The global rise of crustacean fisheries

Robert Boenish[1*], Jacob P Kritzer[1], Kristin Kleisner[1], Robert S Steneck[2], Karl Michael Werner[3], Wenbin Zhu[4], Frederick Schram[5], Douglas Rader[6], William Cheung[7], Jose Ingles[8], Yongjun Tian[9], and John Mimikakis[10]

Globally, wild decapod crustacean fisheries are growing faster than fisheries of any other major group, yet little attention has been given to the benefits, costs, and risks of this shift. We examined more than 60 years of global fisheries landings data to evaluate the socioeconomic and ecological implications of the compositional change in global fisheries, and propose that direct and indirect anthropogenic alterations and enhancements to ecosystems continue to benefit crustaceans. Crustaceans are among the most valuable seafood, but provide low nutritional yields and drive 94% of the projected increase of global fishery carbon emissions, due to low capture efficiency. Unequivocally, the increasing global demand for luxury seafood comes with serious environmental costs, but also appears to offer lucrative fishing opportunities. The potential for more prosperous fisheries carries unevaluated risks, highlighting the need for a nuanced perspective on global fisheries trade-offs. Addressing this unique suite of trade-offs will require substantive changes in both science and management.

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Continuing a global trend that began in the latter part of the 20th century, more people in developing, newly industrialized, and developed countries are now able to afford highly prized seafood, such as lobsters, prawns, and fresh fish (Clark *et al*. 2018). This development emerged from increasingly globalized trading systems, in which fresh goods, alive or chilled, can be shipped at virtually any time to virtually anywhere on the planet (Kearney 2010). In wealthier societies, which place high value on perceived healthy and fancy meals, seafood has consequentially risen to a luxury food product and a symbol of social status. Increases in seafood consumption rates, trade, and the number of trade routes can largely be explained by concomitant increases in individual wealth (Watson *et al*. 2016).

In a nutshell:

- In recent decades, crustacean (crab, shrimp, and lobster) landings have risen faster than other types of seafood
- We evaluated the socioeconomic and ecological implications of global fisheries increasingly dominated by crustaceans
- Expansion of crustacean fisheries has resulted from reduced predation and inherent productivity coupled with a high market value relative to other seafood products
- Despite their market value, crustacean fisheries generate less food and nutritional value, emit much more carbon dioxide per landed ton, and risk creating overreliance and disincentives to rebuild more diversified fishing portfolios
- The ongoing boom in global crustacean fisheries signals the need to manage new ecological and socioeconomic trade-offs

Notwithstanding innovations in food production, wild fisheries are and will continue to be a requisite of global food security, especially for vulnerable human populations in coastal zones (Golden *et al*. 2016; Hicks *et al*. 2019). Although fisheries management efforts include many success stories (Zimmermann and Werner 2019), numerous populations of large marine predators have been depleted (Pauly 1998) and what remains is often heavily size-truncated, a typical sign of overexploitation. Furthermore, reductions in top predators and keystone species have resulted in regional trophic cascades and meso-predator release (proliferation; Paine 2010; Terborgh and Estes 2010; Worm and Paine 2016). Decapod crustaceans, including crab, lobster, and shrimp species, form an increasingly important component of these ecological transitions (Anderson *et al*. 2011).

To understand their role and evaluate costs and risks of rising crustacean fisheries, we compiled global fisheries data from 1950 to 2016 along with information on price, nutrition, and carbon (C) emissions for four major groups of wild-capture fisheries: crustaceans, cephalopods, pelagic fish, and demersal fish. Relative increases in crustacean landings have outpaced all other major species groups since 1990, with crustacean fisheries having nearly doubled their share of global landings, from 4.4% to 7.8% (WebTable 1; Figure 1). In contrast, overall global landings have not changed appreciably during this period, and

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[1] *Environmental Defense Fund, Boston, MA *(robert.boenish@gmail.com); †current address: Northeastern Regional Association of Coastal Ocean Observing Systems, Portsmouth, NH; [2] University of Maine, School of Marine Sciences, Darling Marine Center, Walpole, ME; [3] Thünen Institute of Sea Fisheries, Bremerhaven, Germany; [4] Zhejiang Ocean and Fisheries Institute, Zhejiang, China; [5] Burke Museum of Natural History and Cultures, University of Washington, Seattle, WA; [6] Environmental Defense Fund, Raleigh, NC; [7] University of British Columbia, Institute of Oceans and Fisheries, Changing Ocean Resource Unit, Vancouver, Canada; [8] Quezon City, Philippines; [9] Ocean University of China, Qingdao, China; [10] Environmental Defense Fund, Washington, DC*

show a declining trend if crustaceans are omitted. Although the largest national contribution to the increase in crustacean landings is attributed to China, crustacean fisheries have risen globally in lieu of declining vertebrate landings with or without China's inclusion (Figure 1).

Methods

Analysis design

We used global landings data to relate the landed volume to value, predict greenhouse-gas (GHG) emissions, and draw conclusions concerning global crustacean abundance. Landings and value data were obtained from the Food and Agriculture Organization of the UN (FAO) wild-capture fisheries database (FishStatJ; FAO 2019). For our analysis, we grouped the FAO species groups into four focal groups – crustaceans, cephalopods, demersal fish, and pelagic fish – based on taxonomy and ecology, consistent with established "FAOSTAT" groups (WebTable 2) from 1950 to 2016. For these four groups, we considered only marine-capture fisheries and therefore excluded groups such as freshwater crustaceans and diadromous fish; for consistency, more contrived groups, such as "Marine Fish NEI" ("not elsewhere included"), were also excluded.

We relied on global landings (1950–2016) to indicate crustacean abundance, which raises concerns about the reliability of global fisheries data and whether catch or landings reflect abundance (Pauly and Zeller 2017). Management regimes that limit landings or effort theoretically decouple the relationship between catches and abundance, and there is evidence for both: landings indeed reflecting abundance and landings and abundance becoming decoupled (Zimmermann and Werner 2019). A similar pattern may occur as a result of reporting rates changing over time.

Robust scientific stock status estimates are available for conspicuously few crustacean stocks, and the stock assessments that are available represent only a small fraction of global crustacean capture (WebFigure 1); therefore, in this paper, we assumed landings to be a suitable proxy for crustacean abundance (NOAA 2015; Gaudian *et al.* 2019). To address our own data quality concerns, it was important to examine interregional consistency of fishery trends. Overall, we found consistent trends in crustacean landings across ocean basins from 1990 to 2016 (WebFigure 2). We acknowledge that the broad scale of our approach could not address individual stocks or shifts in population structure that may maintain overall crustacean productivity despite local depletion; consequently, we focused our analysis on decapod crustaceans, for which long-term catch records and ecological research exist for many (albeit data-rich) regions.

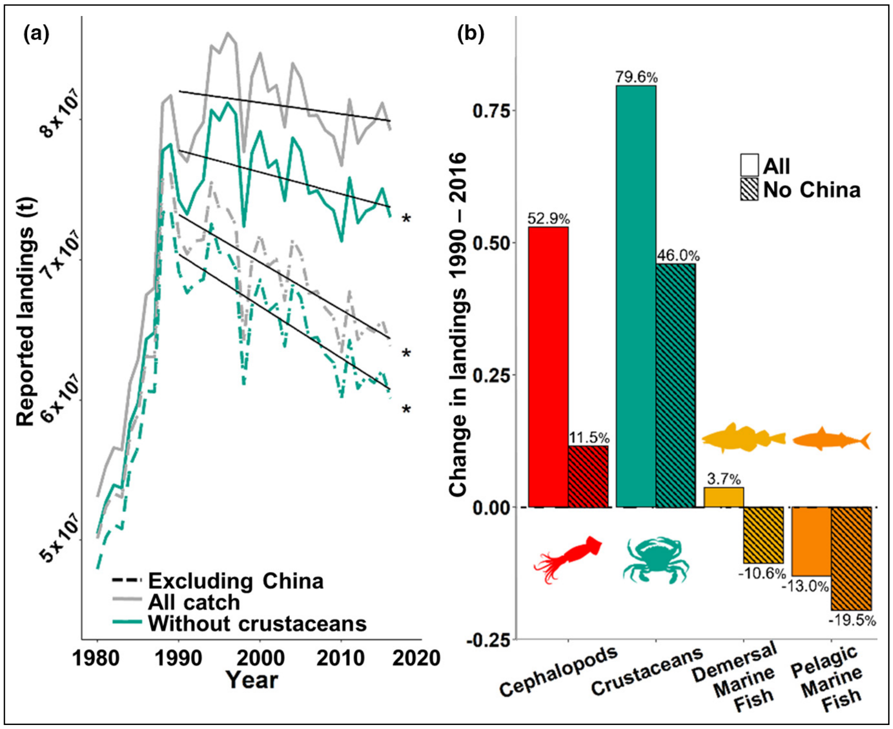


Figure 1. The changing role of crustaceans in global wild-capture fishery landings. (a) Total global landings in metric tons (t), with and without the inclusion of China (1980–2016). Landings from all countries suggest no significant trend in global landings since 1990 (two-tailed *t* test, $P = 0.28$), unless crustaceans are removed, in which case the trend was negative ($P = 0.02$). Excluding China, global landings have declined since 1990, with or without crustaceans (two-tailed *t* test, $P < 0.001$). Asterisks indicate significant trends. (b) Total percentage change in global landings of four major species groups representing 81.3% of global marine wild-capture landings from 1990 to 2016 with China (solid bars) and without China (hashed bars).

Nutritional analysis

Percentage yield and nutritional content data for the four focal seafood groups were used to calculate relative caloric yield. We obtained edible flesh and meat weight data from the FAO (FAO 1989) and other published sources ($n = 143$; WebTable 3) to calculate the percentage of a species that is typically consumed (raw edible flesh and muscle tissue in relation to wet weight). Where estimates of edible flesh were not available, we used meat weight as a proxy for yield. Nutritional data, which included energy (kcal) and 12 micronutrients, were extracted from the Global Expanded Nutrient Supply (GENuS) database for the four focal groups (WebFigure 3; Golden *et al.* 2016; Smith *et al.* 2016). Caloric yield was calculated as the percentage yield multiplied by the caloric content of the consumed seafood. Results are reported relative to the mean values for pelagic fish, which had the highest caloric yield. Because of limited sample size, cephalopod caloric yield was estimated as the product of cephalopod percentage yield and pooled mollusk nutritional information from Golden *et al.* (2016).

Emission projections

We derived short-term GHG emission projections from current trends in landings for the four focal groups. For each group, we calculated the average annual change in landings over 1990–2016, and then projected these trends out for 14 years (over the period 2017–2030; WebTable 4). For these four groups over the selected years, total landings between groups changed little (+2.8%), while intragroup landings changed considerably (–7.0% to 42.8%; Figure 2). We assumed group-specific emission intensities (carbon dioxide equivalent per kilogram [CO_2-eq per kg] landings) from Parker *et al.* (2018). Emissions intensities were assumed stationary (ie the respective fisheries did not become more or less efficient) over the projection period. For split groups such as small and large pelagic fish, we assumed landings-weighted average emission intensities based on the latest year reported in Parker *et al.* (2018).

Socioeconomic factors

To calculate taxonomic group volumes and values as they relate to the global total, we used data from the FAO Yearbook on Fishery and Aquaculture Statistics (FAO 2019) covering the period 2011–2017 (WebTable 5). Although prior FAO yearbooks contain data going back further in time, we did not use earlier yearbooks because of price revisions for several taxonomic groups. Due to small volume and elusive price information, the FAO omits king crabs and squat-lobsters from published economic statistics.

Biological and ecological traits

Crustaceans exhibit several important traits that increase their inherent productivity and resilience (Panel 1), promoting continued increases in catches despite widespread overfishing and depletion of other species. These traits have enabled crustaceans to adapt and benefit from a wide array of anthropogenic alterations (such as overfishing or seabed degradation as a consequence of bottom trawling), some of which are direct and intended to benefit crustacean populations while others are indirect and unintended outcomes of other interventions.

All such enhancements either supplement food and reproduction or reduce competition, natural mortality, and predation risks (Heithaus *et al.* 2008). Examples of direct enhancement include stocking or transplanting (including non-native species; Lorentzen *et al.* 2018), use of bait to supplement diets (Grabowski *et al.* 2010), or collection of wild individuals to be raised in captive conditions (Shelley and Lovatelli 2011). Examples of indirect enhancement include instances where predator abundance has been reduced or habitats have been altered so that ecosystem conditions become more favorable for crustaceans.

Surprisingly, indirect consequences of anthropogenic actions can have comparable or even greater impacts on crustacean populations than intentional interventions. For example, intense harvesting of Atlantic cod (*Gadus morhua*) and green sea urchin (*Strongylocentrotus droebachiensis*) in the Gulf of Maine has resulted in reduced predation and the proliferation of macroalgae that provides a key nursery habitat for crabs and a variety of other invertebrates, thereby increasing juvenile survival and abundance (Steneck *et al.* 2013). Such examples have led to challenges to the notion that booming wild-capture crustacean fisheries are fully "wild" (Klinger *et al.* 2013), but rather that crustacean fisheries exist along a spectrum of relative "enhancement", whereby populations persist in ecosystems ranging from a relatively unperturbed state to artificial conditions similar to aquaculture (Figure 3). Historically overfished and simplified ocean ecosystems around the world are home to most of the largest and most valuable crustacean fisheries (Jackson 2008). This is especially true in Southeast Asia, where ecosystem overfishing and predator removal (Szuwalski *et al.* 2017) have contributed to markedly fast growth of lower trophic groups over the past ~30 years (Ye *et al.* 2017). As a common denominator, landings from some of the largest wild crustacean stocks have risen in recent decades, reflecting the global transition toward more crustacean-dominated fisheries.

Emerging as frequent winners from a mix of intended and unintended human alterations of ecosystems are mid- to low-trophic level generalists, or species that are more resilient to exploitation and changes in temperature, less restricted to a particular geography, and with a tendency for rapid growth. The same traits that provide crustaceans with

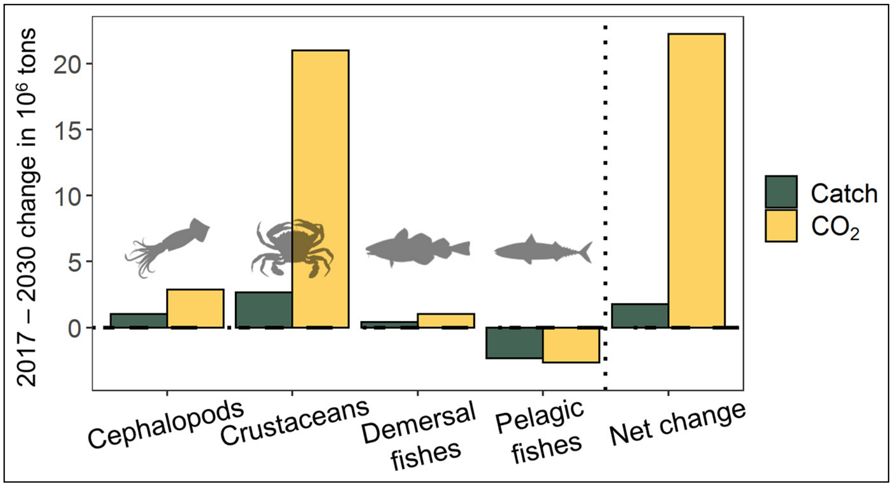


Figure 2. Projected change in global fisheries landings and carbon dioxide equivalent (CO_2-eq) emissions from 2017 to 2030 for four major fisheries groups comprising 81.3% of landings. Changes in overall landings (green bars) are based on mean annual changes from 1990 to 2016 (FAO 2016). CO_2-eq emissions (yellow bars) are based on indices from Parker *et al.* (2018) and expressed in CO_2-eq per kg landings. Despite a projected modest increase of 1.78 million tons in overall catches by 2030, CO_2-eq emissions are projected to increase by 22.25 million tons, equivalent to 15.0% of the overall global fishery emissions in 2016.

Panel 1. Biological characteristics facilitating crustacean success

Feeding plasticity: many crustaceans are feeding generalists (Schram 1986) facilitated by an extensive battery of mouthparts that can process all sorts of food, live or dead, plant or animal, large or microscopic.

Thermal tolerance: relatively low temperature sensitivity (Watson *et al*. 2014) may allow crustaceans to remain in certain habitats as ocean temperatures change and more easily colonize new areas.

Natural defenses: tough exoskeleton and cryptic tendencies may contribute to disproportionate reductions in natural mortality (Steneck and Wahle 2013). Some harvested species possess large claws on the first pereiopods (walking legs that can also be used to gather food), adding to defense capabilities (Schram 1986), whereas many species further reduce predation through nocturnal feeding.

Relatively fast growth: many commercially exploited crustaceans exhibit rapid growth and/or a short life history.

Parental care: most species (ie suborders Dendrobranchiata and Pleocyemata) brood eggs on the mother's pleopods (abdominal legs used primarily for swimming but also for brooding eggs and collecting food), producing highly competent larvae with more than one free larval stage, therefore minimizing competition among themselves (Schram 1986).

robustness and adaptability may also make these species more resilient to climate change. The fossil record provides evidence that the general crustacean body plan has proven to be markedly successful during past iterations of global change (Clark 2009; Bracken-Grissom *et al*. 2014; Rozenberg *et al*. 2015). Coinciding with the adaptive radiation of modern fishes (early invertivores), the diverse assemblage of extant decapods evolved under conditions of high adult mortality.

Ocean acidification and epizootic disease

Among the most discussed yet poorly understood factors related to climate-change impacts on marine ecosystems is the ability of calcifying organisms to persist with increasing ocean acidification. Studies examining the effects of acidification on the life histories of both vertebrates and invertebrates show mixed results, but crustaceans may experience surprisingly modest effects, albeit with important regional and taxonomic variability (Branch *et al*. 2013; Dodd *et al.* 2015; Bednaršek *et al.* 2020). High capacity of osmoregulation, a biogenic and cyclically replaceable covering (Ries *et al.* 2009), mobility, and plasticity in energy allocation (Arnold *et al*. 2009) could dampen the effects of acidification for some species.

An underappreciated threat posed by climate change is the possibility of increased epizootic disease. Substantial evolutionary top-down control has led many crustacean species to evolve nocturnal and cryptic (shelter-dwelling) lifestyles (Steneck and Wahle 2013). As has been seen in systems like the western North Atlantic, removal of predators over time creates an environment sufficient to facilitate increases in decapod density and a carrying capacity far above historical levels under stronger top-down control. Research across invertebrate phyla suggests an increasing propensity of disease outbreaks with rising temperature and population density (Miner *et al*. 2018). However, the study of disease across wild crustacean populations is relatively nascent (Stentiford *et al.* 2012), and so it is uncertain whether and to what degree future risks will change.

Socioeconomic factors

Despite a relatively modest contribution to landings volume (7.8%), crustaceans represent a disproportionate amount of global marine fisheries value (21.3%), making them the most valuable group by landed mass (Figure 4; FAO 2019). The top four seafood types by price are all invertebrates, the top three of which are crustaceans (lobsters, crabs, and shrimps and prawns; FAO 2018). In recent years, prices for crustaceans have continued to rise. From 2011 to 2017, global crustacean landings and prices have increased the fastest among all other major groups (landings +13%, price +4.1%; WebTable 5). Since 1990, reported annual crustacean landings have more than doubled in Africa (+134%) and Asia (+101%), and increased substantially in all regions except Oceania (–4%). Despite their importance and value (Figure 4), crustacean fisheries receive conspicuously little attention from fishery stock assessment scientists, and most remain largely unassessed (WebFigure 1).

Although more crustaceans are being caught than ever before in nearly all regions of the global ocean, it is possible that this more profitable ecosystem state is less stable (Nagelkerken *et al*. 2020). Ecosystem states that produce high economic value from narrower fishing portfolios may reduce overall fisheries yields and revenue in the long run (Robinson *et al*. 2020), eroding both socioeconomic and nutritional resilience. For example, while the West Greenland shrimp and Northwest Atlantic American lobster fisheries have increased in recent years, overall edible seafood caught in the areas decreased due to the generally lower edible yield of crustaceans (Figure 5) and the lower total landings from other fisheries in comparison to previously cod-dominated ecosystems (Worm and Myers 2003). In less developed countries, shifts toward higher value crustaceans may mean greater reliance on exporting to other markets and reduced local consumption, which could be especially important for creating jobs and improving livelihoods and equity. But such benefits are not without substantial risks. Reliance on high-value species brings added potential for overexploitation (Anderson *et al.* 2011),

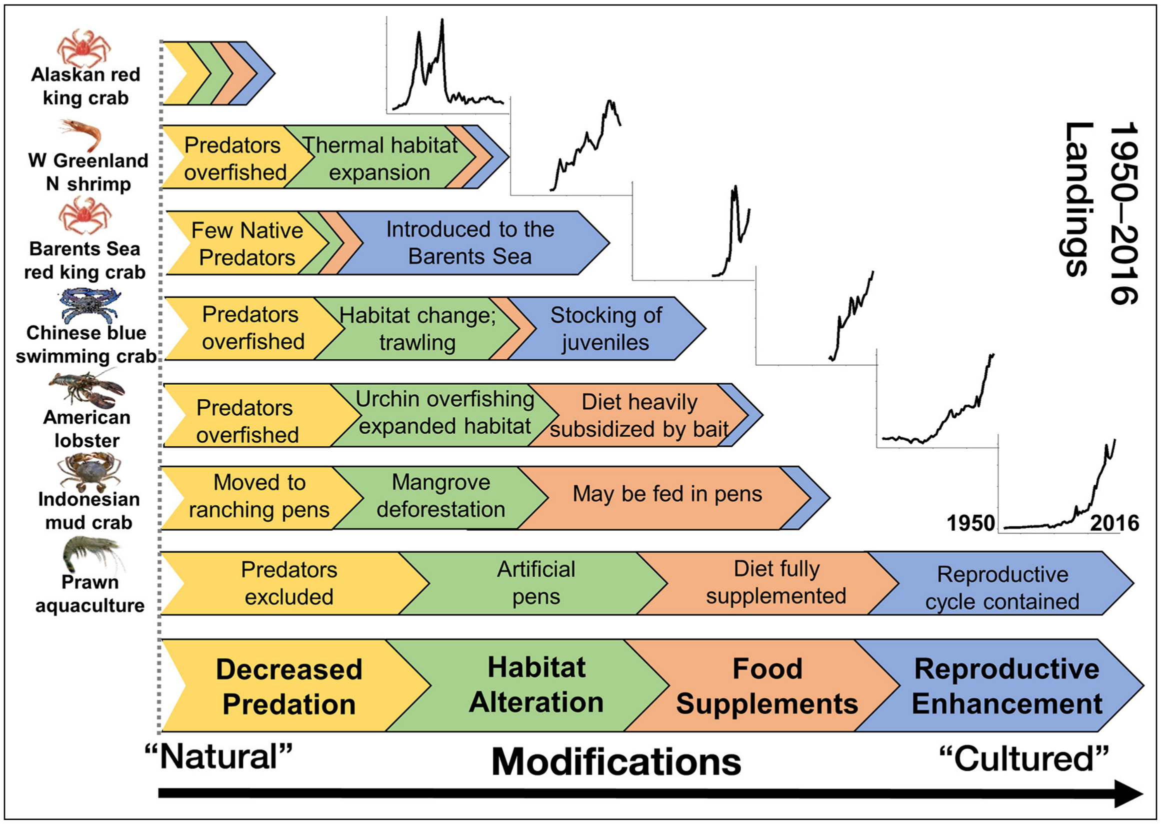


Figure 3. Conceptual spectrum of fishery enhancements through four major types of interventions (decreased predation, habitat alteration, food supplements, and reproductive enhancement), with examples from global crustacean fisheries illustrating a range of system alterations. Using prawn aquaculture as an extreme, we qualitatively considered wild crustacean fisheries with various interventions (arrow size is for visualization purposes only). Species exist throughout the spectrum for all attributes, but similar outcomes may be seen from different combinations of interventions (modified from framework developed by Klinger *et al.* [2013]). References for each species: Alaska red king crab (*Paralithodes camtschaticus*; Kruse *et al.* 2010), West Greenland northern shrimp (*Pandalus borealis*; Arboe and Kingsley 2013; Hedeholm *et al.* 2017), Barents Sea red king crab (*Paralithodes camtschaticus*; Lorentzen *et al.* 2018; Christie *et al.* 2019), Chinese blue swimming crab (*Portunus trituberculatus*; Hamasaki *et al.* 2006), American lobster (*Homarus americanus*; Grabowski *et al.* 2010; Steneck *et al.* 2013), and Indonesian mud crab (*Scylla serrata*; Shelley and Lovatelli 2011).

overdependence, overcapitalization, and social traps (Steneck *et al.* 2011). In the event of a collapse, or even moderate fluctuation, overreliance on a small number of resources can reduce social resilience regardless of a species' value. Moreover, harmful incentives such as government fuel subsidies will continue to play a role in compounding the risks of overcapitalization and overdependence (Sumaila *et al.* 2010). Because Asian countries currently account for 69% of crustacean landings, we predict vulnerable coastal fishing communities in this region will be strongly affected by the social and ecological externalities associated with the global shift toward crustacean fisheries. Diversified fishing portfolios can provide greater resilience to these externalities, but the high value of certain species combined with harmful subsidies can hinder the motivation to rebuild and sustainably manage a broad portfolio.

The shift toward crustacean-dominated fisheries is signaling a global shift down or through the food web (Essington *et al.* 2006), but offers a lucrative counterbalance to the decline in many finfish fisheries. For example, following the historic collapse of Atlantic cod in Atlantic Canada from 1990 to 2016, total fishery landings in the Maritime provinces have declined 51% while overall value (adjusted for inflation) has increased 92%. American lobster (*Homarus americanus*) landings have increased 89% since 1990 and now account for 84% of Atlantic Canada's total wild fishery value (DFO 2019). Increasing crustacean landings apparently can empower communities to leverage emerging economic opportunities, particularly in less affluent countries, with export-oriented luxury foods serving as a crucial step toward poverty alleviation. If managed effectively for a broad base of community objectives and outcomes, the inherent productivity of crustaceans can translate into a powerful and sustainable economic driver.

Food and nutrition

Seafood is a major source of protein and micronutrients for 1.4 billion people worldwide (Golden *et al.* 2016; Hicks *et al.* 2019) and provides employment for 260 million (Teh and Sumaila 2013). Therefore, changes in food security linked to declining fisheries are a global concern. However, the edible yield of crustaceans is, on average, lower than

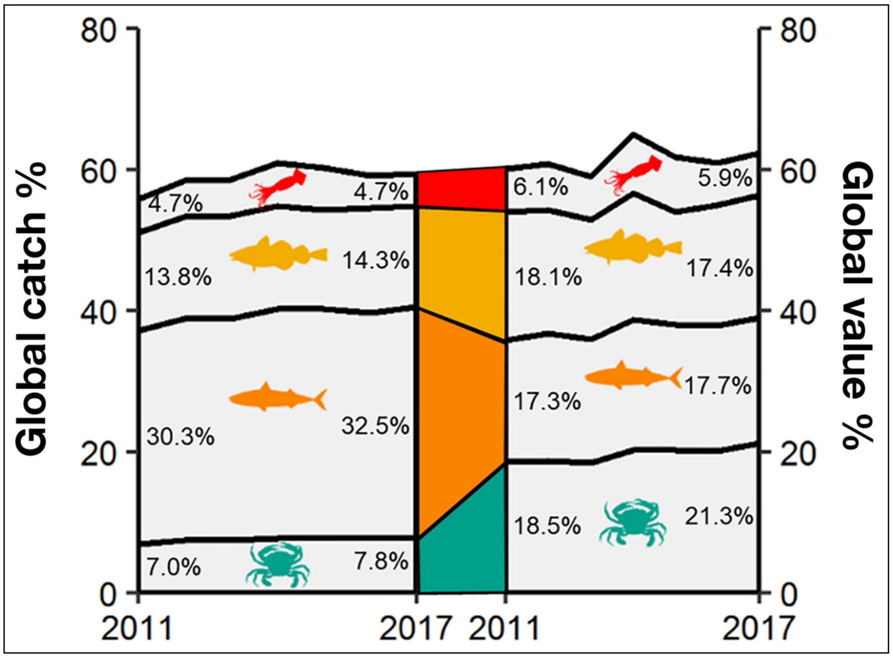


Figure 4. Landings (left) and ex-vessel value (right) of four major wild-capture fisheries groups (crustaceans: green, pelagic fishes: orange, demersal fishes: yellow, cephalopods: red) spanning 2011–2017. Percentages denote beginning and ending proportional contributions to the global total based on FAO (2019).

that of most other seafood (Figure 5a). Approximately 60% of the landed biomass from large vertebrates, such as salmon and tuna, is regularly consumed, and the proportion is even higher for most cephalopods (~70%). Conversely, for a large crustacean like American lobster, the edible yield is 15–25%, depending on season. Moreover, the mean relative caloric yield for crustaceans is only 62% that of demersal fish and 43% that of pelagic fish (Figure 5d). This does not suggest that consumption of crustaceans is unhealthy; on the contrary, the micronutrient composition of crustaceans is generally comparable to finfish and contains high levels of important micronutrients such as calcium, iron, and zinc (Figure 5; WebFigure 3). However, it does suggest that the high-value/low-yield combination of crustaceans creates an expensive nutritional alternative for food-insecure communities. It is more realistic that the high economic value of crustaceans can provide fishing communities with the income needed to secure sufficiently nutritious food, if fishery benefits are distributed broadly and equitably and those food sources are accessible.

Nevertheless, the growth of crustacean fisheries is changing the nature of food harvested from the ocean. As crustaceans continue to replace yields from historically finfish-dominated fisheries, landed biomass provides an incomplete measure of the realized amount of food and nutrition from seafood in much the same way that it provides an incomplete measure of economic contribution. The rising importance of crustaceans shifts the relative socioeconomic contribution of fisheries away from providing nutrition and toward wealth generation.

Carbon footprint

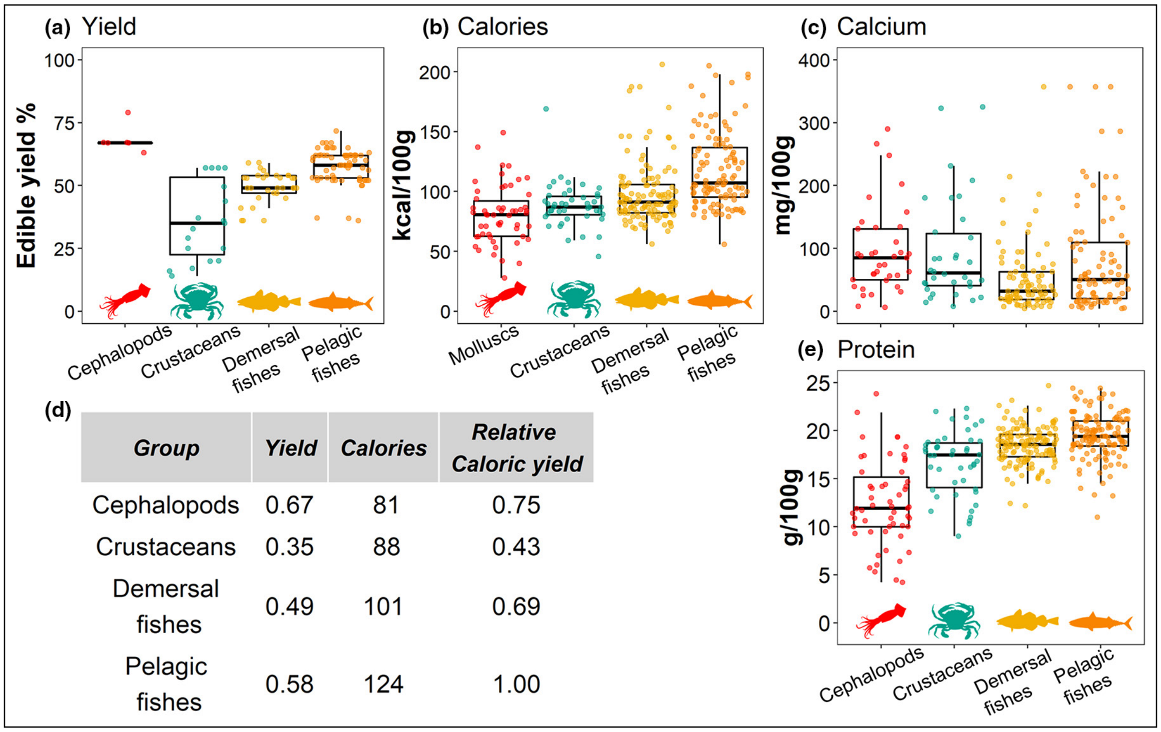
Crustaceans are harvested in many different ways but overall represent the most energy-intensive form of seafood production (Parker *et al.* 2018; Hilborn *et al.* 2018). Trap and trawl fisheries for crustaceans accounted for 22% of global fishery C emissions (CO_2-eq) in 2011, but only 6% of landings. We calculated the average change in fishery landings for four major fishery groups from 1990 through 2016, a period when global fishery landings remained relatively stable, and extrapolated these changes from 2017 through 2030 to compare with published emission intensity estimates (Figure 2; Parker *et al.* 2018). While the modest projected decrease in emissions from pelagic fish landings would approximately cancel increases in emissions from cephalopod and demersal fish landings, by 2030 the overall emissions from global fishing operations would increase by 22 million metric tons (15.0%), 94.4% of which would be driven by crustacean catches (Figure 2).

Comparatively, the emissions intensity (kg CO_2-eq/kg) of fisheries targeting small pelagic fish is nearly 40 times lower than that of crustacean fisheries, whereas the emissions intensities of fisheries for cephalopods, large pelagic fish, and demersal fish are 24–35% those of crustacean fisheries (Parker *et al.* 2018). While heavy fuel use may contribute to high prices, as compared to demersal and pelagic fish, crustaceans provide on average a 34% decrease in value return per unit CO_2. Furthermore, published figures only consider the C footprint associated with active procurement of the target species and not the costs of catching and transporting bait or the emissions associated with increasingly global supply chains. For instance, based on 2016 catch records, the economically important American lobster fishery in New England has a bait-to-landings ratio exceeding 1:1, and exports a large portion of the catch live to Canada and Asian markets.

The total contribution of the fisheries sector to global food production emissions is less than 5% (Hilborn *et al.* 2018). While nutritional attributes are essentially fixed and economic factors are subject to complex dynamics, the C footprint of fisheries can be improved directly through new technologies, fishing behavior, and management strategies that promote fuel-efficient fishing. Nevertheless, greater demand for crustaceans will be associated with higher GHG emissions.

Conclusions

The global appetite for wild-capture crustacean products comes with complex trade-offs from fisheries emerging most strongly in anthropogenically altered systems. It is questionable if the



Group	Yield	Calories	Relative Caloric yield
Cephalopods	0.67	81	0.75
Crustaceans	0.35	88	0.43
Demersal fishes	0.49	101	0.69
Pelagic fishes	0.58	124	1.00

Figure 5. Nutritional summaries of four major wild-capture fisheries groups. (a) Edible yield % (100 × [edible biomass/total biomass]), (b) caloric content (kcal/100 g edible biomass), (c) calcium (mg/100 g edible biomass), (d) relative caloric yield (edible calories per unit of total biomass relative to pelagic fishes) of globally representative species (see WebTable 3 for sources), and (e) protein (g/100 g edible biomass). Horizontal lines within boxes depict median values, boxes represent the interquartile range (25th–75th percentiles), and whiskers (vertical lines) extend to the estimated 95% confidence interval. (c and e) Nutritional breakdown for 387 species (see WebFigure 3 for data on additional micronutrients). In (b), nutritional information for cephalopods is inferred from pooled statistics for mollusks due to data availability.

emergence of these lucrative fisheries, which offer a means for breaking out of poverty, incentivizes policy makers to take action to return to formerly fish-dominated but potentially less lucrative ecosystems. Overall, we recommend adoption of management strategies that work toward diversifying fishery portfolios to reduce risks while still capitalizing on the value and productivity of crustaceans. Such improvements in management should include efforts to mitigate environmental impacts and balance food security with wealth generation.

Our analysis highlights a global trend that is not universally recognized. While the global rise of crustacean fisheries brings opportunities for poverty alleviation and wealth generation, attaining the optimal balance between economic and ecological integrity will be a necessary challenge as we traverse the Anthropocene.

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Supporting Information

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FrontiersEcoPics

Vagrancy in Antarctic and sub-Antarctic pinnipeds

In ecology, vagrancy refers to a species traveling beyond its typical distribution. Individual pinnipeds (seals) are known to venture far beyond their normal habitats, but records of such nomads are scarce, as they often go unreported. In November and December 2018, we observed considerable vagrancy in members of two pinniped species, both of which were injured. The first was a leopard seal (*Hydrurga leptonyx*; top), an Antarctic species, in Port Phillip Bay, Australia. This individual had very worn teeth and what we suspect was a healed propeller wound near its hind flippers. The second was a southern elephant seal (*Mirounga leonina*; bottom), a sub-Antarctic species, in Cape Bridgewater, Australia. This seal had damage to its left eye, but otherwise appeared to be healthy.

Leopard seals are solitary animals that live and breed on Antarctic pack ice, the outermost extent of which is located more than 3000 km from where we observed this individual. Likewise, the closest "colony" (defined here as more than 500 individuals) of southern elephant seals is on Macquarie Island, Tasmania (~60,000 individuals), which is more than 2200 km away from the individual we observed. However, small groups of southern elephant seals can also be found on islands closer to the Australian mainland, including Antipodes Island (New Zealand; ~250 individuals) and Maatsuyker Island (Tasmania; ~4 individuals).

Some researchers have posited that the rare observations of these species from the Australian mainland are examples not of vagrancy, but rather of seasonal transience, where the aberrant individual's presence recurs over time. Perhaps the animals are exploiting an abundant food source? Perhaps these occurrences are in response to changing environmental conditions, or signal the beginning of a colonization event? Perhaps injured individuals cannot compete with healthy adults and wander farther afield to feed and survive?

Benjamin Viola[1,2,3] and Karina Sorrell[3]
[1]Institute for Marine and Antarctic Studies, University of Tasmania, Battery Point, Australia;
[2]Australian Antarctic Division, Department of Agriculture, Water and the Environment, Kingston, Australia;
[3]School of Biological Sciences, Monash University, Clayton, Australia

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