Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Emerging COVID-19 impacts, responses, and lessons for building resilience in the seafood system

David C. Love\textsuperscript{a,b,*}, Edward H. Allison\textsuperscript{c}, Frank Asche\textsuperscript{d,e,f}, Ben Belton\textsuperscript{c,g}, Richard S. Cottrell\textsuperscript{h,i}, Halley E. Froehlich\textsuperscript{j,k}, Jessica A. Gephart\textsuperscript{l}, Christina C. Hicks\textsuperscript{m}, David C. Little\textsuperscript{n}, Elizabeth M. Nussbaumer\textsuperscript{a,b}, Patricia Pinto da Silva\textsuperscript{o}, Florence Poulain\textsuperscript{p}, Angel Rubio\textsuperscript{q}, Joshua S. Stoll\textsuperscript{r}, Michael F. Tlusty\textsuperscript{s}, Andrew L. Thorne-Lyman\textsuperscript{a,b,t}, Max Troell\textsuperscript{u,v}, Wenbo Zhang\textsuperscript{w}.

\textsuperscript{a} Center for a Livable Future, Johns Hopkins University, Baltimore, MD, 21202, USA
\textsuperscript{b} Department of Environmental Health and Engineering, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, 21205, USA
\textsuperscript{c} WorldFish, Bayan Lepas, Pulau Pinang, 11960, Malaysia
\textsuperscript{d} Food Systems Institute, University of Florida, Gainesville, FL, 32611-057, USA
\textsuperscript{e} Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, FL, 32611-057, USA
\textsuperscript{f} Department of Safety, Economics and Planning, University of Stavanger, 4036, Stavanger, Norway
\textsuperscript{g} Department of Agricultural, Food and Resource Economics, Michigan State University, MI, USA
\textsuperscript{h} National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, CA, 93101, USA
\textsuperscript{i} Centre for Marine Socioecology, University of Tasmania, Hobart, Australia
\textsuperscript{j} Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA, 93106, USA
\textsuperscript{k} Environmental Studies, University of California, Santa Barbara, CA, 93106, USA
\textsuperscript{l} Department of Environmental Science, American University, Washington DC, 20016, USA
\textsuperscript{m} Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YW, UK
\textsuperscript{n} Institute of Aquaculture, University of Stirling, Stirling, FK94LA, Scotland, UK
\textsuperscript{o} NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA, 02543, USA
\textsuperscript{p} Fisheries and Aquaculture Officer, Fisheries and Aquaculture Division, Food and Agriculture Organisation of the United Nations, Rome, Italy
\textsuperscript{q} Urner Barry, Toma River, NJ, 08755, USA
\textsuperscript{r} School of Marine Sciences, University of Maine, Orono, ME, 04469, USA
\textsuperscript{s} School of the Environment, University of Massachusetts Boston, Boston, MA, 02125, USA
\textsuperscript{t} Center for Human Nutrition, Department of International Health, Johns Hopkins Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, 21205, USA
\textsuperscript{u} Beijer Institute of Ecological Economics, The Royal Swedish Academy of Sciences, 104 05, Stockholm, Sweden
\textsuperscript{v} Stockholm Resilience Centre, Stockholm University, 106 91, Stockholm, Sweden
\textsuperscript{w} College of Fisheries and Life Science, Shanghai Ocean University, Shanghai, 201306, China

\textbf{ABSTRACT}

The COVID-19 pandemic and subsequent lockdowns are creating health and economic crises that threaten food and nutrition security. The seafood sector provides important sources of nutrition and employment, especially in low-income countries, and is highly globalized allowing shocks to propagate. We studied COVID-19-related disruptions, impacts, and responses to the seafood sector from January through May 2020, using a food system resilience ‘action cycle’ framework as a guide. We find that some supply chains, market segments, companies, small-scale actors and civil society have shown initial signs of greater resilience than others. COVID-19 has also highlighted the vulnerability of certain groups working in- or dependent on the seafood sector. We discuss early coping and adaptive responses combined with lessons from past shocks that could be considered when building resilience in the sector. We end with strategic research needs to support learning from COVID-19 impacts and responses.
1. Introduction

The COVID-19 pandemic and subsequent lockdowns are creating health and economic crises, leading to increasing incidence of poverty (Sumner et al., 2020) and a looming food crisis (Conti et al., 2020; World Food Programme, 2020). The food system has been seriously disrupted with impacts occurring at multiple levels and across supply chains (Hobbs, 2020; Global Panel, 2020; Devereux et al., 2020; Chenarides et al., 2020). Studying these impacts identifies vulnerabilities within the food system as well as opportunities for governments, international bodies, industries, small-scale actors, and civil society to respond, learn, adapt, and build resilience to future shocks. Seafood is one of the most traded food commodities, both globally (Gephart and Pace, 2015) and regionally (Belton et al., 2018), and is composed of many species and production and distribution strategies. Much can be learned about food systems in pandemics by studying COVID-19-related shocks and responses in the seafood sector.

The current pandemic began in China, the world’s giant when it comes to producing, consuming, and exporting seafood (FAO, 2019). As the pandemic spreads and reemerges, a patchwork of impacts and responses are occurring across this sector and across scales. Strategies to absorb shocks, react, and restore the functions of the seafood sector are critical. For hundreds of millions of people, seafood is an integral part of their livelihood, culture, and food and nutrition security (FAO, 2018). Included in these populations are women, migrant workers, and a large informal sector (Kelleher et al., 2012) that may not benefit from pandemic aid funds from governments or financial institutions.

In order to rebuild toward a more resilient food system, it is necessary to understand the scope of recent disruptions, impacts, and range of responses. We applied a food system resilience ‘action cycle’ framework (Fig. 1) (Tendall et al., 2015) as informed by concepts of coping, adaptation (Lebel et al., 2006), and specified vs. general resilience (Folke et al., 2010). We use the term resilience to mean the “capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances” (Tendall et al., 2015). Using these concepts, we ask three central questions: First, how has the seafood system been impacted by COVID-19? Second, what types of responses have occurred thus far to absorb and react to COVID-19 disruptions and what actions have been taken to restore system functions? Third, what lessons from current and past shock events can help to inform actors and institutions as they build resilience to future shocks to pandemics or other types of large-scale disturbances?

2. Materials and methods

2.1. Data

Seafood production, trade, and retail sales were collected through June 2, 2020 from national government agencies and market reporting companies. Many datasets were reviewed and analyzed, and only a handful are presented here to show examples of different types of impacts to regions, sub-sectors, and stages of the value chain. We analyzed China domestic fish sales at 147 wholesale markets (MOA, 2020) to show the early impacts of lockdowns in China. We explored shifts in trade using China imports of edible seafood, China tilapia exports by product form and region (China Customs, 2020), Ecuador shrimp exports by region (Rubio and Schreiber, 2020), Norway farmed salmon exports (Norwegian Seafood Council, 2020), and international trade data (i.e., United Nations Comtrade) (United Nations, 2017). To illustrate consumer shifts in the Global North we examined European Union seafood imports of live-fresh and frozen products, which represents 80% of total import value (European Market Observato, 2020), as well as U.S. reservation data from over 20,000 restaurants (Open Table, 2020), U.S.
Examples of responses were drawn from the database (Gephart et al., 2020) as well as emerging policy statements and technical reports published by governments and development partners during our study period to create Table 1 and Supporting Information Table S1. Utilizing these latter sources, enabled us to rapidly evaluate early responses and strategies around the world and across sectors in the seafood supply chain. Responses and strategies were inventoried and then organized thematically using an iterative and inductive approach as new information became available.

2.2. Terms and definitions

We distinguish between specified resilience (specific to one type of shock) and general resilience to a range of shocks and stressors (e.g., economic, political, climatic, or biotic) (Folke et al., 2010). For either dimension, ‘building resilience’ can be an explicit goal of seafood system governance in the future. When considering responses to shocks, we refer to coping as short-term reactive measures that cannot be sustained for long periods and adapting as longer-term and planned change in practices (Lebel et al., 2006).

3. Results and discussion

3.1. General disruptions from COVID-19 to the seafood system

Published data across news, social media outlets, governments, and development partners provide an emergent picture of disruptions or shocks to multiple stages of supply chains (Fig. 2). These disruptions caused a generalizable range of impacts across different subsectors, product forms, markets, and consumer segments. Impacts from the pandemic were felt first in China and among its trading partners (Fig. 3), but quickly spread around the world. In some cases, disruptions occurred simultaneously to multiple stages of a supply chain. In other cases, the impacts propagated out as a pressure wave ahead of COVID-19 cases, causing second order impacts following shifts in trade. We also expect lagged impacts caused by high uncertainty about future demand or disruptions to production inputs that take longer to be realized. Disruptions in some regions or sectors are magnified by existing stressors such as climate change, natural hazards (Pacific cyclone season, African locust season), resource management, and political or economic instability. Below we use data to discuss specific disruptions to seafood demand, distribution, labor, and production.

3.1.2. Demand disruptions

The first demand impacts were experienced in China in late January and early February 2020, as lockdowns caused domestic seafood trade to drop precipitously with high-value marine fish species sold at restaurants more impacted than lower value farmed carp sold at retail outlets (Fig. 4a). Lower consumer demand in China led to reduced import volumes, however, as the pandemic subsided within China, seafood imports and domestic carp sales rebounded, but sales of high-value marine fish to restaurants have not rebounded (Fig. 4a and b). In high-income countries, such as the United States (U.S.) there was a dramatic shift in all food sourcing favoring eating at home over restaurants due to public health measures to reduce COVID-19 spread (Fig. 4c). This shift in food sourcing is reflected by more online searches for terms “seafood recipes” and “seafood delivery” in the U.S. compared to the previous four years (White et al., 2020). As restaurants typically sell more expensive live and fresh seafood, restaurant closures constrained markets for these products. In the European Union, lower demand at restaurants led to a 30% drop in imported live-fresh seafood prices (Fig. 4d).

In low-income food-deficit countries, such as Ethiopia, public health interventions reduced household incomes, which translated into reduced expenditures on nutrient dense foods that, if sustained, could lead to malnutrition (Hivrvonen et al., 2020). In Yemen, where seafood...
plays a bigger role in diets and economies, there has been a coincidence of war, climate change, and now COVID-19, which has led to famine (na, 2020a). As COVID-19 spreads, poverty and hunger will continue to be concerns in low- and middle-income countries (LMICs) (Laborde et al., 2020).

3.1.3. Distribution disruptions

Seafood trade was disrupted, redirected, or halted by sudden shifts in demand, supply, and limits on the movement of goods and people. Many of the earliest trade impacts radiated from China (Fig. 3). In January 2020, China banned imports of live animals which impacted trade of e.g. live lobsters from many countries (Fig. 3). Some ports were closed for quarantine, which forced cargo ships to reroute and increased congestion at other ports, or shipments were cancelled entirely (Mereghetti, 2020). Cancelled international passenger flights created logistical problems and increased air freight costs for high-value seafood products such as farmed Atlantic salmon (Huffman, 2020). Cancelled shipments left producers and distributors without a market for perishable products or with a shortage of freezer space. In some cases, distributors were able to shift trade to other markets showing signs of greater resilience. For example, frozen Ecuadorian shrimp was re-routed from China to the U.S. and Europe in January through March 2020, and then back to China in April 2020 (Fig. 4e). Norwegian salmon was redirected from China to other countries such as the U.S. and Brazil (Seaman and Harkell, 2020), without a significant change in volume or price (Fig. 4f). As consumers began eating more at home, China dramatically increased their exports of processed tilapia, which are breaded or spiced fillets that are easy to cook at home (Fig. 4g and h).

Trade disruptions have secondary impacts on LMICs. For example, the diversion of China’s farmed tilapia to North America (Fig. 4h) corresponded with a drop in exports to some countries, notably a 50% drop in exports to some developing countries in April 2020. The drop in Chinese tilapia initially opened up markets to local fishers around Lake Victoria (Standard Team, 2020), however, this short-term benefit was dampened as the Kenyan government introduced curfews to control the spread of COVID-19. Curfews decreased night-fishing activity for both expensive export products (e.g., Nile Perch) and affordable nutritious small fish for local consumption (e.g., Dagaa) (Kolding et al., 2019), which along with trade shifts, increased price volatility (Ramsdan, 2020). Tilapia farms on Lake Victoria suffered disrupted feed supplies and responded to increased demand for smaller fish and expanded market opportunities outside of the capital.

As countries increase screening for COVID-19, trade disruptions will continue pending positive detection. China has recently halted seafood trade with Brazil, Chile, Ecuador, Indonesia, India, the Netherlands, and Russia after finding COVID-19 on packaging. While the likelihood of
virus transmission to humans through food is low (Rizou et al., 2020), a risk-averse approach to food safety will result in overly cautious rejection of suspect products.

3.1.4. Labor disruptions

Lockdowns disrupted employment in seafood supply chains for workers, and access to labor for seafood businesses. In many low-income food deficit countries, farms and enterprises in food supply chains provide self-employment and casual work for many people. COVID-19 policy responses impacted the operation of such businesses resulted in lowered incomes and caused substantial unemployment (Reardon et al., 2020; Liverpool-Tasie, Reardon, Belton). Migrant fish workers were not

---

**Fig. 3. COVID-19 timeline and seafood-related impacts first affected China and their trade partners.**

- **a.** COVID-19 case rate in select countries that trade with China (Dong et al., 2020).
- **b.** Exemplary impacts identified in media and trade articles (Gephart et al., 2020). Total seafood trade = sum of imports and export flows with China.

**Legend:**
- A Wild lobster, farmed salmon, geoduck exports cease
- B Farmed salmon exports to China cancelled
- C Cancelled exports continue. Chinese freezers full, ships re-routed
- D Imports of Chinese tilapia slow
- E Chinese aquaculture exports struggling with border and labor restrictions
- F World Health Organisation declare COVID-19 a pandemic
- G Lobster fishery closed due to cancelled exports to China
- H Slow recovery of exports of farmed shrimp to China and US
able to leave fishing boats in India, ports in Thailand, or an Ecuadorian fishing vessel in the South Pacific, and closures of fish markets have rendered many fish workers jobless (Marschke et al., 2020; Havice et al., 2020; WorldFish, 2020). India’s nationwide lockdown also forced the closure of hatcheries, feed mills and processing plants, and sharp drop in demand from the U.S. and Europe reduced international exports of frozen shrimp, which account for 70% of India seafood exports. Similar impacts have been reported in Bangladesh and Myanmar (WorldFish, 2020; Mamun et al., 2020). COVID-19 outbreaks have occurred among seafood process workers in Ghana (Reuters, 2020), the U.S. (Bernton,
3.2.1. Governments and development partners

Seafood production decreases have sometimes occurred in parallel with COVID-19 cases and at other times lagged reductions in consumer demand. COVID-19-related lockdowns have decreased industrial fishing efforts in China, Spain, France, and Italy by 40% to >50% in the first quarter of 2020 compared to 2019 (Clavelle, 2020). Reductions in Pacific tuna fishing are due to port closures and a lack of fisheries observers, while coastal subsistence fishing has increased (na, 2020b). Alaskan fishing and processing vessels experienced outbreaks at sea, and the Alaskan sockeye salmon fishery, which is highly dependent on seasonal workers, saw a 50% reduction in price due to disruptions in trade, air freight, and lower demand for fresh fish (White, 2020).

Aquaculture production has been disrupted as farmers contemplate whether to restock given uncertainty over demand. For example, in April 2020, shrimp farmers across Southeast Asia stopped stocking ponds (Dao, 2020), in some cases due to difficulty importing broodstock, which will produce lagged reductions in supply (UN FAO, 2020). Species with long grow-out periods, such as shellfish and salmon, can be held in the water until markets improve, but not indefinitely and not without economic costs. This range of impacts across the supply chain has been met with diverse responses deployed by governments, the seafood industry, and consumers.

3.2. Reactive actions to COVID-19 by seafood system actors and institutions

We explore the reactivity of multiple actors and institutions in response to COVID-19 through May 2020. These include initial steps to absorb and react to disruptions, and to restore functions to the seafood system (Fig. 1). We categorized these actions as short-term coping and forward-looking adaptive responses. At the time of writing, responses were mostly aimed to: 1) protect public health, including the health of fishery sector workers; 2) support those whose enterprises, jobs, and incomes are affected by COVID-19 related disruptions; and 3) maintain seafood supplies to consumers. Initial coping responses, in particular by governments, sought to maintain the sector’s core functions through the period of wide-spread economic disruption, while protecting the most vulnerable. Longer-term adaptive measures, that often emerge outside of government, can contribute to building COVID-19-specific and generalized resilience to multiple shocks and stressors. Below we discuss specific responses by different actors and institutions which is summarized in Table 1 and Appendix Table S1 with expanded country-specific examples.

3.2.1. Governments and development partners

Government responses have exposed deep tensions between protecting public health and preventing an economic crisis (Appendix Table S1). This is reflected in short-term coping strategies to address immediate challenges posed by the crisis. For example, early on, many governments, including those in Russia, Canada, and South Africa (Seaman, 2020; na, 2020c; Oire, 2020), designated fishers, fish farmers, and fish processors as “essential workers” allowing them to operate in order to maintain the food supply. Along with these actions, protective measures were taken to safeguard worker health (Table 1). These were coupled with social protections to lessen the socioeconomic toll of the pandemic and keep companies going, with efforts to distribute the funds equitably varying in their levels of success (Bloom, 2020; Low Impact Fisheries of Europe, 2020).

Development partners including non-governmental organizations (NGOs) have also acted to support governments in dealing with the immediate impacts of COVID-19. Their actions comprise adaptive responses that can form the basis for building resilience. They targeted countries and regions where governments had limited capacity to implement social and economic measures seen elsewhere. For example, the United Nations Food and Agriculture Organization and WorldFish are providing policy recommendations, technical advice, and support and/or harnessing research to guide government responses (WorldFish, 2020; FAO, 2020). The World Bank is providing grants and loans to countries to assess impacts and develop responses.

3.2.2. Large-scale commercial sector responses

Responses to the pandemic from the industrialized sector have been swift, detecting early signs of weaknesses in global seafood markets and making resources available to rapidly adjust marketing and distribution. Early coping responses focused on protecting worker health, consumer health, and securing production and supply chains during the pandemic (Appendix Table S1). Nevertheless, some seafood workers remained exposed to outbreaks (Reuters, 2020; Berntsen, 2020). The economic response has included reducing the size of workforces to lower expenditures, but some companies have also responded by shifting into or strengthening their positions in retail and online markets, where consumer demand has been high; the ability to make such transitions could represent longer-term adaptation. Companies selling frozen and shelf-stable products as well as companies with strong relationships with retailers have been particularly well positioned to adapt sales from the restaurant sector to retail markets. The use of technology, such as online sales, has allowed companies to promote and market their products and connect with consumers (Appendix Table S1). However, reliance on technology as a solution to the crisis opens the potential for increasing inequity across seafood value chains, as these tools are not available to everybody.

3.2.3. Small scale-sector and non-governmental organization responses

Small-scale fisher responses to the pandemic have predominantly comprised actions that can translate into longer-term adaptive strategies that build resilience. Early on, some small-scale fish worker networks, which are often global with strongholds in LMICs such as India or South Africa, mobilized to share information, document impacts, and advocate for government resources (The International Collective in Support of Fishworkers, 2020). Others formulated recommendations to fight against COVID-19 and improve the working conditions of artisanal fisheries with a specific focus on women (Coalition for Fair Fisheries Arrangements, 2020), who represent a large share of the total workforce (Kleiber et al., 2015). In some cases, producer organizations have bought back fish from their members by applying the withdrawal price — a minimum price guaranteed throughout the year even in the absence of demand. Artisanal fishers and small holders have also turned to food banks and other forms of food sharing to distribute the catch (McVeigh, 2020; Bennett et al., 2020). Some NGOs are working with local fishers and women fish workers to connect catch to private households to support direct marketing of catches that would otherwise go unsold. There has also been a surge in direct producer-to-consumer sales (Stoll et al., 2020). For example, user traffic on the Local Catch Network in the U.S. was up by 310% from March 15, 2020 to May 14, 2020 compared to the previous year.

3.2.4. Consumer responses

Consumer response has been largely conditioned by public health measures that have confined people to their homes. Early responses included panic buying, a shift from restaurants to retail purchases and home delivery and local seafood purchasing (Xia, 2020). Consumers in high-income countries have focused on buying seafood products with longer shelf-life and frozen products, while in low-income food-deficit countries there are early examples of reduced household income leading to shifts towards staple foods and away from nutrient dense foods like fish (Hivronen et al., 2020). There has also been some concern about the safety of seafood as SARS-CoV-2 has been detected on seafood packaging in China (Liu et al., 2020), however, the most common route of transmission is respiratory from person to person (Vella et al., 2020).
3.3. Learning and building resilience to future shocks

COVID-19 has exposed vulnerabilities and power imbalances in the food system, as well as highlighted broader inequalities and health disparities across society (Ahmed et al., 2020; Hooper et al., 2020). Coping and adaptive measures represent early responses during the first five months of the COVID-19 pandemic. Others have identified adaptations such as switching species harvested, selling to alternate markets, supplementing income from other sources, or temporarily stop fishing (Smith et al., 2020). Short-term coping will remain important as the pandemic spreads and re-emerges in countries. Actors and institutions within the seafood sector can carry adaptive responses forward and engage in a process of learning and building robustness to prevent future shocks (Fig. 1). Based on the literature and findings from this study, we provide three key concepts to guide this ‘adaptive cycle’ process.

3.3.1. Identify resilience, vulnerability, and power imbalances in seafood systems

The seafood system is a meshed network of formal and informal producers and distributors, retailers, and consumers. Some supply chains, market segments, companies, small-scale actors and civil society have shown initial signs of greater resilience than others. In high-income countries, food retailers and supply chains selling shelf-stable and frozen seafood have done well following COVID-19-related shifts in food sourcing, while live-fresh and high-value producers selling to restaurants were particularly hard hit. A surge in direct producer-to-consumer sales in the U.S. may foretell a longer-term shift in consumer purchasing habits. Conversely, in many LMICs, such as India, the informal sector was particularly hard hit by restrictive government responses to the crisis that prevented many actors from engaging in their livelihood activities (Balasubramanian and Samuel, 2020), which could lead to less household income and decreased food security.

Maintaining and building diversity and connectivity at the community, company, and country level are ways to build resilience and guard against bad outcomes. Communities with diverse networks, such as in Mexico, were able to mobilize for support in the form of food aid and relief (Ramirez, 2020). Strengthening local food systems, for example in India, is another way to build resilience in communities (Pothan et al., 2020). Companies with diverse portfolios and connections to more markets could more easily switch between commodities or divert products at a global scale (e.g. Ecuadorian shrimp, Chinese tilapia) thus enabling them to continue their business. Diversity and connectivity to markets at the country-level enables continuous supply of seafood.

Many countries, however, are increasingly reliant on food imports from a shrinking number of exporters (Kummu et al., 2020), which makes them more vulnerable to disruptions. The tendency towards concentration in the seafood sector creates power imbalances that risk undermining food security in low-income countries and communities (Osterblom et al., 2015). Companies and countries that were able to diversify and adapt did so, in some cases, by exposing other aspects of the global system (e.g., low-value markets in low-income food-deficit countries) to trade shocks. Efforts to build resilience following COVID-19 should consider resilience to what?, for whom?, and for what purpose? (Lebel et al., 2006), and be attentive to the possibility of propagated impacts from these decisions.

3.3.2. Transition from short-term coping to longer-term adaptation

As the pandemic shifts and reemerges in countries, there will be continuing need for coping responses to maintain the sector’s core functions and protect vulnerable populations working in- or dependent on the seafood sector. Some coping responses, such as removing normal restrictions on fishing or increasing fishing quotas, which result in overharvesting, may be maladaptive or have unintended consequences that undermine the resilience of the seafood system in the long-term. Responses will vary across regions and countries reflecting the different levels of economic, social, and political capital available to address the impacts across sectors in the seafood system, as well as the nature of the labor market. Informally employed workers, many of whom are women and migrants and are especially prevalent in Asia and Africa, are often omitted from social protection schemes and other entitlements.

While short-term coping strategies will remain important for some time, it will be critical for actors and institutions to transition to the preventative phase of the resilience ‘action cycle.’ This phase includes starting the learning process and developing and implementing longer-term adaptation strategies and resilience building, which is necessary to prevent impacts of future shocks and respond to ongoing stressors such as climate change or political instability. These shifts will be staggered in time as actors move beyond the reactive phase and the pandemic progresses through countries and regions of the world. An additional consideration is how specialized adaptations should be as increasing resilience of the seafood sector to future pandemics may reduce general resilience to an unknown array of future shocks ( Folke et al., 2010). Lastly, the United Nations recommends using the COVID-19 shock as an opportunity to transform the food system to be more green, inclusive, and resilient (United Nations, 2020a, 2020b). The idea of shocks as “windows of opportunity” to engage in transformations is a key feature of resilience thinking (Folke et al., 2010). The current seafood system does not work for all people; it falls short in addressing concerns over environmental sustainability ( Troell et al., 2014), social equity (Kittinger et al., 2017), and nutrition security (Hicks et al., 2019).

Returning to business as usual following this shock would be missing an opportunity to build forward better.

3.3.3. Avoid mistakes of past responses

While COVID-19 presents a significant shock to the seafood sector in terms of magnitude, extent of supply chain influence, and global scope, previous shocks offer useful lessons (Davis et al., 2020). Three key lessons relate to trade restrictions, overstimulating production, and food prices and aid.

First, to avoid propagating shocks through trade, as occurred in the 2008 grain crisis, countries should maintain food supply buffers and cooperate internationally to avoid export bans and hoarding behavior (Seeckel et al., 2017; Marchand et al., 2016; Gebrart et al., 2016). As of mid-April, 20 countries representing 5% of the global calorie market had implemented restrictions on food exports, mainly for cereals and grains, and limited restrictions on animal products (eggs, chickens) (Larborde-Debuquet, 2020). While these actions have seemingly not triggered a cascading crisis, seafood flows were disrupted with impacts worse in some areas than others, and additional stressors such as associated economic recessions and future waves of COVID-19 could worsen the situation.

Second, surges in fishing effort in Europe after WWII (Holm, 2012) or more recently in Sri Lanka following the 2004 tsunami (De Silva and Yamao, 2007) led to overfishing. As governments and industries try to reboot the economy in the coming period, there is a risk of overstimulating production in some regions and fisheries, which could harm fish populations and the marine environment. Related to overfishing is the need to continue tracking lapses in monitoring, enforcement, and observers aboard vessels as they could lead to illegal, unreported, and unregulated (IUU) fishing and subsequent environmental impacts (Bennett et al., 2020). This underscores the essential work of onboard observers who continue to work under difficult conditions throughout the pandemic.

Third, during past shocks, the quality of the diet often suffers as families shift purchasing behavior to less expensive staple foods. For example, during the 1997 to 1998 Asian financial crisis in Indonesia, households were largely able to maintain calorie intake, but anemia rates rose following decreased consumption of micronutrient rich foods (e.g., eggs, meat, fish) due to high prices (Klotz et al., 2008). This is confirmed in Bangladesh, where maintaining low staple food prices can benefit lower income consumers by freeing up money to access fish and other pricier foods (Torlesse et al., 2003). It is estimated that the...
COVID-19 pandemic could double the number of people who are acutely hungry, from 130 million currently to 265 million (World Food Programme, 2020). Understanding the complex interplay between household income, food prices, and access for staple foods and micronutrient dense foods (including fish) can help governments and institutions better respond to current and future shocks.

4. Conclusion

This paper describes disruptions to- and responses by actors at multiple levels in the seafood system to fast moving, continually evolving shocks that have a direct impact on livelihoods, economies, food and nutrition security. We use a resilience ‘action cycle’ framework to study the first five months of COVID-19-related disruptions, impacts, and responses to the seafood sector. This framework helps actors and institutions contextualize their responses to the current shock, and learn, adapt, and prepare for future shocks. As the pandemic continues to threaten public health and economies there is much we need to learn. We propose a series of immediate and longer-term research needs to guide strategic research investments, and show examples of new studies that fill proposed research gaps (Table 2). COVID-19 has also highlighted the vulnerability of certain groups working in- or dependent on the seafood sector. Early coping and adaptive responses, combined with lessons from past shocks, can help inform steps to build resilience in the sector.

Author contributions

DC Love, EMN, JSS, PPdS developed the initial concept. DC Love and JAG wrote the abstract. DC Love and EHA wrote the introduction. RSC and DC Love led the section on COVID-19 disruptions with writing as review by MT, JAG, HA, AR, JSS, FP, MFT, and MT. JSS and FP led the section on reactive actions with writing as review by HF, EHA, CH, PPsD, FP, MT, and ALTL. EHA led the section on learning and building resilience with writing as review by JAG, RSC, MFT, FP, CS, PPsD, MT, and DC Love. JSS, FP, CH and ALTL created Table 1. DC Little and ALTL created Table 2. EHA and DC Love created Fig. 1. MFT, MT, DC Little, DC Love, JAG, and EHA created Fig. 2. RSC, JAG, HEP, EMN, and JSS created Fig. 3 and collected data and reviewed media publications/im- pacts for Fig. 3 and Table 1. DC Love, FA, BB, DC Little, AR, and WE created Fig. 4. All authors contributed to the study design and reviewed the manuscript.

Declaration of competing interest

The authors declare the following competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. HEF serves on the Technical Advisory Group for Aquaculture Stewardship Council. JAG is a member of the Oceana Science Advisory Board. DC Little is a Member, Standards Oversight Committee for Global Aquaculture Association, Director Nam Sai, Thailand. JSS owns and operates a small-scale oyster farm; coordinates Local Catch Network. MFT is on the Scientific and Nutritional Advisory Council for Seafood Nutrition Partnership, the Standards Oversight Committee for Global Aquaculture Association, and a judge for Future of Fish Feed Challenge.

Acknowledgements

The CGIAR Research Program on Fish Agri-Food Systems (FISH) (for BB and EHA), and, also for EHA, Nippon Foundation Ocean Nexus program. DC Love, EMN, ALTL acknowledges funding from Johns Hopkins Center for a Livable Future (JHU) via the Santa Barbara Foundation. ALTL acknowledges funding from the Feed the Future Innovation Lab for Nutrition (USAID Cooperative Agreement No. AID-OAA-L-10-00005). RSC acknowledges funding from the National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara. HEP acknowledges support from the University of California, Santa Barbara. MT acknowledge SEAWIN project funded by Formas (2016-00227). CH acknowledges ERC grant number: 759457.

We thank Rahul Agrawal Bejarano (U Michigan), Ruth Young (JHU), and Eric Hofmeister (JHU) for assistance documenting news articles. We thank Mike Milli (JHU) for assistance with graphic design. We thank the EU Market Observatory for Fisheries and Aquaculture, Janice Schreiber, Urner Barry, and the Norwegian Seafood Council for kindly sharing seafood trade data.

The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect those of NOAA or the Department of Commerce.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2021.100494.

References

Ahmed, F., Ahmed, Ne, Pisaniades, C., Stiglitz, J., 2020. Why inequality could spread COVID-19. Lancet Public Health 5 (5), e240. Balasubramanian, S., Samuel, J., 2020. Coronavirus Lockdown Adds to Woes of Climate-Hit Fishers. India Climate Dialogue. Belton, B., Bush, S.R., Little, D.C., 2018. Not just for the wealthy: rethinking farmed fish consumption in the Global South. Global Food Security 16, 85–92.
Bennett, N.J., Finkbeiner, E.M., Ban, N.C., Belhabib, D., Jupiter, S.D., Kittinger, J.N., et al., 2020. The COVID-19 pandemic, small-scale fisheries and coastal communities. Global Food Security 28, 100494.

Clavellé, T., 2020. Global fishing watch. Editor. Available from: https://globalfishingwatch.org/data-bag/global-fisheries-during-covid-19/

FAO, 2020. Q&A: COVID-19 pandemic - impact on fisheries and aquaculture. Available from: http://www.fao.org/2019-ncov/q-and-a/impact-on-fisheries-and-aquaculture/en/

Kleiber, D., Harris, L.M., Vincent, A.C., 2015. Gender and small-scale fisheries: a case for counting women and beyond. Fish Fish. 16 (4), 547–562.

Hicks, C.C., de Pee, S., Thorne-Lyman, A., Kramer, K., Bloom, M., 2008. Nutrition in the perfect storm: why micronutrient malnutrition will be a widespread health consequence of high food prices. Sight Life Mag. 2, 6–11.

Kolding, J., van Zwiert, P.A., Martin, P., Funge-Smith, S., Poulain, F., 2019. Freshwater fish and the global food and fisheries in the main African Great Lakes and Reservoirs in relation to Food Security and Nutrition. Food and Agriculture Organization of the United Nations.

Kummu, M., Geetha, R., Antony, J., Vasagam, K.K., Arand, P., Ravivankar, T., et al., 2020. Prospective impact of Coronavirus disease (COVID-19) related lockdown on shrimp aquaculture sector in India – sectoral assessment. Aquaculture 531, 735922.

Liu, P., Yang, M., Zhao, X., Guo, Y., Wang, L., Zhang, J., et al., 2020. Cold-chain transportation in the frozen food industry may have caused a recurrence of COVID-19 cases in destination: successful isolation of SARS-CoV-2 virus from the imported frozen cod package surface. Biosaf. Health.

MOA, 2020. Information platform of key agricultural markets. Available from: http://www.scxx.moa.gov.cn:8080/misportal/public/agricultureStaticReportView.jsp.

Nielsen, 2020. How Americans are shopping during COVID-19. Available from: https://www.nielsen.com/global/en/consumer-insights-for-fmcg-retail-manufacturers-co.^/consumer-behavior-insights-during-covid-19/.

OECD, 2020. Low Impact Fisheries of Europe. Covid-19 and small-scale fisheries. Available from: https://www.oecd.org/officialdocuments/publicdisplaydocumentdata/0,9774,en_2649_38441_47131802_1_1_1_1,00.html.

UN, 2020a. Tens of Millions of Nigera’s Devastated by Unabated War and COVID-19. UN News.

UN, 2020b. SPC Warns of Threat to Fisheries from Covid-19. Radio New Zealand.

World Bank, 2020. Immediate impact of COVID-19 across tropical small-scale fishing communities. Available from: https://www.bloomassociation.org/appel-citoyen-petite-peche/.

World Bank, 2020. Vulnerability to shocks in the global seafood trade network. Environ. Res. Lett. 11 (9), 095009.

World Bank, 2020. Food supply chains during the COVID-19 pandemic. Can. J. Agric. Food. 11 (1), 912–913.

World Bank, 2020. Food export restrictions during the Covid-19 crisis. In: (IFPRI). IFPRI.

Hicks, C.C., Cohen, P.J., Graham, N.A., Nash, K.L., Allison, E.H., Johns Hopkins University, Chenarides, L., Manfredo, M., Richards, T.J., 2020. COVID-19 and food supply chains. Appl. Econ. Perspect. Pol.
Seekell, D., Carr, J., Dell`Angelo, J., D’Odorico, P., Fader, M., Gephart, J., et al., 2017. Resilience in the global food system. Environ. Res. Lett. 12 (2), 025010.

Seshagiri R, Nagireddy M, Raju VR, Nagireddy S, Rangacharyulu P, Rathod R, et al. Impact of Nationwide Lockdown on Freshwater Aquaculture in Andhra Pradesh, India.

Smith, S.L., Golden, A.S., Ramenzoni, V., Zemeckis, D.R., Jensen, O.P., 2020. Adaptation and resilience of commercial Fishers in the Northeast United States during the early stages of the COVID-19 pandemic. PloS One 15 (12), e0243886.

Sorensen, J., Echard, J., Weil, R., 2020. From bad to worse: the impact of COVID-19 on commercial fisheries workers. J. Agromed. 1–4.

Standard Team, 2020. For Nyanza Fishermen, it is the Best and Worst of Times. Standard.

Steenbergen, D.J., Neihapi, P., Koran, D., Sami, A., Malverus, V., Ephraim, R., et al., 2020. COVID-19 restrictions amidst cyclones and volcanoes: a rapid assessment of early impacts on livelihoods and food security in coastal communities in Vanuatu. Mar. Pol. 121, 104199.

Stoll, J.S., Harrison, H.L., De Sousa, E., Callaway, D., Collier, M., Harrell, K., et al., 2020. Alternative Seafood Networks during COVID-19: Implications for Resilience and Sustainability.

Sumner, A., Hoy, C., Ortiz-Juarez, E., 2020. Estimates of the Impact of COVID-19 on Global Poverty. United Nations University.

United Nations, 2020a. Policy Brief: the Impact of COVID-19 on Food Security and Nutrition. Rome.

United Nations, 2020b. Policy Brief: the Impact of COVID-19 on Food Security and Nutrition: Developing Effective Policy Responses to Address the Hunger and Malnutrition Pandemic. Rome.

USDA, 2020. Food expenditure series. Available from: https://www.ers.usda.gov/data-products/food-expenditure-series/.

van Senten J. Effects of COVID-19 on US aquaculture farms. Appl. Econ. Perspect. Pol.

Vella, F., Senia, P., Ceccarelli, M., Vitale, E., Maltezou, H., Taibi, R., et al., 2020. Transmission mode associated with coronavirus disease 2019: a review. Health 1, 2.

White, C., 2020. Alaska’s Seafood Processors Hit Hard by COVID-19 Costs. Seafood Source.

White, E.R., Froehlich, H.E., Gephart, J.A., Cotrell, R.S., Branch, T.A., Agrawal Bejarano, R., et al., 2020. Early Effects of COVID-19 on US Fisheries and Seafood Consumption. Fish and Fisheries.

World Food Programme, 2020. Targeting and Prioritization of Impoverished and Food-Insecure Populations Affected by COVID-19.

WorldFish, 2020. COVID-19 impacts on fish and aquatic food systems. Available from: https://www.worldfishcenter.org/pages/covid-19/.

Xia, R., 2020. Environmental Groups Urge Americans to Eat More Fish while Hunkering Down against Virus. Los Angeles Times.

Troell, M., Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H., Folke, C., et al., 2014. Does aquaculture add resilience to the global food system? Proc. Natl. Acad. Sci. Unit. States Am. 111 (37), 13257–13263.

UN FAO, 2020. COVID-19 dampens the initially positive shrimp forecast for 2020. Available from: http://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/1296667/.

United Nations, 2017. UN comtrade database. Available from: https://comtrade.un.org/.

Torlesse, H., Kiess, L., Bloem, M.W., 2003. Association of household rice expenditure with child nutritional status indicates a role for macroeconomic food policy in combating malnutrition. J. Nutr. 133 (5), 1320–1325.