FSAs. FSA sites and networks offer great potential as conservation bright spots to replenish fished populations, rehabilitate marine ecosystems, and ensure the flow of ecosystem services to the millions of people that rely upon them for their wellbeing. We call for urgent global recognition of FSAs as effective spatial nexus for addressing multiple interconnected global policy targets for a sustainable ocean.

KEYWORDS
adaptive management, ecological monitoring, fish habitat, fish spawning aggregations, fisheries management, protected areas, sustainable ocean

1 INTRODUCTION

There are few more spectacular life-replenishing events below water than the mass migration of fish to very specific areas of the ocean where they aggregate in huge numbers to spawn (Figure 1). Fish spawning aggregations (FSA) occur at predictable times and locations. Seasonal, lunar, and diel cues govern the timing of FSA formation. FSA locations are typically associated with abrupt discontinuities in seafloor structure such as shelf edges, ridges, promontories, and channels where oceanographic conditions and connectivity to settlement habitat are suitable for the survival of sufficient progeny for populations to persist. These special places form a spatial nexus for reproduction often attracting multiple species to aggregate and spawn, sending pulses of eggs and nutrients cascading through complex food webs (Erisman et al., 2017; Heyman & Kjerfve 2008; Sadovy de Mitcheson et al., 2013). For the hundreds of marine fish species worldwide that aggregate for spawning, these events are critical to their future existence and for the millions of people that depend on coastal fisheries for food security and livelihoods (Sadovy de Mitcheson et al., 2013). Despite these important socioecological dependencies, FSAs and the species that rely on this reproductive strategy are fast becoming another tragedy of the Anthropocene. Here we contend that co-conservation networks of people and institutions using a blend of scientific and local knowledge to cooperatively monitor and actively manage networks of FSAs offers an effective and pragmatic approach to regenerate fished populations, safeguard marine biodiversity, and achieve sustainable fisheries. FSAs can be
considered “bright spots” where protection can accelerate progress towards global policy targets as defined by the Convention on Biological Diversity (Aichi Biodiversity Targets) in 2010 (https://www.cbd.int/sp/) and Life Below Water (Sustainable Development Goal [SDG] 14) of the United Nations General Assembly in 2015 (https://sustainabledevelopment.un.org/sdg14).

2 | FISH SPAWNING AGGREGATIONS AND THE ILLUSION OF PLENTY

Harvesting masses of large adult fish at specific locations and times seem indicative of healthy stocks, but these large catches at transient FSAs present a paradoxical “illusion of plenty.” Regardless of the overall population size, fishes may continue to form FSAs and catch per unit effort (CPUE) may be relatively constant over time. This condition is termed “hyperstability” and can mask population declines and cause unanticipated collapse of FSAs (Erisman et al., 2011; Sadovy de Mitcheson et al., 2013).

The illusion of plenty has plagued fisheries management for decades. For example, Nassau grouper (Epinephelus striatus) was among the most productive fisheries in many Caribbean nations as recently as the 1970s, but fishing at FSAs has resulted in 60% of the known Nassau grouper FSAs being eliminated. Nassau grouper is now categorized on the IUCN Red List of Endangered Species as “Critically Endangered” (Sadovy de Mitcheson et al., 2013) and classified as “Threatened” under the U.S. Endangered Species Act. At least 20 other aggregating species are at risk of extinction if current trends continue (Sadovy de Mitcheson et al., 2013). Worldwide, an estimated 30–40% of grouper and snapper aggregations are experiencing decline with a further 45–48% of unknown status and only 35% have some form of management in place (Russell et al., 2014).

Since the size of fish aggregations and variability in reproductive potential is often unknown, some fishers have unwittingly contributed to the marine ecosystem equivalent of asset stripping. In fact, FSA fisheries can very quickly become unsustainable in just a few years, or even months, of intensive fishing (Jupiter, Weeks, Jenkins, Egli, & Cakacaka, 2012). Fishing at FSAs inevitably removes large old fecund female fishes truncating the size and age structure of the population, a state not easily reversed (Hixon, Johnson, & Sogard, 2014; Barneche, Robertson, White, & Marshall, 2018). It is now clear that intensive fisheries targeting transient spawning aggregations are not sustainable.

3 | LINKING SCIENTISTS, FISHERS, AND MANAGERS

Increasing evidence suggests that collaborative community-centered partnerships supported by effective knowledge
exchanges and learning through social networks best supports societal transformations toward sustainability for small-scale coastal fisheries (Armitage et al., 2009; Gutierrez, Hilborn, & Defeo, 2011). This shift to community-led conservation and the challenges of implementing adaptive co-management usually requires diverse stakeholder participation including scientists (Armitage et al., 2009; Hamilton, Potuku, & Montambault, 2011; Heyman et al., 2019) and aligns with global sustainable development and biodiversity conservation policy recommendations for strengthening partnerships, capacity building including science/technology, and integrating local knowledge. In the case of FSAs, we recognize that fisher knowledge of FSA locations and the timing of aggregations is unparalleled and is the primary mode of discovery for nearly all FSAs (Johannes, 1998).

We propose a co-conservation partnership defined here as a community-centered, ecosystem-informed conservation strategy, involving close dialogue and working relationship between fishers, managers, and scientists (Heyman, 2011; Heyman et al., 2019; Kobara, Heyman, Pittman, & Nemeth, 2013). Such a co-conservation approach includes participatory monitoring and surveillance that integrates local knowledge with emerging scientific understanding and approaches, empowers fishers within the management process, and fosters voluntary compliance and sustainable fishing practices (Armitage et al., 2009; Gutierrez et al., 2011). These partnerships foster the co-creation of knowledge and the cooperative design of adaptive management strategies to sustain resilient fisheries and coastal economies.

4 | FISH SPAWNING AGGREGATIONS AS SENTINELS OF ECOLOGICAL CHANGE

Where overfishing occurs, well-documented and assessed fisheries tend to move toward sustainability more readily than unassessed fisheries (Costello et al., 2012). FSAs offer locations at which to efficiently and cost-effectively monitor the status and trends of fish populations whose geographic ranges often transcend entire regions (e.g., Nassau grouper whose range spans the wider Caribbean). We propose regional monitoring networks that link the efforts of fisher—scientist–manager teams to monitor the status and trends at key multispecies FSA sites and inform the development of effective site-based adaptive management plans and actions (Erisman et al., 2017; Hamilton et al., 2011; Kobara et al., 2013). These “sentinel sites” function as the information nodes for a regional monitoring network with the goal of restoring and sustaining populations across entire species’ ranges spanning multiple national jurisdictions (Figure 2).

Network partners use common monitoring protocols and indicators, standardized methods for biological sampling, and a suite of in situ remote sensing instruments and models to monitor and characterize the FSA conditions (Kobara et al., 2013). Harmonizing data collection and reporting will permit comparisons at single sites over time, among sites within regional networks and across regions. The data infrastructure will enhance knowledge exchange, permit status, and trends assessments (population structure, range shifts, changes in phenology), provide early warnings of ecosystem changes, and inform adaptive corrective actions. Long-term monitoring at locations where fishing communities have effectively removed or reduced fishing pressure on FSAs has shown that depleted FSAs can recover populations restoring ecosystem integrity and the flow of ecosystem goods and services (Aburto-Oropeza et al., 2011; Chollett et al., 2020; Hamilton et al., 2011; Kobara et al., 2013; Nemeth, 2005) (Figure 1). For example, a fisher—scientist–manager partnership in the Cayman Islands monitoring FSAs for 15 years found that Nassau grouper populations had tripled in response to conservation efforts (Waterhouse et al., 2020). In the U.S. Caribbean, average density and biomass of spawning red hind (E. guttatus) increased by over 60% within 5 years of a permanent fishery closure (44 km²) implemented through a partnership between fishers, local scientists and fishery managers (Nemeth, 2005). High rates of recovery can often be achieved with relatively small area fishery closures. In the Coral Triangle region, for example, regular monitoring of a small (<0.2 km²) community-based MPA located at a fished FSA revealed a 10-fold increase in grouper (E. polyphekadion) density within 5 years of closure (Hamilton et al., 2011). Although evidence globally is scarce, scientific monitoring at once extirpated FSAs reveals that some (17%) of these sites too can recover when fishery closures are effectively implemented (Chollett et al. 2020).

5 | FISH SPAWNING AGGREGATIONS, TRANSNATIONAL CONNECTIVITY, AND CLIMATE CHANGE

Connectivity models now recognize fisheries as “small-world networks” where a few key spawning areas (nodes) supply larvae to many regions thereby increasing the risk of disproportionately widespread impact to regional sustainability from disturbance to just one of these pivotal sites (Claro, Lindeman, Kough, & Paris, 2019). Countries in West Africa, the Caribbean, Oceania, and Northern Europe have been predicted to be most vulnerable to disrupted flow of progeny from FSAs located in waters under the care of other nations, making it critical to understand where these important sites exist and the nature of their interdependencies (Ramesh, Rising, & Oremus, 2019). Connectivity modeling, acoustic
telemetry, and seascape genetics will help understand regional dispersal and retention patterns, population resilience to disturbance, and efficacy of conservation measures (Munguia-Vega et al., 2014) and assess the recovery potential of extirpated FSAs (Chollett et al., 2020).

The geographic range of many tropical fishes is creeping poleward as a result of climate change. For those species that spawn within only a narrow thermal range, however, poleward shifts may limit the availability of suitable spawning and nursery habitat (Asch & Erisman, 2018). In addition, for tropical island-based spawning populations warming tropical waters may increase isolation with implications for resilience. The co-conservation network will provide a crucial observing tool and early warning system to monitor climate-induced changes such as shifts in species geographical ranges and the timing of reproductive processes. Data from the network will ensure that forecasting models can be trained and validated which in turn can be used by coastal communities in preparing effective adaptation strategies to mitigate the effects of shifting stocks.

**FIGURE 2** FSA co-conservation network. The elements and information exchanges in a co-conservation network of fishers, scientists, and managers to ensure information-based decision making for replenishment of FSA.

**6 | FISH SPAWNING AGGREGATIONS AS SPATIAL NEXUS FOR SUSTAINABLE OCEAN POLICY**

Despite the close connections between food security and fisheries productivity (Arnason, Kobayashi, & de Fontaubert, 2017), very few sustainable development strategies specifically focus on conservation of FSA (Claro et al., 2019). Our proposed FSA co-conservation network concept addresses this oversight recognizing that FSAs underpin a thriving ocean with important well-being benefits for coastal communities. The FSA co-conservation network has great potential to address multiple existing global sustainable ocean policy targets (Figure 3) and should now be considered as a key priority for the Post-2020 Global Biodiversity Framework where the Zero Draft’s action-oriented targets continue the momentum to “Protect sites of particular importance for biodiversity through protected areas and other effective area-based conservation measures, by 2030 covering at least [60%] of such sites” (CBD/WG2020/2/3, 2020). FSA sites are prime candidates for recognition for Areas of Particular Importance for marine biodiversity and ecosystem services and as Ecologically or Biologically Significant Areas since they are required for many fish populations to survive and thrive, provide significant ecosystem services, and are highly susceptible to degradation or depletion by human activity.

Relevant existing goals and targets include Target 6 of the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD) requiring all fish stocks to be sustainably managed and depleted stocks recovered by 2020. Aichi Target 11 aims to conserve, by 2020, at least 10% of coastal and marine areas, especially areas of importance for biodiversity and ecosystem services, through effectively and equitably managed, ecologically representative, and well-connected systems of protected areas. This area-based target for marine protected areas is likely to increase to 30% with 10% under strict protection (CBD/WG2020/2/3, 2020), although other effective area-based conservation measures
will be considered. In 2015, the 2030 Agenda for Sustainable Development introduced an ocean-focused SDG (SDG 14 Life Below Water) recognizing that conservation and sustainable use of biodiversity is key to sustainable development. By 2020, with regard to fisheries, Target 14.4 seeks to effectively regulate harvesting, and end overfishing, illegal, unreported, and unregulated fishing and destructive fishing practices and implement science-based management plans to restore fish stocks in the shortest time feasible.

FSA co-conservation has demonstrated success in reducing overfishing and unregulated fishing through strong community participation (Aburto-Oropeza et al., 2011; Erisman et al., 2017; Kobara et al., 2013). The use of local knowledge, community participation, knowledge sharing, and capacity building are recognized as key support mechanisms by the CBD Strategic Plan for Biodiversity 2011–2020. In support of small-scale fishers in developing countries, United Nations SDG 14 Target 14A and 14B seeks to increase the scientific knowledge, research capacities, and transfer of marine technology. Capacity building and knowledge exchange is a core function of the proposed FSA co-conservation network. Our multipartner community conservation network concept aligns with the shared empowering vision of the U.N. Conference on Sustainable Development 2012—The Future We Want (Resolution (66/288)), which recognizes that opportunities for people to influence their lives and future, participate in decision-making and voice their concerns are fundamental for sustainable development.

Furthermore, while transient FSAs are critical life-replenishing phenomena they can exist only through connectivity to other healthy areas. Identifying, safeguarding, and rehabilitating habitats that are critical to all life stages of aggregating fishes (i.e., nursery seascapes, migration corridors) will also be necessary. In the United States, fish-habitat linkages have long been recognized by the Magnuson–Stevens Fisheries Conservation and Management Act (1976) (NMFS, 2007). Similarly, the Food and Agriculture Organization recommends protection and rehabilitation of all critical fisheries habitat in the Code of Conduct for Responsible Fisheries (FAO, 2005). The long-term ecological performance and resilience of FSAs will likely be optimized where co-conservation activities are an important component nested within a broader ecosystem-based approach to marine management.

### 7 | BUILDING A COMMON VISION AND MAKING IT REALITY

We call for immediate strategic investments in building regional co-conservation networks for FSA fisheries to help effectively and rapidly address multiple interconnected global sustainable development policy targets. Relatively small investments in the protection and adaptive co-conservation of FSAs can offer disproportionately large benefits to ecosystems and the people that depend on this flow of services (Erisman et al., 2017). From a natural capital perspective, investors in sustainable ocean futures must recognize FSA sites as high-performing ecological capital of the oceans. Investment in FSA management offers strong, reliable
returns, making aggregation sites a sure bet for inclusion in any conservation portfolio (Erisman et al., 2017). We contend that large multispecies FSA sites should be treated as fish replenishment areas where co-conservation efforts can create ocean “bright spots” for restoring a thriving ocean for the benefit of all.

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