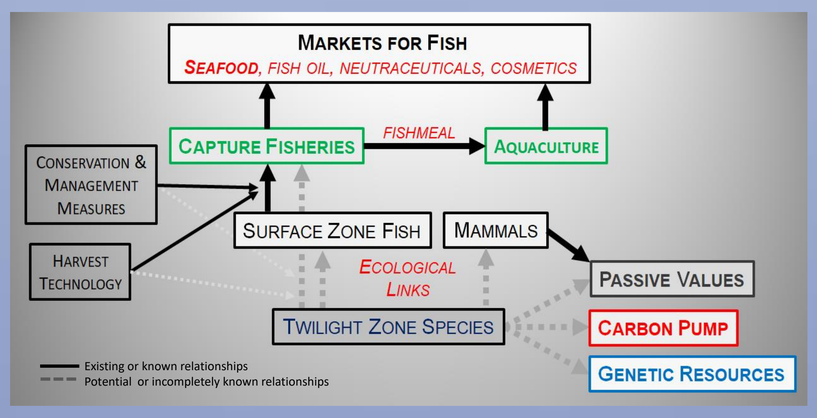
# Scaling the Benefits of and Risks to the Ecosystem Services of the Midwater


**Porter Hoagland and Di Jin**
Marine Policy Center
Woods Hole Oceanographic Institution
Woods Hole, MA 02543 USA


ICES CIEM — ICES Annual Science Conference 2018

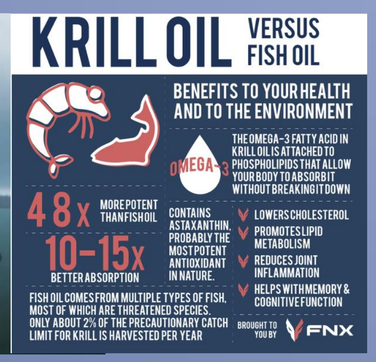
The midwater, or the "ocean's twilight zone" (OTZ), is renowned for its unusual life forms, including 13 species of bristlemouths, which are thought to be the most numerous vertebrates on earth. Irigoien *et al.* (2014) have raised the median estimate of midwater fish biomass by an order of magnitude to ~11x10$^9$t. Some observers have suggested that **these fish constitute an enormous potential source of protein that literally could "feed the world."**

Diel vertical migrations of zooplankton lead to the consumption of epipelagic phytoplankton, and the zooplankton, in turn, are consumed by the midwater's fish. **This ecological cycle comprises one central element of a "biological carbon pump" (BCP) that leads eventually to the very long-term sequestration of carbon** in deep waters or on the deep seabed. While the net amounts of carbon sequestered in this way are highly uncertain, estimates range between 4 to 12x10$^9$t annually.



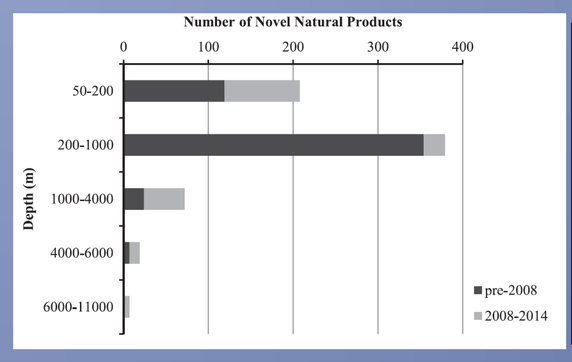

**The oceans twilight zone (OTZ) can be conceptualized as a stock of natural capital, subject to capital gains or losses, that may yield flows of benefits, termed "ecosystem services."** In any future period, the economic value of the natural capital is the discounted value of service flows and capital gains, where the discount rate is adjusted up (down) by removals from (additions to) the stock (Fenichel *et al.* 2016).

In this work, we have been focusing on developing estimates of the economic scales of flows of OTZ ecosystem services. **Understanding the benefits that are associated with these services is fundamental to assessing the opportunity costs of proposed activities that might mitigate those benefits, such as unregulated fishery exploitation or the effects associated with climate changes in the ocean**, including temperature increases, acidification, decreased dissolved oxygen levels, or shifts in biological diversity .


In September 2018, a formal international conference initiated work on a new international legally binding instrument (ILBI) under the law of the sea, focusing on the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction (the so-called BBNJ). **Despite a growing recognition by marine scientists of the importance of the OTZ, its ecosystem services were essentially ignored during the BBNJ's preparatory discussions.**

Here, we report on approaches to estimating the scales of the economic values of the midwater's ecosystem services and the nature of anthropogenic risks to those services. We conclude that identifying ecosystem services, assigning values to them, and assessing anthropogenic risks is still very much in its early stages. **An ultimate objective of our ongoing research will be to strengthen the links between emerging marine science, ecosystem services, and the international discussions over the conservation of the biodiversity of the high seas.**




The density of novel natural products by depth, showing the relative importance of the OTZ. **Scientific research on marine genetic resources (MGRs, one type of *provisioning service*) is nascent, but growing.** It is one major motivation for the BBNJ deliberations at the United Nations. Source: Harden-Davies (2017).

## Provisioning Services

Provisioning ecosystem services are the "products obtained from ecosystems, including: food, genetic resources, biochemicals, natural medicines, pharmaceuticals, or biological materials that serve as sources of energy" (MA 2005) . **Benefits:** undetermined, but commercial fishing interests have expressed interest in the potential exploitation of twilight zone fish for supplying fishmeal, neutraceuticals, or cosmetics. There have been several earlier efforts to exploit the OTZ fish biomass, specifically myctophids (lanternfish), as depicted in the global map below (from various sources), but most were abandoned eventually due to high costs and technical problems. **Risks:** the potential over-exploitation of resources that are not well-characterized. Further, because of the likely ecological linkages with apex predators in the surface waters, including tunas, billfish, sharks, squids, large whales, seals, and penguins, commercial exploitation could lead to unknown effects on predator stocks (see the discussion of Supporting Services below).

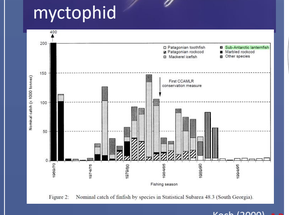
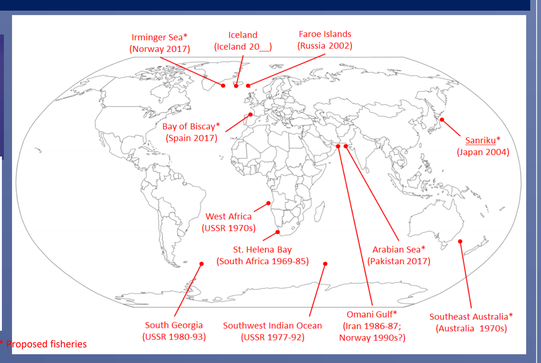




Figure 2: Nominal catch of finfish by species in Statistical Subarea 48.3 (South Georgia).

Koch (2000)




*Proposed fisheries

Commercial fisheries are regulated by coastal nations within their own 200nmi exclusive economic zones (EEZs), and to a limited extent on the high seas by regional fisheries management organizations (RFMOs), comprising cooperative management across interested fishing nations. Because of the midwater's depth boundaries, roughly from 200-1000m, **OTZ fisheries are likely to be located mainly on the high seas**, except for nations with narrow continental shelves, implying that their EEZs could encompass depths that lie within the OTZ. High seas fisheries have come under increasing international scrutiny, and both soft and hard law, including the UN Fish Stocks Agreement, have been adopted in attempts of varying effectiveness to curb overfishing.

Because the yields of fish from the high seas are small relative to world catches, supplying a relatively minor role in world food security (Schiller *et al*. 2018), some analysts have called for a moratorium on high seas fishing. The establishment of such a policy could yield significant benefits to EEZ fisheries, if the high seas serves as a refuge for stocks also caught in exclusive economic zones (EEZs) (White & Costello 2014), but it seems unlikely to be accepted by most countries of the world. **More pragmatic approaches may involve precautionary conservation and management measures, such as those adopted under provisions of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) for the exploitation of species like the Antarctic krill *Euphausia superba*.** Further, marine protected areas, established with the cooperation of multiple stakeholders, such as those recently adopted for commercial krill fishing in Antarctic waters, may be effective due to the likelihood that boundaries and fishing restrictions would be respected by industry (see the figure below right). Area based management measures on the high seas, such as MPAs, are now one central focus of the BBNJ deliberations at the United Nations.

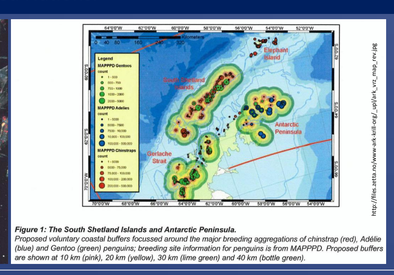



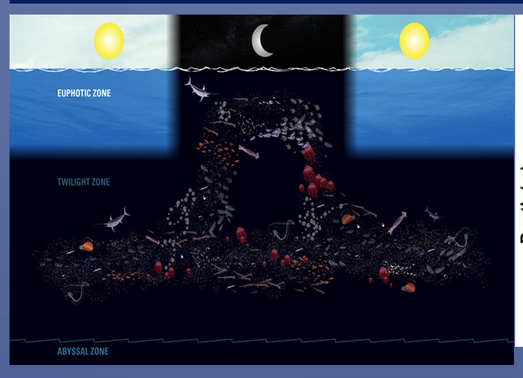

*Figure 1: The South Shetland Islands and Antarctic Peninsula.*
*Proposed voluntary coastal buffers focussed around the major breeding aggregations of chinstrap (red), Adélie (blue) and Gentoo (green) penguins; breeding site information for penguins is from MAPPPD. Proposed buffers are shown at 10 km (pink), 20 km (yellow), 30 km (lime green) and 40 km (bottle green).*

## Regulating Services

Regulating ecosystem services are the "benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases" (MA 2005). **Benefits:** there exist a wide range of estimates of OTZ ocean carbon sequestration, from 4 to 12x10$^9$t per year. Using a mid-range estimate of a "carbon price" of $30/t of CO$^2$ ($110/t of C) this regulating service benefits the world on the order of $400-1,300 billion each year. Using a social rate of time preference of 3%, the asset value of this service would range from $13-43 trillion. **Risks:** the ocean's carbon sequestration is threatened potentially by the effects of climate change in the ocean, leading to phenomena such as thermal stratification and acidification that could affect carbon fluxes to deep water. Further, the possibility of commercial fish harvests could affect the functioning of the biological carbon pump (BCP) in some locations in unknown ways.

The **biological carbon pump (BCP) sequesters organic carbon** in the deep ocean via marine organisms. Approximately 1% of the total particulate organic carbon (POC) produced by phytoplankton at the surface sinks to the ocean floor where it is considered to be sequestered permanently. Larger amounts are exported to the deep ocean where carbon may be sequestered for millennia (see the figure below right). Without the BCP, atmospheric CO$^2$ could be as much as 200ppm higher than today, making the ocean's carbon sequestration a critical ecosystem service.

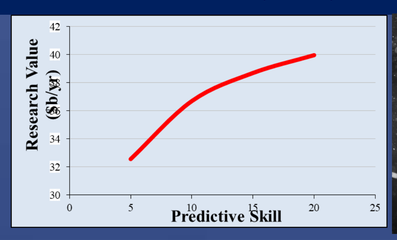
Global estimates of carbon sequestered by the BCP range from 4 to 12x10$^9$t per year. **Because of this wide range, the economic value of oceanographic research undertaken to reduce this range could be substantial.** With a more accurate estimate of ocean carbon sequestration, society could make better-informed decisions regarding the mitigation of CO$^2$ emissions.




Source: Buesseler *et al.* (2007)

Shah *et al*. (2018; unpub.) developed a Bayesian decision framework for estimating the value of oceanographic research in reducing the uncertainty surrounding the estimate of ocean carbon sequestration. This estimate depends upon both predictive skill and the scale of future climate-caused economic damages. **The authors' estimate of this value is on the order of tens of billions of dollars each year.** The estimated value is positively correlated with the level of uncertainty, but the authors found that increases in research investments to enhance predictive skill exhibited diminishing returns (see the figure below left).

Because improvements in predictive skill are likely to take place over time as observations are compiled and interpreted, an extension of the framework would model the benefits of increases in prediction accuracy as research advances and more knowledge is gained. Further, the potential economic damages from ocean acidification have not yet been incorporated into estimates of the carbon price, and these may be especially important to take into consideration with respect to potential climate change effects in the OTZ.

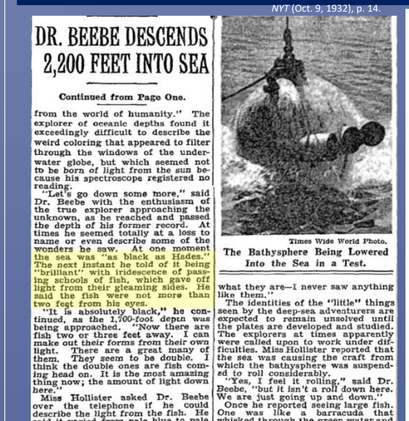




## Cultural Services

Cultural ecosystem services have been defined as the "non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, *e.g.*, knowledge systems, social relations, and aesthetic values" (MA 2005). **Benefits:** undetermined. **Risks:** lack of public knowledge about the OTZ; loss of the functioning of physical and ecological processes.

It seems farfetched, at present, to expect that the OTZ could be a locus for recreation, a direct, but likely non-intrusive use. **Social scientists would describe these other non-material benefits as "passive uses," and methodologies exist—but have not yet been applied--to estimate the "nonmarket" economic value of passive uses of the OTZ.** Such uses can be expected to grow in tandem with the development of scientific knowledge about the OTZ and its widespread dissemination.



*NYT* (Oct. 9, 1932), p. 14.

DR. BEEBE DESCENDS 2,200 FEET INTO SEA

Continued from Page One.

from the world of humanity." The explorer of oceanic depths found it exceedingly difficult to describe the weird coloring that appeared to filter through the windows of the underwater globe, but which seemed not to be born of light from the sun because his spectroscope registered no reading.

"Let's go down some more," said Dr. Beebe with the enthusiasm of the true explorer approaching the unknown, as he reached and passed the depth of his former record. At times he seemed totally at a loss to name or even describe some of the wonders he saw. At one moment the sea was "as black as Hades." The next instant he told of it being "brilliant" with iridescence of passing schools of fish, which gave off light from their gleaming sides. He said the fish were not more than two feet from his eyes.

"It is absolutely black," he continued, as the 1,700-foot depth was being approached. "Now there are fish two or three feet away. I can make out their forms from their own light. There are a great many of them. They seem to be double. I think the double ones are fish coming head on. It is the most amazing thing now; the amount of light down here."

Miss Hollister asked Dr. Beebe over the telephone if he could describe the light from the fish. He said it varied from pale blue to pale green—no deep tones.

"It must be from the normal luminescence of the creature," he said, sending a request to those above to be "lowered down further." At 1,750 feet there were dozens of lights all about the bathysphere; at 1,900 feet he reported it was "very brilliant—everything lit up."

At 2,000 feet radio listeners heard an order to stop the bathysphere. The adventurers took picture after picture of the strange denizens that flashed and flickered through depths that resemble a clear sky at night. The grinding of the camera as the explorers took their pictures was plainly heard over the radio and wire circuit linking the bathysphere with New York networks. Near the 2,000-foot depth Dr. Beebe told of seeing "loads of little—I don't know what they are—I never saw anything like them."

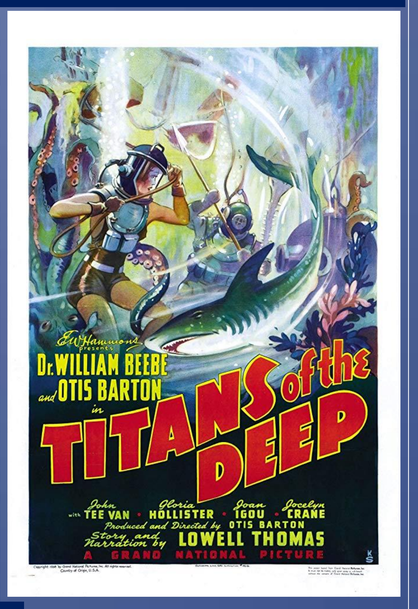
The identities of the "little" things seen by the deep-sea adventurers are expected to remain unsolved until the plates are developed and studied. The explorers at times apparently were called upon to work under difficulties. Miss Hollister reported that the sea was causing the craft from which the bathysphere was suspended to roll considerably.

"Yes, I feel it rolling," said Dr. Beebe, "but it isn't a roll down here. We are just going up and down."

Once he reported seeing large fish. One was like a barracuda that whisked through the green water and was off before a good description of it could be broadcast. At numerous depths Miss Hollister asked the scientist to report the condition of the "stuffing box," which is the watertight mechanism around the door through which the men enter or leave the sphere. Dr. Beebe generally reported promptly on most occasions, as failure of the stuffing box on a recent test lowering of the bathysphere allowed the sphere to fill with sea water. Temperatures were also taken frequently, registering around 70 degrees, Fahrenheit.

"Let's go down some more," Dr. Beebe repeated as the bathysphere neared the level where the broadcast ended. "You're on your way," said Miss Hollister as the creaking winding-gear on the vessel told of wheels turning to let out more cable.

Times Wide World Photo.
The Bathysphere Being Lowered Into the Sea in a Test.



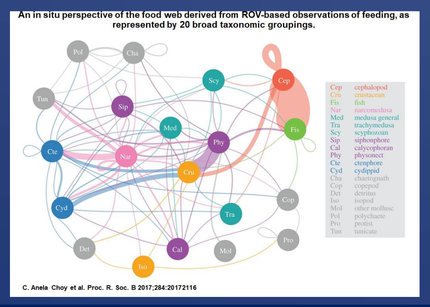

In the 1930's, William Beebe and Otis Barton descended to the OTZ in a bathysphere off of Nonsuch Island, Bermuda. The two explorers relayed observations back to their ship-based colleague, Gloria Hollister, and they also reported their experience live on NBC radio. A subsequent film, ***Titans of the Deep***, sought to capture the public's interest using a dramatic theme, but it was a commercial flop.


The more recent documentaries, *Blue Planet* and *Blue Planet II*, produced by the BBC Natural History Unit and presented by David Attenborough, have been more successful, receiving wide acclaim. Too, these productions have helped to spur ocean conservation efforts, including drawing attention to the fate of plastics as a form of ocean pollution. **Further, they have been linked to educational programs designed by the Open University, contributing to ocean literacy, a form of "engagement."** The public's demand for such productions and programs can be viewed as a rough measure of the value of the OTZ as a cultural ecosystem service.


## Supporting Services

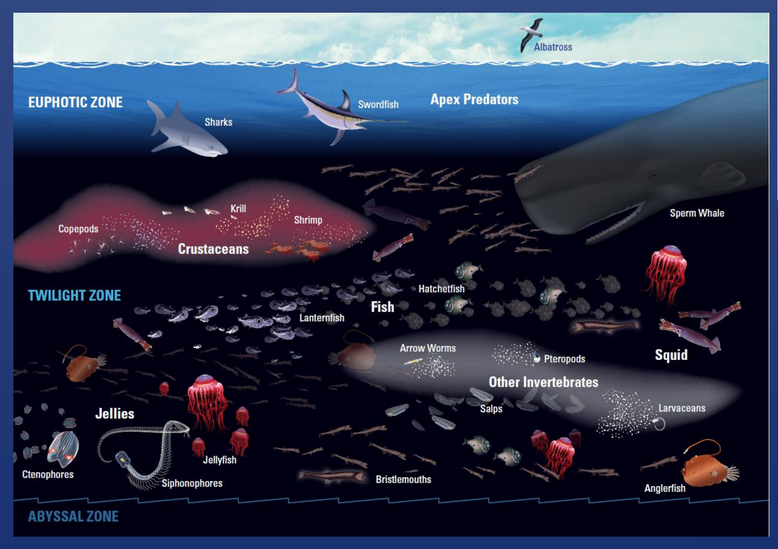
Cyclothone

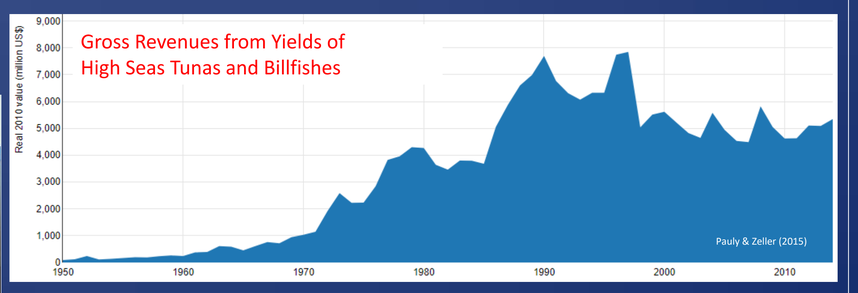
Sigmops




Supporting services are "those environmental features and ecological elements that contribute to [or "support"] provisioning, regulating, and cultural ecosystem services" (MA 2005). **Benefits:** undetermined. **Risks:** over-exploitation of apex predators; climate change effects in the ocean.

In the OTZ, these services comprise light levels, temperature, and nutrients, as well as the midwater fish, salps, jellies, zooplankton, and bacteria and other microbes. By definition, ecosystem services in their supporting roles are not used directly by humans, implying that assigning economic values to those services sometimes can be problematic. **Where commercial uses are linked to supporting services, such as in the case of predator-prey relationships among commercial fisheries for tunas and twilight zone fish, in principle, the net social value (resource rents) from the commercial fisheries could be imputed to the twilight zone fish in their supporting role.** In undertaking such a valuation, it would be important to avoid the "double-counting" of economic values.




Gross revenues from the catch of tunas and billfishes on the high seas were ~$5-6 billion in 2014 (see the figure above; data from the *Sea Around Us* project [Pauly & Zeller 2015]). This value represents about 40% of the value of the world catch of these apex predators in that year. Globally, subsidies in all commercial fisheries have been estimated to approach $30 billion a year, however, and a study of the total resource rents that obtained from tuna fisheries in the Western Central Pacific Ocean approached a ***negative*** $1 billion (Sumaila *et al*. 2010, 2014). **The absolute dissipation of resource rents through over-fishing abetted by subsidies would imply that society imputed *no value* for twilight zone organisms in the role of a supporting service for ecologically linked epipelagic fish.** Thus, the conservation of apex predators is important to characterizing the economic value of the ocean twilight zone as a supporting service.


**Acknowledgements**

This research is supported by funding as part of the Audacious Project, a collaborative endeavor, housed at TED; travel to the ICES Annual Science Conference was supported by NSF Grant No. 1456314. We thank Ankur Shah and Aria Finkelstein for research assistance and Peter Wiebe, Ken Buesseler, Heidi Sosik, Dana Yoerger, Larry Madin and all the other members of the WHOI Ocean Twilight Zone Project Team for their inspirations and insights [https://twilightzone.whoi.edu/].



**References**

- Buesseler KO, Lamborg CH, Boyd PW, Lam PJ, Trull TW, Bidigare RR, Bishop JKB, Casciotti KL, Dehairs F, Elskens M, Honda M, Karl DM, Siegel DA, Silver MW, Steinberg DK, Valdes J, Van Mooy B, Wilson S. 2007. Revisiting carbon flux through the ocean's twilight zone. *Sci*. 316:567-570.
- Choy CA, Haddock SHD, Robison BH. 2017. Deep pelagic food web structure as revealed by in situ feeding observations. *Proc. R. Soc. B* 284:20172116.
- Fenichel E, Abbott JK, Bayham J, Boone W, Haacker EMJ, Pfeiffer L. 2016. Measuring the value of groundwater and other forms of natural capital. *PNAS* 113:2382-2387.
- Harden-Davies H. 2017. Deep-sea genetic resources: new frontiers for science and stewardship in areas beyond national jurisdiction. *Deep-Sea Res. II* 137:504-513.
- Irigoien X, Klevjer TA, Røstad A, Martinez U, Boyra G, Acun JL, Bode A, Echevarria F, Gonzalez-Gordillo JI, Hernandez-Leon S, Agusti S, Aksne DL, Duarte CM, Kaartvedt S. 2014. Large mesopelagic fishes biomass and trophic efficiency in the open ocean. *Nature Comm.* 5:3271.
- Koch K-H., ed. 2000. Understanding CCAMLR's approach to management. Hobart, Australia: Scientific Committee, Commission for the Conservation of Antarctic Marine Living Resources , 70pp.
- Millennium Ecosystem Assessment (MA). 2005. https://www.millenniumassessment.org/en/index.html.
- Pauly D, Zeller D, eds. 2015. *Sea Around Us Concepts, Design and Data*. www.seaaroundus.org.
- Shah A, Jin D, Hoagland P. 2018. Value of research on the biological carbon pump. Mimeo. Woods Hole: Marine Policy Center, Woods Hole Oceanographic Institution.
- Shiller L, Bailey M, Jacquet J, Sala E. 2018. High seas fisheries play a negligible role in addressing global food security. *Sci. Adv.* 4(August):eaat8351.
- Sumaila UR, Dyck A, Bask A. 2014. Subsidies to tuna fisheries in the Western Central Pacific Ocean. *Mar. Pol'y* 43:288-294.
- Sumaila UR, Khan AS, Dyck AJ, Watson R, Munro G, Tydemers P, Pauly D. 2010. A bottom-up re-estimation of global fisheries subsidies. *J. Bioecon*. 12:201–225.
- White C, Costello C. 2016. Close the high seas to fishing? *PLOS Bio.* 12(3):e1001826.