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Viewpoint

Induced innovation in fisheries and aquaculture

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A B S T R A C T

Some classical economists, most notably Malthus, predicted that scarcity would undermine long-term human well-being. John Stuart Mill, in contrast, predicted that the threat of scarcity creates incentives for innovation that help to avoid some of the worst outcomes. Popular claims of marine ecologists often apply the Malthusian narrative to supplies of seafood, yet global supplies have continued to grow. We examine the modern seafood industry and evaluate Mill's claims about innovation. We argue that the mechanisms that Mill discusses–innovation in response to and in anticipation of scarcity–account for much of what we see. Scarcities induce technological, policy, and market innovations that enable seafood supplies to grow, and these innovations can build on each other. The challenge for policy makers is to avoid knee-jerk responses to Malthusian narratives and craft policy responses that encourage innovation while recognizing physical limits of ocean resources.

…the conduct of human creatures is more or less influenced by foresight of consequences…population is restrained by the fear of want rather than by want itself.

John Stuart Mill

Over the last several decades, many scientists have documented threats to the oceans from human activity. Yet, alarming messages about declines in fisheries contrast sharply with sustained increases in production and consumption of seafood globally. Average global seafood consumption passed 20 kg/capita in 2014, a new record (FAO, 2016). This contrast is not unique to the marine environment; it is a recent example of debate that originated with the classical economists. Thomas Robert Malthus predicted scarcity would manifest as declining labor productivity as society reached absolute limits of the total available agricultural land. David Ricardo also predicted that scarcity would manifest as declining labor productivity and argued the mechanism would sequentially bring ever lower quality agricultural land into production. Despite somewhat differing views on scarcity, both classical economists predicted limited food availability and long-term human well-being, a view we will lump together as "Malthusian." A third classical economist, John Stuart Mill, argued that technological and policy innovations can alleviate scarcity: "There is, thus, no possible improvement in the arts of production which does not in one or another mode exercise an antagonistic influence to the law of diminishing return to agricultural labor. Nor is it only industrial improvements which have this effect. Improvements in government, and almost every kind of moral and social advancement, operate in the same manner …." John Stuart Mill (from Barnett and Morse, p. 68). Mill acknowledged absolute physical limits but highlighted innovation as a likely response to anticipated scarcity.[1] To what extent do Mill's ideas describe the global seafood system and account for increased production?

Poignant claims from marine ecologists about threats to ocean resources echo Malthusian views. For instance, based on the paper Worm et al. (2006), the lead author dramatically predicted "if the long-term trend continues, all fish and seafood species are projected to collapse within my lifetime – by 2048." (Schmid 2006). Lumping all fisheries together calls attention to absolute limits of the resource base, and highlights a clear concern with Malthusian scarcity. Based on Pauly (1998), the lead author with similar drama stated: "We are eating bait and moving on to jellyfish and plankton," as humans are fishing down marine food webs (Krulwich, 2014). An accompanying cartoon graphic used to promote this idea shows a thick arrow cutting downward through smaller and smaller schools of fish toward tiny jellyfish (http://www.fishingdown.org/, accessed 1/2/18). Pauly's notion suggests a series of resource depletions that result in sequencing lower quality resources that have lower trophic levels (i.e. are lower on the food

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[1] The juxtaposition of Mill's views on innovation in response to scarcity with Malthus and Ricardo is an important theme in Barnett and Morse (1963).

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web), and no human response or feedback is predicted. Hence, notions of global collapse by 2048 and fishing down marine food webs follow Malthusian thinking by ignoring innovation and its effects on scarcity.

In fisheries and aquaculture, numerous innovations have responded to growing demand for seafood and what might otherwise be stagnating supplies. As Mill suggested, these innovations include both technology and policy responses to scarcity. They also involve market innovations that offer new products and product forms. Some of the most interesting seafood market changes combine technological, policy, and market innovations. In capture fisheries, for example, open access is widely considered the cause of overexploitation and rent dissipation, and growth in catching power and fish finding technologies have made open access even more untenable. In this sense, technological innovation necessitated policy innovation to enclose the commons. The culmination of this policy innovation is rights-based management that has sparked market innovations to spread fresh product over longer seasons and improve product quality and yield. In aquaculture, technological innovations have lowered costs to make farmed fish competitive with their wild counterparts, and thereby expanded the global production capacity for seafood. The resulting market penetration of farmed fish has contributed to wider geographic and temporal availability of products such as fresh salmon as well as a proliferation of product forms.

Tensions between the path of innovation and potential for absolute physical limits paint a picture of what is likely to govern seafood market development in the coming decades. In this paper we provide an analysis of these tensions. Hicks (1932) first introduced the term induced innovation to clarify that innovation does not take place until it is needed, that is, until there are incentives to provide it. We argue that the mechanisms that Mill and Hicks discuss–innovation in response to and in anticipation of scarcity–account for much of what we see in seafood.[2] We examine case studies in fisheries and aquaculture in which seafood scarcity plausibly has induced technological, policy, or market innovation, and we use these cases to illustrate how seafood production and consumption is likely to change in the coming decades.

1. Technological, policy, and market innovations

Only a century ago, there was still scientific debate about whether depletion of seafood supplied by the oceans was even possible. A leading fisheries biologist, Thomas Huxley, in his inaugural address at the London fisheries exhibition in 1883 stated: *"I believe, then, that the cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery, and probably all the great sea fisheries, are inexhaustible; that is to say, that nothing we do seriously affects the number of the fish. And any attempt to regulate these fisheries seems consequently, from the nature of the case, to be useless." (Huxley [1883] 1998).*

By the second half of the 20th century, it was clear that Huxley was simply wrong, and global landings of wild-caught seafood suggested some extent of Malthusian scarcity. Aggregate landings increased rapidly from the 1950s until the mid-1980 , after which production leveled off (Fig. 1). This leveling off suggests a Malthusian limit was reached, although the actual process that grew total landings appears more Ricardian. Over time, total landings grew by exploiting new stocks of fish that previously had been unexploited. Some new fisheries were high value but costly to exploit, while others were low value and low cost to exploit. Expansion of wild-caught seafood reflected both growth in distant water fishing fleets and exploitation of nearshore species that previously were not used commercially.

Overfishing played a role in perceived Malthusian scarcity. Exploitation of new fisheries often ramped up dramatically in an unsustainable way, but continued additions of new fisheries allowed total

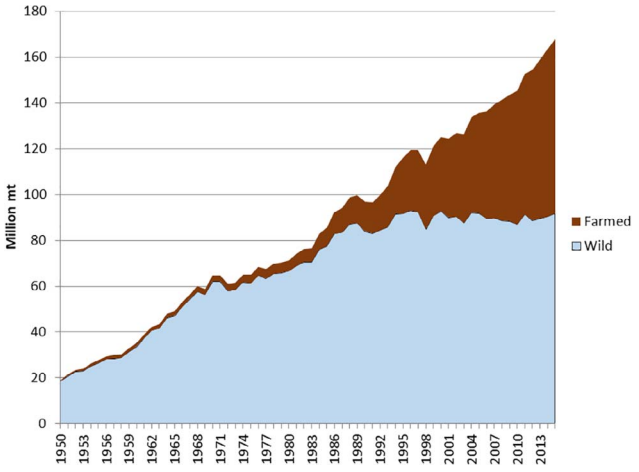

Fig. 1. Global production of wild-caught and farmed seafood.
Source: FAO.

production to grow even as harvests from some declined precipitously as stocks were overfished. These patterns of global fisheries exploitation are consistent with Pauly's fishing down metaphor and Worm et al.'s collapse framing.[3] The sequential nature of Ricardian exploitation, though not specifically tied to food webs and fishery biology, loosely follows Pauly's fishing down idea because many high-value species are larger and thus tend to be from higher in the food web (Smith and Wilen, 2002). Moreover, the pattern of steep ramp-up and precipitous decline in landings within a fishery is precisely what produces Worm et al.'s prediction of complete collapse by 2048.

However, Malthusian scarcity is never fully realized. Predicted declines in seafood production have not occurred. Instead, global seafood production continued to rise after the 1980s, and global wild-caught production stabilized but did not decline substantially. The anticipation of scarcity, or as Mill put it, "the fear of want," provided incentives for innovation that prevented the doom and gloom. Increased scarcity of a product leads to a higher price expectation, thereby providing incentives to increase production or to provide substitutes for the product in question. Increased price incentivizes technological innovation within the fishery itself, policy innovation to address scarcity, and the use of substitutes. For a particular seafood market, substitutes can come from trade in wild-caught seafood from other regions or production of alternatives using aquaculture. Key innovations in the seafood sector enabled the alleviation of the scarcity or, if nothing else, a substantial delay in the bite of scarcity despite rising global population and growing demand for food.

New harvest technologies in fisheries illustrate the process of technological innovation in response to concerns about scarcity. Increased vessel horse power, fish finding technology, and new forms of fishing gear all contributed to increasing catches and eventually maintaining them even as stocks declined. However, technological advance on its own has limits. While initially technology lowers the costs of exploiting a depleted stock (Squires and Vestergaard, 2013), the process exacerbates the scarcity because technological improvements make it economically viable to reduce the stock to still lower levels. Technological advance thus reinforces the incentives for policy innovation. The Norwegian Lofoten cod fishery provides a useful example. Substantial technological advance unfolded over 130 years, but wage growth failed to keep pace with growth in agricultural wages. From the 1850s, the fishery transitioned from open sail boats, to decked boats, and then motorized boats by 1920. A series of gear changes occurred culminating with the introduction of synthetic fiber nets and

[2] Johnson (2000) makes a similar argument with respect to technological change in agriculture, although he does not focus on scarcity-induced innovation as in Mill and Hicks.

[3] Not all biologists agree with Pauly's interpretation of the data, as illustrated by the discussion in Pauly et al. (2013).