# The future of wild-caught fisheries: expanding the scope of management

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In recent years, the approach to wild-caught fisheries management has expanded beyond traditional single-fishery management. In this article, we examine potential market failures within the fisheries sector that may arise because of a failure to account for key features of wild-caught fisheries and that an expanded scope can address, including multiple species being caught together, multiple fisheries targeting the same stock, and other ecological and socioeconomic interconnections within ecosystems. We also examine market failures that may arise when external factors such as climate change and species invasions are not considered in fisheries management policy decisions or if policies do not consider factors such as multi-sector use of seascapes, the linkages between water pollution and fisheries, and market failures that cut across fisheries and non-fisheries sectors that involve under provision of publicly available data and lack of information sharing along the supply chain. We find that policies that address these market failures typically have distributional effects – there will be winners and losers, even if aggregate efficiency increases. We conclude that both research and policy design need to more explicitly consider equity-efficiency trade-offs when seeking to address market failures and we propose priorities for policy and research aimed at supporting the sustainability of wild-caught seafood.

## Introduction

Wild-caught fisheries[4], also called capture fisheries, make significant contributions to human well-being, including by contributing to food security and alleviating poverty. However, poor management and external stressors can undermine the environmental, economic, and social sustainability of these fisheries.

In this article, which is part of a symposium on The Future of Seafood,[5] we examine potential gains from expanding the scope of management policies that impact fisheries, framing our examination around market failures beyond those traditionally considered by economists in the fishery management context. In particular, we view wild-caught fisheries from a broad perspective that goes beyond the traditional single-species fishery management paradigm. We generally follow the recent scope of fisheries management policy and economic research in developed countries, which has shifted from a single-fishery single-species focus to a broader perspective called Ecosystem-Based Fisheries Management (EBFM); this includes interactions between fished species and the broader ecosystem as well as interactions between the biophysical subsystem and human subsystem and complexities within the human system (Hilborn, 2011; Marshall, et al., 2018). We pay particular attend to how fishers are part of coastal communities that are linked to the broader economy and society.

With this broader socio-environmental context in mind, we expand the scope with each section. We first provide a brief background on well-established market failures and management solutions in fisheries, and then examine the various and interacting market failures that are endogenous and exogenous to the capture fisheries sector. Next, we identify and examine cross-cutting market failures. We then examine

[4] There is no single definition of a fishery. Throughout this article we use the term fishery generally to indicate a management unit, regardless of specific management unit attributes such as species, fishing gear or geographic location.

[5] The other articles are by Abbott et al. (2022), who discuss the future of recreational fisheries, Asche et al. (2022), who focus on aquaculture, and Cojocaru et al. (2022), who provide a synthesis of the other three articles in the symposium and discuss key issues concerning the global seafood system.

the trade-off between efficiency and equity. Throughout these sections we identify a tradeoff between fully addressing all market failures through policy (which would be excessively costly) and adopting a narrower scope (which may fail to address costly market failures). In the final section, we highlight priorities for future policies and research aimed at supporting the sustainability of wild-caught fisheries.

## Background

Over the past half century, economists have helped shift the policy discourse concerning wild-caught fisheries management from focusing on ecological sustainability through limits on catch to maximizing the economic benefits from fisheries (Wilen, 2000). In this section we provide an overview of catch shares as an approach to correcting market failures in fisheries and a short summary of the heterogeneity in fisheries regulation worldwide.

### Catch Shares to Correct Fisheries Market-Failures

It has been well-established in the economics literature that market failures can lead to policy failures and under-performance in terms of the economic efficiency of a fishery (e.g. Clark (1990)). When there is no regulation on who can fish, but fish are relatively cheap and easy to access, the well-known tragedy of the commons emerges with too many boats racing to catch too few fish (Gordon, 1954). Two common market failures in fisheries have been carefully studied: stock and congestion externalities (Smith, 1969). Stock externalities arise due to the actions of one fisher affecting the fish stock, which in turn affects the economic well-being of other fishers targeting the same stock because of the decreased availability of fish and the increased costs of fishing. A congestion externality arises when fishing costs increase because of crowding of the fishing grounds.

Lack of regulation can lead to erosion of economic value of unregulated fisheries, which has led to the emergence of policies such as catch shares that can improve economic efficiency (Sanchirico and Wilen, 2007). Catch share program designs have been informed by economics research and include management that allocates shares of the available catch to fishers, fishing communities, or other entities. The security of the allocated shares helps alleviate the race to fish. Individual transferable quota (ITQ) programs are a common type of catch share that set a cap on total catch, assign fishers a portion of the catch, and allow them to trade their allocations. This can substantially increase economic efficiency because the allocations will flow through trade to those that value them the most in an efficient allocation market.

To-date there are more than 200 catch-share programs implemented worldwide (Figure 1), with many covering a single stock. Early on, only a few programs, such as those in New Zealand and Iceland, involved relatively comprehensive coverage across commercially caught species (e.g. Wilen (2000)). Indeed, historically fishery management plans have focused on the management of a single fishery (e.g. Collie et al. (2016)). Although multi-species catch share programs have become more common over time, about half of the documented catch share programs cover only a single species (Figure 1).

Evaluation of catch share impacts has been somewhat limited with past economics research on the design and evaluation of wild-caught fisheries management policies generally focusing on impacts within the catch share program fisheries. Early research on catch shares focused on biological outcomes in catch share fisheries (Costello et al., 2008). More recently, research has expanded to include economic and other social outcomes (e.g. Asche et al. (2018); Hoshino et al. (2020)). For example, catch shares can increase fishery profitability through mechanisms such as lengthening fishing seasons to allow fishers to catch fish when prices are high (Birkenbach et al., 2017) and enabling switching to more valuable fish products (e.g. Homans and Wilen (2005)), for example by catching larger and often more valuable fish (Stoeven et al., 2021). Additionally, catch shares that provide security related to catch allocations can improve fisher safety (Pfeiffer & Gratz, 2016) by providing fishers the opportunity to choose safe times to fish their allocations over a long season. There is also evidence though, that catch share management may be more expensive than alternatives such as closing the fishery when a catch limit is hit. However, Mangin et al. (2018) find that catch shares appear to increase net fishery profitability even once these increased management costs are considered.

Although these market-based programs have transformed fisheries management, they face considerable opposition for reasons including impacts on those not directly involved in the catch share fishery, such as coastal communities. In fact, there has been a slowdown in the number of new catch-share programs implemented in the past decade (Figure 1). In addition, recent work finds that there are still barriers to maximizing societal benefits from wild-caught fisheries (e.g. Marshall, et al. (2018)), suggesting an important role for economists in future fisheries management design.

## Global Heterogeneity in Regulation and Enforcement

There is established heterogeneity in regulation and enforcement that results in different types of market failures and management challenges worldwide. To-date most implementation and evaluation of catch share programs has occurred in developed country contexts (Jardine and Sanchirico, 2012), where institutions are strong enough to support the required catch accounting, monitoring, and enforcement. A phenomenon driven by weak or no monitoring and enforcement is illegal and unreported fishing – a major concern in global fisheries, particularly in countries with relatively weak institutions and regulations and in the high seas (Agnew, et al., 2009). For example, (Agnew, et al., 2009) estimate that illegal and unreported catches accounted for 18% of reported catches in 2003, a slight drop compared to their estimates for the 1980s and 1990s. The study reports big differences in the share of illegal and unreported catches both across fisheries and regions, with Eastern Central Atlantic having the highest share (37%). This is in line with the results of other studies (e.g. Pauly and Zeller (2016)), but more work is needed to reduce the uncertainty in estimates of illegal fishing.

Stricter regulations and enforcement of fish harvesting in some parts of the world can reduce supply from these regions, which can increase price and create an incentive to increase fishing of resources in other parts of the world where the regulation is weaker. While developed countries are moving in the direction of more sustainable fisheries management, the opposite is true for many developing countries, which struggle with overcapacity, over-exploitation and declining stocks (Ye & Gutierrez, 2017).

## Market Failures Endogenous to the Wild-caught Fisheries Sector

In this section, we examine market failures that are endogenous to the wild-caught fisheries sector and arise from: multi-species catch; cases where multiple fisheries are regulated separately but target the same stock; and the potential for ecological or socioeconomic interconnections to exist within an ecosystem (Figure 2). In the remainder of the section, we describe each market failure and potential management systems that have been used to address them.

### Multispecies Catch

It is common for catch to be composed of multiple species. However, this can result in externalities, including impacts on non-target species (bycatch) and unregulated species. Bycatch, which occurs when species other than the targeted species are incidentally caught,[6] can negatively impact the ecological health of the incidentally caught species population. It is a common and well-studied fisheries problem (see, for example, Smith (2012) for a review).

In addition to the issue of bycatch, fishers often jointly target groups of species, particularly in multispecies groundfish complexes, which can lead to market failures through inefficient catch of some or all species.

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[6] This may include both iconic species (such as dolphins) and less iconic species.

In some cases, the species group may be managed jointly (e.g., the Norwegian cod, haddock and saithe trawl fisheries), but in other cases, only one or a subset of species is managed, which has implications for the type of market failure we expect. Birkenbach et al. (2020) explore the case of joint management of a species group and find that even in a multispecies fishery that is regulated through individual vessel catch limits for all species, the regulations as well as the market and biological conditions of one species can influence outcomes for other species. Quaas and Requate (2013) find that when one or a subset of total fished species is managed, there can be increased incentives to fish others (e.g., through interactions on fish markets). In Norway's pelagic fisheries, reducing quotas for a subset of species targeted by a fleet was found to increase pressure on other species targeted by the fleet (Asche, et al., 2007). Similarly, in the case of rockfish species in the US West Coast groundfish trawl fishery, Holland (2010) finds that a small catch limit on one species (relative to limits for other species) results in rare and uncertain catch of that species, which potentially constrains catches of other species with larger catch limits.

Harvesting of non-target species, either unintentionally as bycatch or intentionally, results in a similar choice between two potential solutions: broadening the scope of management and bringing the non-target species under the same program management as the target species and simultaneously determining the efficient catch for all species or implementing a solution that may be less costly to implement but may not fully resolve the externality (Smith, 2012). Future technological advances may enable fishers to be more selective in what they catch and may reduce the externality(ies) associated with a narrower management scope. For example, O'Neill, et al. (2019) examine how the fishing industry can improve selectivity (that is, reduce impacts on non-target and unregulated species) by using the latest available technologies to learn more about the interaction of fish and fishing gears. However, as we will discuss in the final section, more research is needed to identify opportunities for gains from a broader management scope and design policy that takes advantage of the potential gains.

## Multiple Fisheries Regulated Separately that Target the Same Stock

It is relatively common for fishers in multiple separately managed fisheries to target the same stock, which can lead to market failures when the allocation of catch between fisheries is not efficient. Specifically, this type of market failure can arise when fishers are divided into fisheries based on type of activity (e.g. recreational or commercial fishing), fishing gear used, or the age or size classes of the fish species targeted. In more well managed fishing regions, a total allowable catch (TAC) for a species is generally set and then allocated between the fisheries to ensure the total catch is sustainable. In this case, an allocation to one fishery directly reduces what is available to the other(s). Additionally, one fishery can affect another through habitat impacts (such as trawl gear dragged across the seafloor damaging the habitat on which the species depend, thus impacting the fish stock and other fishers using other gear). This means that an economically efficient allocation between fisheries requires efficient allocation both across fisheries as well as within each fishery.

One way to improve the efficiency of cross-fishery allocations of catch is to implement a catch share program that allows trade between participants across fisheries or that allows gear switching (e.g. from a fishing gear like trawl to hook and line) so that quota flows to users that place the highest value on access to the catch. However, this approach could be costly in the short run due to factors that go beyond direct management costs (e.g., capital adjustment costs associated with purchasing new fishing gear) and could be difficult to implement from a political economy perspective. Indeed, recreational and commercial allocations of the TAC have historically been contentious in many fisheries (Abbott, et al., 2022), as have allocations between types of fleets (e.g. trawl vs. longline). In addition, an efficient management approach would account for different impacts on habitat and ages of fish targeted, which are difficult to assess and incorporate into management programs. This suggests that resolving market failures due to multiple fisheries fishing the same stock may be challenging for political as well as informational reasons.

## Potential for Ecological and Socioeconomic Interconnections within an Ecosystem

Within an ecosystem fished species and the fishers and communities that rely on them are connected in multiple ways. One way an externality can arise in these types of connected systems is if the interactions between species in the foodweb[7] are not considered during the quota setting process, leading to decisions in one management unit imposing externalities on others through the impacts of fishing one species on the others in the foodweb. Accounting for these interactions can lead to changes in catch limits that support the ecological sustainability of the overall system and maximize system-wide economic yield (e.g. Sanchirico et al. (2008)).

Recently, there have been calls from researchers and policymakers to examine fisher decisions related to choices including where, when, and what species they will fish and the broader socioeconomic outcomes of fisheries management from a similar ecosystem-scale perspective. These more holistic EBFM approaches are intended to account for the connections within and between the human and natural systems (Marshall, et al., 2018). This broader scope allows for explicit acknowledgement that fishers may consider many fisheries when deciding where, when and how much to fish. In the remainder of the subsection, we describe three key considerations related to broadening management from the single-fishery to ecosystem-scale: cross-fishery participation spillovers, diversification of fishing portfolios, and costs of ecosystem-scale management.

*Cross-Fishery Participation Spillovers*

One market failure that such a broader scope may be able to address is the efficiency of fishers' adjusting allocation of effort across fisheries in response to management or other changes in a single fishery.

[7] Ecologists have collected data and developed models to demonstrate these interactions (e.g. Collie, et al. (2016)).

Economists have studied the effect of catch shares on fisher participation decisions and results suggest that impacts are often not confined to the catch share fishery. (Holland et al., 2017) find that catch shares may decrease diversification of fishing portfolios, which could be a sign of consolidation of the fleet, increased specialization, and efficiency. However, consolidation within the catch share fleet may have impacts beyond that fishery. For example, spillovers have been found to occur with fishers moving from a fishery implementing a catch share to another fishery (e.g. Cunningham et al. (2016) and Kroetz et al. (2019)). In these cases, the catch share program may increase the economic efficiency of the target fishery, but impose externalities such as increased participation and the potential for an associated decrease in economic efficiency of those fisheries toward which fishers reallocate their fishing effort. In addition, spillover of effort into fisheries with poorer stock regulation could result in negative consequences for stock sustainability.

*Diversification of Fishing Portfolios*

Another market failure can arise due to efforts of fishers to mitigate risk. One unique characteristic of fisheries as a natural resource is that there is no insurance available to fishers to protect them in bad years. This creates an incentive for risk-averse fishers (who are willing to trade off expected profit from fishing for a decrease in variability of profit), to diversify effort across fisheries to essentially self-insure. Empirical evidence supports the argument that fishing portfolio diversification can smooth income (e.g. Kasperski and Holland, (2013)). However, this individual behavior can be viewed as a market failure as it can reduce aggregate system profit. Similarly, fishing communities or regions may also aim to diversify catch portfolios to smooth income, as empirical evidence at the community level suggests that diversifying community catch portfolios can smooth income (e.g. Cline et al., (2017)).

*Costs of Ecosystem-Scale Management*

Despite the potential to address market failures related to effort spillovers through an EBFM approach, there are few examples where such an ecosystem-scale perspective has influenced fisheries management (DePiper et al., 2021). This raises questions about the feasibility and cost of these approaches and whether the potential benefits in terms of market failure reductions exceed the costs.

Indeed, in general, the potential benefits of resolving market failures needs to be weighed against both the potential management costs of such an approach and equity concerns.[8] Although this broadening of the scope of research and policy increases the extent to which market failures can be accounted for in policy design, the gains in efficiency from internalizing some of the externalities and accounting for other market failures that exist across species and within ecosystems may be lower than the costs of collecting data, designing models, and implementing management programs for such a large system (e.g. Hilborn (2011)). Additional work is needed to develop a full accounting of costs and benefits that include future management costs under various management scopes. Management costs include the data and modeling efforts needed to understand the complexities of system linkages and the responses of the system to shocks. Additionally, there are challenges to designing and administering relatively large management systems. However, as discussed later, cheaper data storage and computing power, with expected continued advances in the future, are likely to mitigate some of these costs.

## Market Failures Exogeneous to the Wild-caught Fisheries Sector

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services' global assessment report on biodiversity and ecosystem services, the most important drivers of biodiversity decline in marine ecosystems are (in order of importance): direct exploitation (discussed above), changes

[8] We discuss equity issues below.

in seascape use, climate change, pollution, and invasive alien species (IPBES, 2019). This suggests that although endogenous market failures are important, as they determine patterns of direct exploitation, exogenous market failures also play a key role in wild-caught fisheries outcomes. Thus, it is important to understand these exogenous stressors and their interactions with wild-caught fisheries. In this section, we examine the market failures associated with the latter four exogenous stressors, focusing on their impacts on – and implications for management – of the wild-caught fisheries sector (Figure 2).

## Changes in Seascape Use

Seascape uses other than wild-caught fisheries, including shipping, energy production, mariculture (i.e., fish farming in marine waters), and conservation, are expanding. Most commodities and goods are currently shipped over the oceans, with the volume of goods shipped globally increasing (UNCTA, 2021). Offshore wind energy is also growing rapidly and projected to continue to expand in the future (IEA, 2020). Furthermore, mariculture is emerging as a competing use of seascapes (Asche et al., 2022), and the share of the seascape area covered by marine protected areas has increased and is expected to expand further (UN, 2015).

Given the finite nature of the seascape, these trends suggest that there are tradeoffs between competing uses. As there are not markets for seascape use which would resemble land markets, there is a potential for market failures: the actual seascape uses might not reflect the economically most efficient pattern. Governing institutions such as state and country governments can address these market failures through policies that support efficient allocation of the seascape to each use. While such policies may be effective in cases where institutions such as state and country governments have explicit control over the space, they are not as effective in cases where the marine space is effectively a commons such as the seascape that falls outside country territory or in cases with weak territorial governance. Moreover, marine spatial planning entails costs and faces political challenges (Ehler, 2021). Given the economic significance and projected growth in alternative seascape uses and the finite nature of the seascape, it appears likely that the optimal allocation of space for wild-caught fisheries will be a reduction from current levels.

In terms of determining the optimal seascape use, marine protected areas (MPAs) are particularly relevant for fisheries because they can increase fish population growth over the entire area (i.e., within and beyond the MPA) and increase profitability through spillovers of fish from reserves to fished areas. MPAs have been extensively studied in the fisheries literature. They have been found to be effective in restoring fish populations, especially if they are well enforced, long lasting, and large (Edgar, et al., 2014). However, if the fishery is unregulated, the extent to which protecting an area improves economic returns depends on fish movement ecology (e.g. Sanchirico and Wilen, 2001) and fisher behavior (Smith and Wilen, 2003).

## Climate Change

Climate change is an exogenous form of disturbance to marine ecosystems that has substantial and complex effects on wild-caught fisheries, which can lead to market failure. In the remainder of the subsection we discuss documented effects of climate change on fish and fisheries, how market failures can arise if climate change is not accounted for in management, and conclude with challenges to implementing management that accounts for climate change.

Climate change can affect fish in many ways, including through its impacts on habitat and fish characteristics such as maturation or growth, which in turn affects fisheries. While there are large uncertainties about how these effects will play out at the individual species level, it has been shown that fish species often have an optimal temperature at which they thrive and reproduce best (Hänsel et al., 2020). The fisheries science literature has also identified climate change effects on fisheries at the global level. Fish stocks move geographically and vertically in the ocean as climate change alters the conditions in marine ecosystems, with fished species shifting predominantly to higher latitudes and greater depths (Pinsky et al., 2020). This characteristic has implications for the consumer benefits derived from fisheries.

In fact, Moore et al. (2021) estimate that the losses in present value consumer surplus due to climate change for 16 of the most important US fisheries are US$ 2-4 billion. Although the impacts of climate change on the productivity of marine living resources are dominated by the negative effects, climate change will lead to some regions of the world becoming better suited for valuable fish species (Free, et al., 2019).

Market failures due to lack of consideration of climate change in management can arise through multiple pathways. First, when fisheries management programs that influence fisher behavior fail to consider these climate-related effects in policy design, fisher behavior may deviate from what would be optimal if climate change were considered. Additionally, market failures can arise due to an inconsistency between the scope of management authority and the scope of the stock distribution. This can cause inefficiencies in fishing effort and harvest regulation if the stock is not fully contained within the manager's jurisdiction and efforts to support sustainable stock use within the jurisdiction are undermined by fishing activity outside the jurisdiction. The re-distribution of fishing resources is a matter of concern at both local and regional scales because stock shifts can impact groups of local fishers who may not be able to travel to follow the stock as it shifts northward or farther offshore as well as create regional impacts due to overall changes in the variability of, timing, and/or availability of fish. Climate change may pose a particular challenge to food security in countries in the tropics (Oremus et al., 2020), suggesting it also creates challenges for equity in the fisheries sector.

Although there are benefits to designing management strategies to account for climate-induced market failures, these types of programs are difficult to implement and therefore overall efficiency requires weighing the benefits of new policy designs against the costs. Challenges to accounting for shifting stocks due to climate change include uncertainty over future stock sizes and distributions and political economy issues arising from which fishers have access to the stock – those who fished the stock prior to the shift or those closest to the current location (Hannesson 2007). Management strategy evaluation is one approach that can incorporate limited data and uncertainty related to stock size and location, but operationalizing it within EBFM contexts remains challenging (e.g. DePiper et al. (2021)).

## Pollution

Many coastal marine environments suffer from pollution, including from agricultural runoff and marine plastics (Diaz and Rosenberg 2008; Abbott and Sumaila 2020), which can negatively impact fisheries. Additionally, some fish species filter water improving the quality and generating positive impacts beyond the fishery. We elaborate on the potential for pollution to generate a negative externality on fisheries, the potential for fisheries to generate positive externalities for coastal water quality, and management challenges associated with accounting for these externalities below.

Agriculture and other upstream water use have been shown to have negative impacts on nutrient runoff into marine waters, which can reduce water quality, which in turn can negatively impact fisheries (Diaz and Rosenberg 2008). The impacts on water quality include eutrophication, high concentrations of plant-available nutrients, which can lead to expanded zones of low oxygen concentrations. Smith et al. (2017) find that this increases the price of large shrimp relative to small shrimp in the Gulf of Mexico, which reflects the adverse effects of low oxygen concentrations on shrimp growth. Marine plastics pollution and toxic substances such as heavy metals also have negative effects on marine waters, as such pollution directly diminishes the quality of the fish products as well as affecting the productivity of the natural resource itself (Abbott and Sumaila 2020).

Fisheries have also been shown to lead to positive externalities. This is especially true for mussels and marine mollusks that live from food they directly filter out of the water. The effect of such positive externalities is that the long run optimal harvest is higher than it would be otherwise. Instances where fisheries generate positive externalities related to water quality have been documented in the Baltic Sea (e g. Nielsen et al., (2019)) and Chesapeake Bay (DePiper et al., 2017).

Efficient management requires balancing higher management costs associated with expanding the management scope to include water polluting sectors, in addition to fisheries, against the benefits of accounting for the cross-sector positive and negative externalities. Designing this type of management strategy is challenging because it requires understanding the linkages between these the polluting sources and the fishery(ies) to estimate the value of the pollution activity and the value of the water quality. Moreover, political economy issues are likely to arise as fish and water resources in many areas have historically been managed separately (Kroetz et al., 2020a).

## Invasive Species

Human activities increasingly introduce new species to ecosystems, whether intentionally or accidentally. Often, these alien species are considered invasive, especially if they cause damage to humans and ecosystems. Some invasive species in marine ecosystems cause harm to humans, such as jellyfish in the Black Sea (e.g. Knowler and Barbier, 2005). The main approach to managing a damaging invasive species (if the invasion can be controlled at all) is to try to prevent the spread early on, because containment later is costly (Frésard and Ropars-Collet, 2014). Jardine and Sanchorico (2018) find that if the marginal costs of invasion control are constant, then full eradication, rather than just containment, may be the economically optimal policy. Policies can also be implemented to prevent species from entering and invading new ecosystems (Finnoff, et al., 2010).

However, not all biological invasions are detrimental from a fisheries profitability and consumer perspective. For example, despite their possible adverse ecosystem consequences, the King crab in Russian and Norwegian waters in the North Atlantic is a profitable fishery (e.g. Skonhoft and Kourantidou, 2021). An ecosystem approach to fisheries management would include the management of such invasive species.

## Cross-cutting Market Failures

We have examined endogenous and exogenous market failures in the context of wild-caught fisheries, but there are also market failures that cut across the wild-caught fisheries sector as well as other sectors of the local and/or global economy. Such market failures include an under provision of publicly available data and limited information and traceability within seafood supply chains (Figure 2). We discuss each of these market failures in more detail below.

### Under Provision of Public Data

Data is a public good but is often under-provided to stakeholders in the fisheries sector. Although in recent decades, there has been rapid growth in data on the oceans and human activity from new technology platforms such as satellites, autonomous vehicles, remote sensing, and mobile technologies, much of these data are controlled by governments, companies and researchers and are not widely available. This under provision of publicly accessible data can be viewed as a market failure that contributes to suboptimal resource use and management. Providing and making better use of existing data offers great potential for increasing the value creation from fisheries resources (Brett et al. (2020)). This is particularly important in developing countries, where the potential for improved fisheries management is the highest, while digital competencies and access to new technologies are relatively low.

Maximizing the value of wild-caught fish requires supplying the right product with the right attributes to the right customer at the right time. This is a particularly challenging task in the case of wild-caught fisheries because they vary considerably over time and managing supply requires coordinated effort across the supply chain from the point of catch to consumption (Knútsson et al., 2016). Data sharing between fishers, processors, and retailers can enhance this coordination. In particular, better data from the fishing grounds on the attributes of the wild-caught fish can enable processors and retailers to increase the value of the catch. In addition, better data on what customers want and when would enable fishers (particularly in well-regulated fisheries with longer seasons) to maximize value by catching the right fish at the right time.

## Information Sharing and Traceability within Seafood Supply Chains

Market failures can arise due to lack of information on wild-caught seafood product attributes along the supply chain, leading to a recent focus on traceability of fish (the ability to fully trace products from point of sale back to point of origin). Attributes include whether the product is obtained through Illegal, Unregulated and Unreported (IUU) fishing or mislabeled in terms of characteristics such as the species it is or region it is from (e.g. Kroetz et al. (2020b)). Market failures can occur when retailers, consumers or other seafood purchasers purchase seafood for a higher price than they would be willing to pay if they had full information regarding the product. Market failures can also happen when regulators lack sufficient information on the production process related to products they are regulating in the fishery, at the point of import, or within national product markets, to implement efficient regulations.

Recently, wild-caught seafood supply chains have been characterized by increasing market orientation focused on traceability of seafood products from the point of catch to consumption, helping to address some market failures. Progress has been made providing information to retailers about the provenance of products as well as providing consumers information about sustainability attributes of seafood products through consumer-facing third-party certification programs (see e.g. Roheim et al. (2018)). However, in their review of seafood markets, Roheim et al. (2018) emphasize that continued evolution of seafood supply chain management is needed to reach sustainability goals. Better information management systems enable both seafood firms and control agencies to record and use information for better decisions and performance, which can enhance traceability, ensure consistency in certification processes (such as those for health, catch and point of origin), increase enforcement, and improve quota management in fisheries. Improved knowledge about seafood products can also benefit consumers by reducing health risks from consumption. In addition, strong traceability systems can be used to provide product information that supports socially responsible fisheries by enabling better informed decisions.

In the longer run, reliable end-to-end traceability will likely become a requirement for operating in many seafood markets as there is already a push for this through government regulation and commitments by the retail sector. However, technologies to support this evolution are still in their infancy. Blaha and Katafono (2020) argue that there is currently a lack of standardization in how traceability systems are implemented both within and across countries. This suggests a need for closer cooperation between different national agencies, such as health and fisheries control agencies, and for more international standardization. Indeed, Blaha and Katafono (2020) present several recent examples of blockchain technology being used to track fish from capture to landing to processing and distribution, and all the way to the consumer. Thus far, blockchain has primarily been used to track high-value fish species such as tuna and Patagonian toothfish (Blaha and Katafono (2020)). However, blockchain technology has generally not been applied to more complex seafood value chains, suggesting more work is needed before the technology can be used more widely. Ensuring a proper match between physical asset and digital asset will be even more challenging for lower valued and smaller species like anchovy and herring, where physically tagging each fish is prohibitively expensive with current technologies (Blaha and Katafono (2020)). While advanced traceability technology for seafood is still in its infancy, it has the potential to significantly improve seafood sustainability.

## Equity

Policies designed to correct market failures generally focus on achieving economic efficiency. However, in practice, societies are generally concerned with issues of distributive justice and equity. For example, fisheries policies often reflect broader goals rather than focusing strictly on facilitating perfectly competitive quota markets (efficiency). Instead, objectives are often related to economic, social and environmental sustainability (e.g. Hoshino et al., 2020). For example, both the Magnuson-Stevens Fishery Conservation and Management Act of 1976 governing marine fisheries management in the United States and the Common Fisheries Policy of the European Union (Regulation (EU) No 1380/2013) require consideration of social outcomes, in addition to the economic outcomes associated with management policies. Therefore, in this section, we examine equity as a policy goal with implications for the previous market failures we discussed (Figure 2). Specifically, we begin by discussing the potential for a tradeoff between equity and efficiency, then discuss the potential for fisheries policy to support equity objectives, implications of equity concerns for program implementation, and finally the nexus between equity and global production.

## Equity - Efficiency Tradeoff

One important issue for policy makers is whether social equity and economic efficiency should be considered jointly. In Figure 3, we use a simplified example to motivate thinking around whether there is likely a tradeoff. In both panels, the solid blue lines represent the possibility frontier achievable without the option to redistribute returns from fishing post policy implementation and the red arrows represent examples of policy change from the status quo. In both cases, when the status quo is located on the interior of the solid line, the potential exists for an improvement in either equity or efficiency with no impact on the other, or an improvement in both outcomes.

The shape of the possibility frontier determines whether there is a tradeoff between equity and efficiency once on the frontier. The left panel shows the extreme case where maximum efficiency can be achieved simultaneously with maximum equity (left panel, solid line); it is possible to realize a large range of equity outcomes without reducing efficiency with the policy that maximizes both equity and efficiency at the corner of the solid blue line. In the right panel, however, once on the frontier, achieving higher equity comes at the cost of lower efficiency. In this case there is an equity-efficiency tradeoff, and the optimal policy is an empirical question depending on society's preferences. If economists use economic efficiency as the main criteria for policy design in this case when society also values equity, they will recommend a policy that is not socially optimal.

Recent empirical work has explored the tradeoffs between equity and other fishery outcomes. Asche, et al. (2018) find that indicator scores for social, economic, and ecological outcomes across over 100 fisheries are positively correlated, suggesting that in many fisheries changes from the status quo can improve equity as well as other outcomes. On the other hand, Hoshino et al. (2020) conclude that ITQ fisheries tend to perform better in terms of ecological and economic outcomes than social outcomes and argue that more careful policy design and better data on social indicators can improve social performance.

In practice, many equity outcomes that are important to society occur beyond fishery participants, increasing the chance that a market failure will arise with a traditional catch share program. Specifically, even if the catch share program balances equity and efficiency outcomes for program participants, this may not maximize social welfare. Like most other sectors, wild-caught fisheries have effects on local communities, such as through the generation of jobs and support for local economic activity (see e.g. Watson et al. (2021)). This means that the trading of quota within market-based catch shares will affect individuals other than those directly involved in the transaction. Indeed, such market-based approaches to fisheries management have been shown to have employment impacts (Abbott et al., 2010). More broadly, increasing the efficiency of operations can lead to consolidation and concentration of the fishing industry (see e.g. Gunnlaugsson et al. (2018)), which can result in the returns to fishing benefiting fewer people, firms, and communities. Coastal communities that depend on fishing activities to survive can also be vulnerable to threshold effects associated with decreased fishing activity (such as minimum deliveries to keep processors open). This can lead to a form of market failure because members of the community who value keeping the quota locally may not actually participate in the quota market. Similarly, non-market values for fishing community health and persistence represent an externality in quota markets.

## Fisheries Policy to Support Equity

To strike a balance between efficiency and equity objectives, managers can take a variety of steps. One option is to add safeguards to market-based management programs. For example, the transferable quota system in Norway restricts quota trade between geographical regions (north and south) and between different size segments of the fishing fleet to promote fishing activity and employment all along the coast and maintain a diversified fishing fleet (Hannesson, 2013). However, such safeguards may be costly if they reduce the economic efficiency of the fishery (Kroetz et al., 2015), and this cost needs to be balanced against the benefits to society of a more equitable outcome.

Another option is for the government to implement an efficient program design, impose a special tax on fishing, and redistribute some of the profit to compensate those who would otherwise have been made worse off by the management program. Returning to the example in Figure 3, if we introduce the option to redistribute resource rent, the possibility frontier can shift to the right. Governments have also taken this approach in practice. For example, in Iceland, the government has introduced a fishing fee on wild-caught catch and redistributed some of the resource rent to the public to increase public acceptance of the system (Gunnlaugsson et al., 2018). In contrast to a labor tax, where such redistributive taxation distorts behavior and lowers efficiency (Piketty and Saez, 2013), fish resources generate resource rents, which could be taxed in a non-distortionary manner (Boadway and Keen, 2015). This suggests that governments can achieve increased economic growth by shifting the tax burden from distortive taxes to resource rent tax. Although there is a large literature on optimal tax design in the context of non-renewable resources (see e.g., Boadway & Keen, 2015), more research is needed on this issue in the fisheries context.

## Equity and Program Implementation

Equity issues can affect when programs get implemented and thus the overall efficiency of a program over its lifetime. Many proposed market-based solutions have failed due to political economy issues resulting in stakeholders not supporting the proposed program (e.g. Grainger and Parker (2013), Guyader and Thebaud (2001), Kokorsch and Benediktsson (2018), and Leonard et al. (2019)). Expanding the scope of program design increases the number of stakeholders and could further exacerbate delays. Thus, in the long run, less efficient programs implemented earlier may be more efficient choices when considering the net present value of the full stream of rent changes.

## Equity and Global Production

Equity is also an important issue when examining global production of wild-caught fish, especially production in developing countries. Generally, to improve fisheries outcomes in the long run, it is necessary to reduce fishing in the short run to allow depleted stocks to rebuild. However, this intertemporal tradeoff can be difficult, especially in relatively poor areas, where fish tends to be an important food source (Wilen, 2013) or fishing is a source of income to buy food. Thus, in the developing world, poverty itself is a source of fishery resources degradation (e.g. Ye and Gutierrez (2017)). This highlights the importance of correcting market failures and compensating those who are adversely affected by a policy of reducing harvests today to have larger harvests in the future. Redistribution of harvest over time introduces additional challenges (those who gain might not be able to compensate those who lose), as well as costs, compared to the case where only economic versus social sustainability in the present are at odds. Because land-based and sea-based economic activities are often linked, especially in developing countries, our understanding of fisheries outcomes and the development of new management approaches may also benefit from a broader perspective that considers the entire local economy and food system (e.g. Lindsay et al. (2020)).

## Conclusions: Policy Recommendations and Research Priorities

This article has examined the potential for gains from expanding the scope of management policies that impact fisheries, framing our examination around market failures beyond those traditionally considered by economists in the fishery management context. With the problem of overfishing continuing at the global scale (FAO, 2020), more policy-oriented research is needed to address the classic stock and congestion externalities, as well as additional complexities we have identified within this paper. With this in mind, we conclude with some recommendations for policy and research priorities for the future.

### Pursue a Comprehensive Approach to Sustainable Fisheries that Considers Equity

Our primary recommendation is that there needs to be a more comprehensive approach to fishery socioeconomic goals that integrates social sustainability. To be successful, this approach requires more research and policy design initiatives that more thoroughly consider equity-efficiency trade-offs. A less comprehensive approach could result in potentially undesirable equity outcomes such as a loss of smaller-scale fishers and fishing communities and could undermine the capacity of fisheries as a sustainable food source, posing a roadblock to further progress in implementing market-based management in global fisheries. Efforts to pursue a more comprehensive approach should include examining contributions that wild-caught fisheries can make that go beyond affecting the livelihoods of those directly involved in the sector, such as supporting communities and local economies. Furthermore, fisheries and fish products have historically been viewed in isolation; more research is needed to examine how fish and agricultural products can jointly contribute to a sustainable food system and support food security.

## Encourage Technological Advances and Data Sharing

Recent technological advances such as increases in data storage, computing power, and satellite resolution provide new opportunities to collect and process data to support sustainable fisheries, to improve enforcement and monitoring, and to expand research beyond the traditional single-fishery scope. However, policies are needed to encourage further technological advances, adoption of new technology, and data sharing in ways that support social goals.

## Weighing the Costs and Benefits of Expanding the Scope of Marine Resource Management

EBFM has the potential to both address many of the market failures endogenous to the capture fisheries sector and improve fishery sector sustainability, but more work by economists is needed to fully assess the benefits and costs of such approach. Work in this area is especially timely because EBFM is still being tested in practice. Rethinking management policy at an ecosystem-scale may provide more flexibility to react to the consequences of climate change, especially changes in ecological conditions and the spatial distribution of fishery resources.

Our examination of exogenous and endogenous market failures also suggests additional priorities for other economics research in this area. The future sustainability of fisheries will depend on exogeneous market failures that are highly uncertain such as biological invasions and climate changes that cannot be overcome by fisheries policy alone. For example, climate change poses a challenge for the future of wild-caught seafood not only because of its predicted overall negative effect on the productivity of stocks, but also because the issue of shifting fish stocks is generally not covered by current approaches to fishery management. Other exogeneous market failures such as competing seascape uses and cross-sector pollution must be addressed across sectors. In these cases, it is important to assess the costs and benefits of policies that explicitly considers seascape use by multiple user groups and water quality outcomes and impacts across multiple sectors. For exogeneous market failures that occur on a more local scale (such as impacts on fish populations from agricultural pollution), fisheries managers may be able to team up with the sectors generating the externality to develop efficient solutions. Across all these cases, recommendations about the scale of management will need to be made with limited data and substantial and potentially deep uncertainty, suggesting the need for economists to work with other researchers to provide input into management design under these conditions.

## Integrated Research on Equity and Technology

There are also important points of nexus between exogenous and endogenous market failures and equity and emerging technology considerations. First, research is needed to identify socially optimal resource use that involves multiple groups of fishers and multiple sectors of the economy, and to design policies that support improvements in resource allocation. We see recent advances in data storage and computing power and satellite technologies as opportunities to support improved policies and decision-making from fish production to consumption that support economic, social, and environmental sustainability, and to facilitate cross-sector resource allocation. To realize the full potential it will be important to support technological knowledge and capacity-building to strengthen developing countries' institutional and government capabilities. Additionally, although it is important to consider the costs of more complex management structures to address market failures, technological improvements are likely to continue to reduce these costs, thus creating new opportunities for improved policy design and outcomes in the future.

As we have discussed, the shift toward expanding the overall scope of fisheries management beyond the traditional single-fishery paradigm provides an opportunity for economists to play a key role in identifying and meeting the broad range of policy challenges facing the fisheries sector.

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# Figures

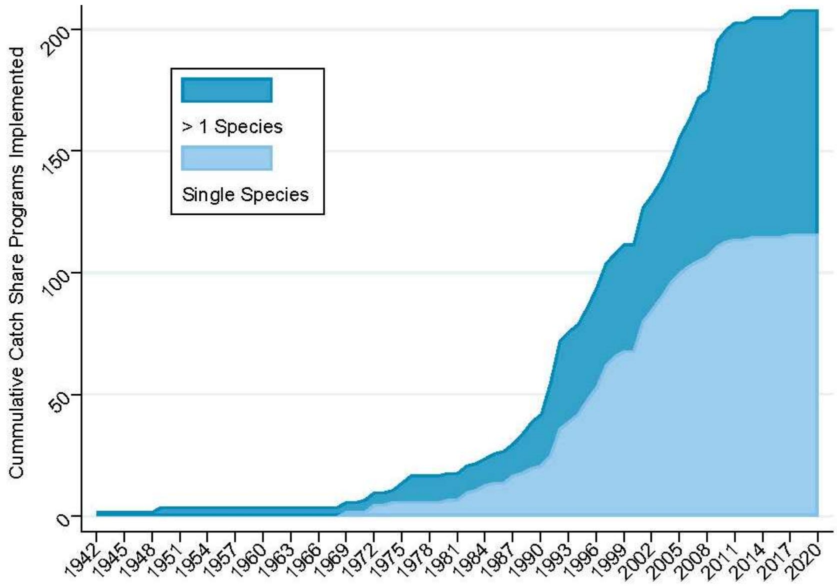


*Figure 1. Cumulative count of catch share programs. Light blue corresponds to programs that cover only a single species. Dark blue corresponds to programs that cover more than one species. The figure is based on data from Environmental Defense Fund's Fishery Solution Center database accessed in February of 2021:*

http://fisherysolutionscenter.edf.org/database. We did not include programs for which the start year was missing from the database and no estimated start year was available in supplementary sources.

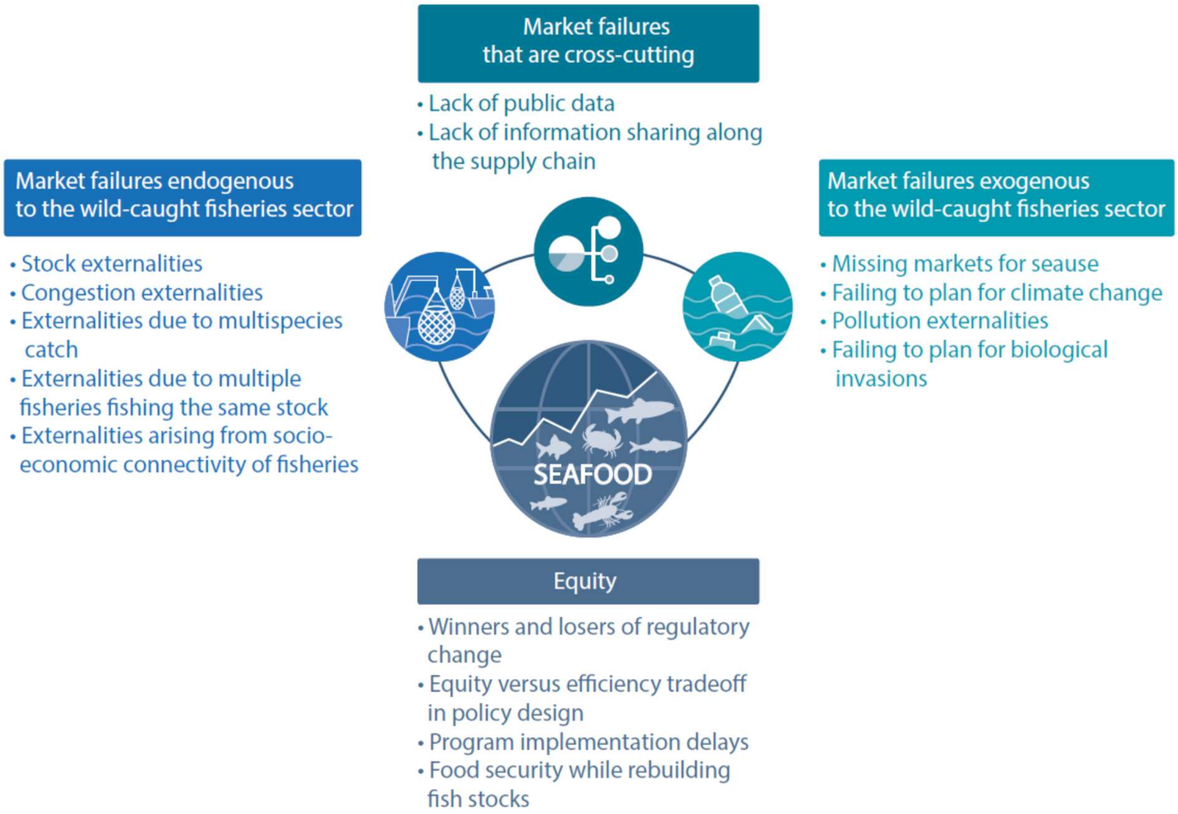


***Figure 2. Conceptual diagram of key market failures involving wild-caught fisheries.*** *Market failures endogenous to the capture fisheries sector, market failures exogeneous to the capture fisheries sector, and cross-cutting market failures, are interlinked. Equity issues underpin these various components.*

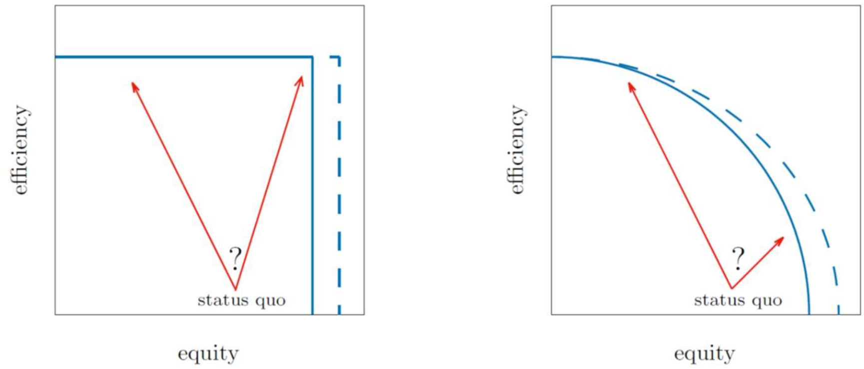


***Figure 3. Equity versus Efficiency Tradeoffs.*** *In some circumstances equity does not vary with the efficiency of policy options, so maximum efficiency can also be socially optimal (left panel, solid blue line), but in other cases there is a tradeoff between the two objectives and maximizing efficiency may not be socially optimal (right panel, solid blue line). It is also possible to address equity goals through redistribution (dotted lines), potentially allowing for improved equity for a given level of efficiency. An example of a measure of economic efficiency is resource rent. An example equity is the inverse of the Gini coefficient of resource rent distribution across fishing-dependent communities.*