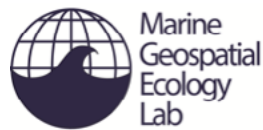


POLICY BRIEF

A review of the impacts of fisheries on open-ocean ecosystems

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Highlights

- There is a robust and growing body of evidence to suggest that fishing is one of the key drivers of ecological change in the open-ocean.
- Straddling and migratory stocks are particularly vulnerable to overfishing; with twice the rate of overfished stocks or those experiencing overfishing than stocks within national jurisdictions.
- Bycatch in open-ocean fisheries and the indirect impacts of abandoned, lost or discarded fishing gear have been implicated in the severe decline of fish, sea turtle, shark, seabird and marine mammal populations.
- Open-ocean fisheries have been shown to reduce pelagic biodiversity and ecosystem resilience.
- Fisheries have altered trophic relationships in open-ocean communities, generating trophic cascades that can lead to ecosystem-level impacts and regime shifts.
- The ecological impacts of open-ocean fisheries and climate change can act synergistically to induce profound transformations of ecosystem dynamics.

Background

Up until the 1960s, the open-ocean in areas beyond national jurisdiction (ABNJ) was one of the last frontiers of fisheries exploitation. The magnitude and inaccessibility of open-ocean ecosystems¹, as well as technological constraints, deterred fisheries from operating intensely in them. However, open-ocean fisheries expanded exponentially from the 1960s through the 1980s and 1990s, at which point global fish catches peaked, plateaued and possibly began to decline². While catches remain at best stagnant, fishing effort and all the ecosystem impacts associated with it, has continued to grow in areas beyond national ju-

risdiction³. Despite this rapid growth, ecological research in open-ocean environments has lagged behind coastal environments and limited our understanding of their dynamics and how they may be affected by anthropogenic stressors such as fishing.

Most fisheries impacts in coastal zones were well described by the turn of the century^{4,5,6}. Understanding of impacts on similarly static, deep sea habitats followed quickly^{7,8,9} and have been reviewed recently¹⁰. Conversely, impacts on open-ocean ecosystems (including all pelagic areas beyond national jurisdiction) have mostly been enumerated in the last decade and have yet to be aggregated in single assessment. Here we review the impact of fisheries on open-ocean ecosystems across three ecological scales: species, communities and ecosystems. In addition to examining the state of target species, we discuss effects on non-target species, how both of these impact open-ocean communities and ultimately how these trophic instabilities may affect the dynamics and functioning of the ecosystems themselves.

Species-level impacts on open-ocean ecosystems: Direct effects

• Much higher levels of overfishing and overfished stocks in ABNJ

Straddling and migratory stocks are particularly vulnerable to overfishing, mismanagement and IUU fishing given the difficulty of managing their entire range and ensuring the compliance of all parties that harvest such stocks¹¹. In 2011, the FAO estimated that straddling stocks were overfished or experiencing overfishing at a rate twice that of stocks within national jurisdictions (64% vs 28.8%)². Similarly, an assessment of the 48 highly-mobile fish stocks managed by the world's 18 Regional Fisheries Management Organizations (RFMOs) concluded that 67% of these were either overfished or depleted, all of which are open-ocean species¹². Specific examples abound: according to an international scientific committee (<http://isc.fra.go.jp>), Pacific bluefin tuna (*Thunnus orientalis*) have declined 96.4%. Other studies have indicated very strong (99%) declines for Oceanic whitetip sharks (*Carcharhinus longimanus*) in parts of their range¹³ and other predatory species in the Northwest Atlantic¹⁴.

• Bycatch threatens non-target species

The incidental capture of non-target species in fishing gear, or bycatch, can lead to unsustainable mortality on less productive species and represents a food security issue on a global scale. Bycatch in open-ocean fisheries can incur high bycatch rates and have been implicated in the collapse of many sea turtles¹⁵, seabirds¹⁶, marine mammals¹⁷, and sharks^{18,19}. For example, bycatch of Pacific loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) turtles in pelagic longline gear may have played a role in the severe (>80% and >95%, respectively) declines in the nesting populations of these species over 20–30 years^{20,21}. Further, all 22 species of albatross and 19 of 21 oceanic elasmobranchs are listed as at least Near Threatened by the IUCN with bycatch cited as the main threat^{16,22}.

• Discards can alter foraging behavior and trophic relationships

Species have learned to take advantage of discards, which can lead to the generation of new trophic relationships and alterations to community structure of the ecosystem²³.

• Increased variability in biomass of exploited species

Selective fishing for adults results in age-truncated fish stocks which magnify fluctuations in population levels and can ultimately contribute to stock collapses²⁴.

• Increased extinction risk

A recent report concluded that 36% of the 153 migratory or potentially migratory chondrichthyan fishes are threatened with extinction²⁵, where declines for species like the Oceanic whitetip shark (*Carcharhinus longimanus*) are thought to be as high as 99% in parts of their range¹³.

Species-level impacts on open-ocean ecosystems: Indirect effects

- **Contraction in species' ranges leads to change in community structure**

A recent study of the range-abundance relationship in exploited marine predators uncovered range contractions in 9 of the 13 species of tuna and billfish assessed²⁶. Reductions in the range of a predatory species may result in alterations of the trophic relationships and community structure wherever that predator has ceased to occur in high densities.

- **Decreases in body size affect trophic relationships**

Prolonged commercial fishing on open-ocean species may also lead to changes in the average body mass of the harvested species; a study in the tropical Pacific Ocean showed body mass reductions between 29–73% in 11 of the 12 predatory species assessed²⁷. This type of fisheries-induced evolution could also lead to earlier age and smaller size at maturation and reduced yields^{28,29}. Further, reductions in the average body size of a stock can decrease its reproductive potential, decrease recovery times and increase the variability of offspring survivorship³⁰.

- **Loss of genetic diversity can increase extinction risk, increase recovery time, and decrease adaptability to changing climates**

Another significant, yet more cryptic, threat these exploited target and non-target populations face relates to the loss of genetic variation³². This can be measured as loss of heterozygosity through targeted catch, which can reduce effective population size and augment the loss of genetic variation, or the loss of allelic diversity, which can compromise the ability of a population or subpopulation to adapt to future conditions and can also be induced through high rates of non-targeted exploitation^{32,31}. Moreover these fishing-induced genetic changes can increase the risk of extinction and decrease the rate of recovery of overfished stocks^{32,33}.

Community-level impacts on open-ocean ecosystems: Trophic cascades

In the last two decades, development of complex ecosystem models have allowed for the assessment of fisheries impacts on entire communities^{34,35}. A growing body of scientific literature acknowledges the role of top-down trophic processes in defining the composition and structure of pelagic marine communities and how marine fisheries may be triggering changes in these dynamics^{15,36,37,38}.

- **Removal of top predators leads to mesopredator release and changes in community structure**

A comparative study of the tropical Pacific pelagic community between the 1950s and 1990s found that during this period, the abundance predatory species declined severely by a factor of 10, while that of lower trophic level taxa was either maintained or increased; the same trend was also observed for the mean body mass of these lower trophic level taxa³⁰. Two such studies demonstrated how tuna fishing in the Eastern and Central North Pacific Ocean led to trophic imbalances in the biological communities where these operated, reducing the abundance of higher trophic level species which led to increases in the abundance of intermediate trophic level species, such as skipjack tuna, due to partial predatory release^{39,40,41}. Several other studies have similarly found mesopredator releases in oceanic systems as a result of declines in apex predator guilds^{42,43,44}.

- **There are also non-consumptive effects:**

Fishing-induced non-consumptive effects, such as changes in prey behavior, growth or development, are rarely considered and could play an important role in understanding the top-down control mechanisms in open-ocean systems, particularly given the changes in community composition caused by fishing⁴⁶. A known example is the foraging relationship between seabirds and tuna in tropical regions, where the feeding events by tuna facilitate the consumption of forage fish by seabirds in surface waters⁴⁵. Decreases in density or abundance of tuna may lead to decreases in foraging success for associated seabirds.

Ecosystem-level impacts on open-ocean ecosystems:

Changes at this level are mostly expressed as transitions between alternative states of the ecosystem, which affect both the system's dynamics and functionality; these are known as *regime shifts*^{46,47,48,49}. Ample evidence supports the claim that regime shifts are more likely to occur when the resilience of an ecosystem is reduced by actions such as the reduction of biodiversity, removal of functional groups of species or trophic levels from a biological community^{50,51}.

- **Reductions in biodiversity (species richness and density) reduces ecosystem resilience...**

Evidence suggests that the steep declines in abundance of oceanic species triggered by decades of intense commercial fishing activity, have reduced the biodiversity and altered the trophic configuration of oceanic marine communities; which are two necessary ecological components to ensure the resilience of marine ecosystems to stressors across different spatial and temporal scales^{52,53}. Over the last several decades the biodiversity, measured as species richness and density, of open ocean predators across all ocean basins has declined between 10 and 50%; these trends were correlated with increases in fishing pressure, while no trend was found between loss of biodiversity and decadal oscillations in oceanography during the study period (1960s-1990s)⁵⁵.

- **... and can lead to regime shifts in open-ocean communities**

Large, abrupt and persistent ecosystem-level changes in dynamics can be caused by the cumulative effects of fisheries-induced changes in the biological community and climatological alterations of the system⁵⁴. Two continuous state shifts described in the North Sea (1983-1993 & 1993-2003) involved a change in the control mechanisms for the pelagic stocks, from top-down (fishery) prior to the shift, to bottom-up (climatological) control⁵⁰. Ample evidence is also available from pelagic areas in large inland seas⁵⁵.

Other Considerations:

- **Interactions between climate change and fisheries impacts**

Several of the species-level impacts described above have been identified as factors that can lead to increases in the sensitivity of exploited species to climatic variability⁵⁶. Altering the spatial structure of species at the population or sub-population level can increase the sensitivity of the species to fluctuations in climatological conditions at different temporal scales⁵⁷. The removal of larger individuals truncates the age-structure of the population, which in turn can increase fluctuations in abundance and upset the spawning dynamics of the population as these are the most fecund and spatiotemporally widespread individuals^{58,60}. Thus, making spawning, larval recruitment and the population more vulnerable to fluctuations in environmental conditions. These implications extend beyond the species-level. Regime shifts induced by overfishing and climate variations⁵⁹ may change the control for pelagic systems from top-down to bottom-up mechanisms⁶⁰. Such shifts further increases the sensitivity of these systems to climate fluctuations.

- **Abandoned, lost or discarded fishing gear (ALDFG):**

The negative effects of abandoned, lost or discarded fishing gear (ALDFG), known as ghost fishing⁶¹, on marine fauna is of increasing concern as it can continue catching target and non-target species, including threatened or endangered species such as sea turtles⁶², sharks⁶³, and seabirds⁶⁴. Entanglement may occur as these groups feed or migrate⁶⁵. Ghost fishing is listed under the UN Code of Conduct for Responsible Fisheries as one of the most detrimental impacts of fisheries⁶⁶ and given its harmful and indiscriminate impacts, led, in part, to the closure of the high seas drift net fishery^{67,68}.

Conclusions

Given their life history characteristics, spatiotemporal distribution and form of management, straddling and migratory species are more vulnerable to overfishing. The severe declines in many of these stocks, and other species affected as bycatch, have caused reduction of their genetic diversity, contraction of their ranges and decreases in average body mass. Further, open-ocean fisheries alter the trophic relationships in open-ocean communities causing trophic cascades that modify the configuration and behavior of these systems and can lead to ecosystem-level impacts. Open-ocean fisheries have reduce the biodiversity and resilience of these ecosystems to other stressors like climate change. Impacts from fisheries can also act synergistically with climate change impacts and can induce profound transformations in ecosystem dynamics potentially resulting in regime shifts; a scenario which is not explicitly addressed in the existing management schemes for these systems.

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Acknowledgement

This policy brief is part of the Nereus Scientific & Technical Briefs on ABNJ series. The briefs are products of a workshop held prior to the 4th International Marine Conservation Congress in St. John's, Newfoundland (July-August 2016). The series includes policy briefs on 1) Area-based management tools, 2) Climate change in oceans beyond national jurisdictions, 3) Open data, 4) Tech transfer, 5) AIS data as a tool to monitor ABMTs and identify governance gaps in ABNJ fisheries, and 6) Impacts of fisheries on open-ocean ecosystems. These briefs were prepared for the second meeting of the BBNJ Prep Com. Further briefs will be prepared for upcoming Prep Com meetings. All briefs are available at nereusprogram.org/briefs. The briefs were organised by Dr. Daniel Dunn, Nippon Foundation Nereus Program Senior Fellow & research scientist in the Duke University Marine Geospatial Ecology Lab. Please contact daniel.dunn at duke.edu for any further inquiries. The workshop and coordination of the briefs was supported by the Nippon Foundation Nereus Program. All briefs are the product of the specified authors, not the organiser or Nereus. We thank them for their incredible generosity with their time and effort to inform this important process.