*Avoiding tradeoffs between global wild seafood production and seafloor impacts through fisheries innovation*

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Keywords: Seafloor disturbance; global impacts; trawl fisheries; maximum sustainable yield

Abstract

Wild harvested seafood is an important component of the global food supply, satisfying 8% of animal-based protein demands1. While challenges with overfishing remain, many of the world’s fisheries have reached sustainable levels of harvest. Recent global assessments2,3 indicate that many fish stocks are fished conservatively and may have capacity to increase harvest to meet an ever growing global seafood demand. Yet the benefits of fishery food production come at a cost of impacts to marine ecosystems. Trawls and other bottom-tendered gears, in particular, can cause reductions in the abundance of epifauna and other benthic structural habitat features that support marine ecosystem integrity. Consequently, mitigating benthic impacts is a key ecosystem consideration for maintaining sustainable fisheries. Here, we make the first estimate of global benthic habitat impacts from fishing and quantify tradeoffs between maximizing food production from the sea and the associated habitat impacts from increased fisheries effort. Globally, we estimate 8% of the world’s continental shelf seafloor (3.4 million sq. km of seafloor) is currently impacted by trawls and other bottom-tendered fishing gear. If bottom-tendered fisheries were managed to achieve maximum sustainable yield, we estimate global harvests from these gears could increase sustainably by 22% (9.1million mt of additional harvest), but at a cost of a 10% increase in the area of seafloor impacted (290,000 sq. km). These competing objectives necessitate an informed discussion about tradeoffs between seafood production and habitat impacts from fishing. Existing strategies to reduce habitat disturbance from fishing are dominated by approaches that either displace the problem elsewhere, as may be the case with marine reserves, or require directly reducing fishing effort, and thus seafood production. However, technological solutions that modify fishing gear or maintain high catch rates to reduce gear-seafloor interactions may provide an alternative means to overcome this impasse. We estimate that a global reduction in gear-seafloor interactions by 30%—an amount within the range of existing examples of bottom contact adjustments achieved through gear modifications—could mitigate the increase in habitat impacts associated with fishing that maximizes sustainable harvests from bottom tendered fisheries.

Introduction

Wild harvested seafood is a key component of diets throughout the world, accounting for 8% of all animal-based protein consumed globally1. Human population growth coupled with increasing per capita protein consumption is projected to increase global demand for protein by as much as 50% by 20504. Meeting this demand will require increasing production across multiple food sectors including wild harvested seafood. Although the annual harvest of wild seafood has remained relatively stable over the last several decades, recent global analyses have indicated that increasing global harvest may be achieved not only by improved management of overexploited stocks, but also by increasing fishing pressure on underexploited stocks2.

All food sectors must contend with environmental tradeoffs5, and habitat conversion associated with food production systems represents a primary threat to biological diversity globally6. Indeed, one of the most controversial environmental costs associated with wild capture fishing is disturbance to the seafloor from trawls and other mobile bottom-tendered gears (hereafter collectively referred to as trawls), which together account for 41% of all wild harvested seafood7. Seafloor impacts from trawls are well documented, from removal of epibenthic organisms to scattering of geological structural formations such as cobble piles, which provide refuge for marine organisms and may threaten the sustainability of wild harvested fish8,9.

Recent compilations of global fishing effort derived from the satellite monitoring Automatic Identification System (AIS)10 have provided a view of the global extent of fishing pressure on the seafloor. These data have been interpreted to show that the total footprint of all fishing activity from 2013 - 2016 covered up to 55% of the world’s oceans10. However, there are limitations when estimating the scale of seafloor impacts from the global fishing effort footprint. First, the potential for seafloor impacts is dominated by bottom-tendered trawl and dredge fishing, whereas pelagic fishing activity results in little or no contact with the ocean bottom. Second, typically only specific components of a bottom trawl’s gear touch the seafloor such that the contacted area associated with a trawl event is less than its total swept area path11. Third, the organisms and geological features that create habitat structure on the seafloor demonstrate varying degrees of susceptibility to contact and capacity to recover from damage or removal12. Thus, estimating disturbance to the seafloor – defined here as the areal extent in which benthic features have been damaged or removed by trawling and not yet recovered to pre-trawling levels – requires a dynamic impact and recovery model that incorporates both habitat specific vulnerabilities and gear characterisitcs13.

Minimizing seafloor disturbance is a high priority for many of the world’s fishery management bodies (e.g. 14,15) and a prerequisite for maintaining ocean ecosystem integrity8. Marine reserves have been the primary tool to meet this objective. While marine reserves have demonstrated successes, especially when protecting highly vulnerable seafloor habitats, they have limitations. In many cases, fishing effort is displaced elsewhere, such that marine reserves may not achieve success without other corresponding policies to reduce effort, such as reducing total allowable catch16. But as global demand for protein mounts with increasing human population, reducing fishery harvest to reduce seafloor impacts from fishing may come with tradeoffs in environmental impacts associated with producing substitute protein from other food systems, such as terrestrial crops or livestock. One means to avoid this tradeoff between benthic habitat impacts and foregone fishery harvest is to minimize seafloor disturbance by reducing gear-seafloor interactions – a direct solution that may be met through gear modifications to reduce bottom contact from fishing, or increases in catch efficiency that maintain harvest rates but with less expended effort.

Here, we quantify seafloor impacts from fishing and explore options for navigating seafood production and environmental impact tradeoffs. We first assess the areal extent of global seafloor disturbance by trawling activities using a dynamic impact and recovery model13, stratifying the analysis by large marine ecosystems (LMEs). We then use a catch-only stock assessment model to evaluate the potential for sustainable harvest increases from trawl fisheries globally and within LMEs to meet growing protein demands, and estimate the increase in seafloor disturbance associated with increasing fishing pressure to achieve maximum sustainable harvest under business as usual fishing practices. Finally, we demonstrate how innovations in fishing gear technology and/or improvements in capture efficiency may reduce the effects of trawling on the seafloor and help mitigate the habitat cost of global fishing.

Results/Discussion

We used a dynamic benthic habitat impact and recovery model13 and time series of AIS-derived fishing effort data through 2018 to estimate the current scale of global seafloor disturbance (Fig. 1A), finding that total global seafloor disturbance from trawls was 3.4 million km2 (8% of the world’s continental shelves). This estimate includes upward adjustments for ten LMEs which were identified to have low AIS coverage of their trawl fleet based on their significantly low relationship between trawl harvest and fishing effort (see Supplemental Material). The distribution of seafloor impacts from trawling varied widely among LMEs. Seven of the world’s 66 LMEs had no substantive bottom trawl activity, however, among the remaining 59 LMEs with bottom trawl fisheries, seafloor disturbance ranged from a low of 0.2% (Hudson Bay) to a high of 45.9% (Celtic-Biscay Shelf) of shelf area. Mid- and high-latitude LMEs in the Northern hemisphere, excluding those in the Arctic, generally had higher levels of seafloor disturbance than low-latitude and Southern hemisphere LMEs. The highest concentrations of LMEs with high disturbance (>25% of shelf area were in European waters and Eastern Asia waters. Arctic and Antarctic LMEs had relatively low levels of disturbance (<5%) with the exception of the Barents and Norwegian Seas (Arcitc LMEs), which we estimate to have >10% seafloor disturbance.

This disturbance to the seafloor is an environmental cost of harvesting ≈40 million mt of seafood (including both reported and reconstructed catches)7 from the world’s oceans each year by bottom trawls. Globally, this amounts to 11.9 mt of seafood harvested per km2 of seafloor disturbed, though the efficiency of this tradeoff is highly variable among LMEs (Fig. 1B). Recognizing that terrestrial land use for food production poses ecological consequences that differ substantially from those incurred from seafloor disturbance, comparisons of habitat impact – protein production tradeoffs among key animal production systems provides insight into the opportunity cost of foregone wild capture fisheries production. The edible protein yield of seafood averages about 11% of live weight of fish caught17 resulting in an average of 1.3 Mg edible protein harvested per km2 of seafloor disturbed for bottom trawl fisheries annually?. This compares to average beef production yields of 0.41 Mg edible protein km-2 of land for pasture and cropland for feed, and 11 Mg edible protein km-2 of land for cropland for pork and poultry production18.

As the human population grows to a projected 10 billion people over the coming three decades19, pressure will mount to increase production across food sectors to meet protein demands. Using a catch-only stock assessment model to evaluate current exploitation rates of bottom trawl fisheries20, we found that over 80% (1,192/1,430) of bottom trawl-caught stocks are currently harvested at rates below that associated with maximum sustainable yield (MSY; see Supplemental Material) and thus global trawl harvest has the potential to sustainably increase by 9.1 million mt year-1 – a 22% increase over current harvest levels. In four LMEs, bottom trawl fisheries as a group are currently overfished and would require reductions in effort to achieve MSY, presenting opportunities to simultaneously increase harvest and reduce seafloor disturbance. However, increasing catches in most LMEs would require additional fishing effort (Figure 2). Aggregating across all assessed stocks, net global bottom trawl fishing effort would need to increase 45% under current catch rates, adding over 8 million additional hours of fishing to the world’s oceans each year. Under an assumption that this increase in fishing effort would be distributed comparably to past fishing effort, the cumulative effect on the seafloor would be proportionally less, increasing total seafloor disturbance by 10% (>290,000 sq. km) as fishing impacts overlap in space with already disturbed habitat21 (see Supplemental Materials).

While global bottom trawl fisheries have potential for significant increased harvest potential, increases in seafood from these resources will present an apparent tradeoff between accepting additional seafloor impacts across most LMEs, or alternatively, shifting this foregone harvest to land-based food systems to meet future protein demands. For example, to supply the 1 million Mg of additional protein harvested if MSY were achieved with beef-sourced protein would require an additional 2.4 million km2 of land devoted to pasture and agricultural land for feed; pork and poultry would require 90,000 km2 for of agricultural land for feed. However, it may be possible to avoid this impasse through innovations that allow trawl harvest to increase without incurring additional effects to the seafloor. Two approaches show promise in this regard. First, opportunities exist to modify fishing gears to reduce seafloor contact, while still maintaining catch performance. For example, a simple gear modification of attaching small spherical lifting ‘bobbins’ to the footrope of a bottom trawl has been demonstrated to reduce seafloor contact by up to 95% without significant effect on the catch efficiency of targeted groundfish11 (Figure 3). In other examples, novel trawl door designs have been used to dramatically reduce bottom contact of trawl gear components22 (Figure 3), and newly developed pulse trawls utilize electrical pulses to stimulate groundfish or shrimp into moving upwards for capture off the seafloor23. Second, policies or technologies that increase catch efficiency such that less effort is expended per unit harvest can reduce seafloor impact in attaining prescribed catches. By aligning economic incentives with long term sustainable fishing practices, dedicated access privileges based fisheries management has been demonstrated to reduce wasteful fishing practices and reduce fishing effort to achieve a given catch24. For instance, upon transitioning to individual harvest quota-based management, total days at sea for Nova Scotia offshore scallop decreased by 15 – 20%25.

Through innovative approaches to modify fishing gear or increase catch efficiency, it may be possible to significantly reduce the seafloor impact of bottom-tendered fisheries at seascape scales. Using our global dynamic impact and recovery model and aggregating across LMEs, we find that MSY harvest levels from bottom trawl fisheries could be achieved with no net increase in aggregate seafloor impact if trawl fleets were to employ gears with 30% less contact, increase CPUE increase by 33%, or combine both efforts in lesser extents (Figure 3). Regardless of future catch targets, innovations to reduce seafloor contact would be beneficial for reducing ocean ecosystem impacts from fishing under current harvest levels. For example, we estimate that fishing gear modifications that lead to a relatively small 10% reduction in bottom contact would lead to a global sparing of 136,000 km2 of seafloor disturbance, whereas a 50% reduction in contact—within the limits of existing successful gear modification experiments—would spare 782,000 km2 of seafloor disturbance across ocean shelfs.

While land use efficiency in terrestrial-based animal protein systems has continued to advance over the last half century26, we argue that fisheries innovations have progressed at a slower pace. Impediments to fisheries innovations are both economic and regulatory, however, solutions to catalyze progress may be available. The costs to research and implement new fishing technologies can be high, especially for undercapitalized fisheries but growing activity in conservation finance27 may provide capital to accelerate technological advances. Similarly, fisheries governance reforms that align economic incentives with reductions in seafloor impacts through individual habitat quotas may spur gear and fishing practice innovations among fishers28.

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