

Seagrass meadows support global fisheries production

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Abstract

The significant role seagrass meadows play in supporting fisheries productivity and food security across the globe is not adequately reflected in the decisions made by authorities with statutory responsibility for their management. We provide a unique global analysis of three data sources to present the case for why seagrass meadows need targeted policy to recognize and protect their role in supporting fisheries production and food security. (1) Seagrass meadows provide valuable nursery habitat to over 1/5th of the world's largest 25 fisheries, including Walleye Pollock, the most landed species on the planet. (2) In complex small-scale fisheries from around the world (poorly represented in fisheries statistics), we present evidence that many of those in proximity to seagrass are supported to a large degree by these habitats. (3) We reveal how intertidal fishing activity in seagrass is a global phenomenon, often directly supporting human livelihoods. Our study demonstrates that seagrasses should be recognized and managed to maintain and maximize their role in global fisheries production. The chasm that exists between coastal habitat conservation and fisheries management needs to be filled to maximize the chances of seagrass meadows supporting fisheries, so that they can continue to support human wellbeing.

KEYWORDS

biodiversity, eelgrass, fisheries, marine, nursery ground, sustainability, zostera

1 | INTRODUCTION

Seagrass meadows are important for seafood supply through the fisheries that they support (Kritzer et al., 2016; Nordlund, Koch, Barbier, & Creed, 2016), but this is not acknowledged in the policy designed to protect and enhance marine resources, particularly fisheries. With our rapidly expanding global population driving increasing demand for protein sourced from the sea, maximizing fisheries productivity is imperative. Seagrass meadows support fisheries productivity and food security across the globe, but their hugely significant role is not adequately reflected in the management action afforded these systems.

Seagrasses are marine flowering plants that form extensive meadows in shallow seas on all continents except Antarc-

tica. The distribution of seagrass, from the intertidal to about 60 m depth in clear waters, makes seagrass meadows an easily exploitable fishing habitat. Seagrass associated fishery productivity arises directly from the provision of nursery and foraging grounds for invertebrates and fish of subsistence and commercial value (Nordlund et al., 2016; Unsworth & Cullen, 2010) such as tiger prawns, conch, Atlantic cod, and white spotted spinefoot (Kritzer et al., 2016; Lilley & Unsworth, 2014; McDevitt-Irwin, Iacarella, & Baum, 2016). Seagrasses also support contiguous habitats (Saunders et al., 2014) by providing trophic subsidy to adjacent fisheries (Heck et al., 2008) that in turn support fishery productivity (Figure 1).

In this policy perspective, we examine the evidence for these links between seagrass and fisheries and discuss the need for an integrated approach to their management governed

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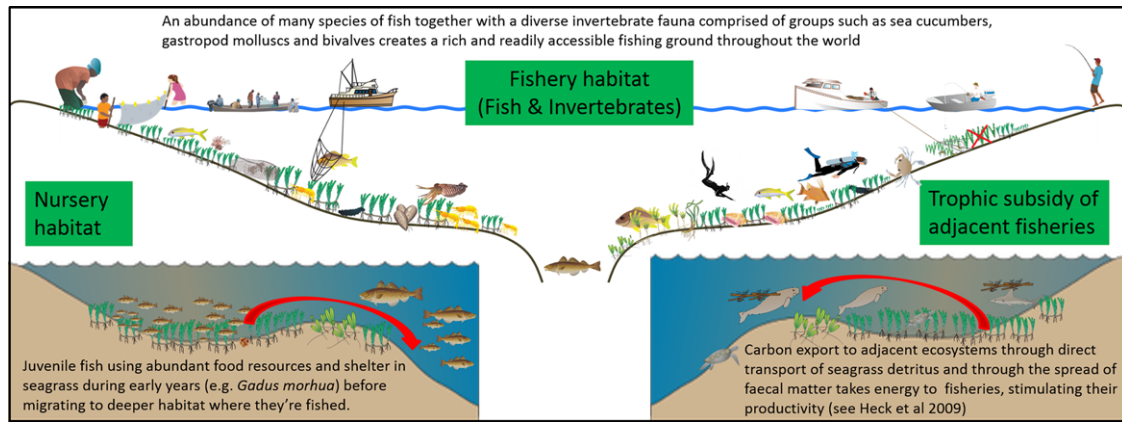


FIGURE 1 Seagrass meadows support global food security by (1) providing nursery habitat for fish stocks in adjacent and deep water habitats, (2) creating expansive fishery habitat rich in fauna, and (3) by providing trophic support to adjacent fisheries. They also provide support by promoting the health of fisheries associated to connected habitats (e.g., coral reefs)

at local, regional and international levels. Building on this we present a series of policy-relevant recommendations that recognize the role of seagrass in global fisheries.

2 | SEAGRASS SUPPORTS INDUSTRIAL AND SMALL-SCALE FISHERIES

We assessed the diversity of fish species utilizing seagrass meadows at some stage in their lifecycle by drawing on existing peer reviewed studies and creating a database of seagrass-associated fauna (see Supplementary Material 1). In the Indo-Pacific, 746 species of fish are documented to utilize seagrass meadows, 486 in Australasia, 222 in the North East Pacific, 313 in the Caribbean, and 297 in the North Atlantic. These seagrass associated fish species contribute to both industrial and small-scale fisheries (SSF).

Seagrass meadows support major industrial offshore fisheries (Supplementary Material 1, Table 1). Seagrass provides valuable nursery habitat (Lilley & Unsworth, 2014) for 21.5% of the landings from species' recorded on the FAO "Top 25 most landed species" list (FAO, 2016); this includes the most landed species on earth, the Alaska (Walleye) Pollock (Table 1, Supplementary Material 1). However, our database highlights the need to expand research into nursery habitat links to mature exploited fish stocks (such as the Alaska Pollock), which remains challenging due to the disproportionately poor research effort focused on species of such importance. Data gaps also exist with respect to invertebrate fisheries, which are expanding globally (Anderson, Mills Flemming, Watson, & Lotze, 2011). Available information on invertebrate species utilizing seagrass meadows at some stage in their lifecycle remains poor.

In the Mediterranean, seagrass covers <2% of the sea floor, but seagrass-associated fish and invertebrate species comprise

30%–40% of the total value of commercial fisheries landings (Jackson, Rees, Wilding, & Attrill, 2015). In 2014 global marine capture fisheries equated to 81.5 million tons, the share of world fish production utilized for direct human consumption continues to increase. The importance of seafood supply to meeting the protein requirements of human populations is irrefutable. But most industrial scale fishing activity takes place offshore with catch often exported, so buyers and consumers are largely detached from the supply chain and provisioning habitats. The link between seagrass meadows and offshore fisheries may be ill appreciated as a result of perceived spatial disconnect and as such, activities leading to seagrass damage are largely decoupled from the importance of this habitat to large-scale industrial fisheries. Large-scale international strategies such as the European Unions (EU) Common Fisheries Policy (CFP), that sets out rules for managing fishing fleets and conserving fish stocks, need to formally acknowledge the significance of seagrass meadows (and other habitats) as nursery grounds from which offshore fisheries are stocked. For example, in the case of the EU, public information and knowledge delivered through the European Maritime and Fisheries Fund could include programmes to fill the outlined gaps in our knowledge and transfer existing and new knowledge to stakeholders engaging with seagrass meadows. It would also be beneficial for international fishery management strategies such as the EU CFP to include assessments of the presence and viability of nursery habitats into fishery stock models that help determine stock sustainability. The key here is formal recognition and widespread knowledge transfer regarding the role of a currently ill acknowledged or ignored habitat.

Seagrass support for SSF is manifest through both the direct provision of fishing grounds (Nordlund, Cullen-Unsworth, Unsworth, & Gullstrom, 2018; Unsworth & Cullen, 2010) and indirectly through the provision of valuable nursery habitat and trophic subsidies for adjacent fisheries. One example

TABLE 1 Fish species associated to seagrass found in the FAO top 25 most landed species list (FAO, 2016)

Rank in FAO Top 25	Species	Species common name	Landing 2014	Probability of occurrence in seagrass (%) [*]	Data quality score (%)	Average density (no/ha)	Estimated occurrence density (no/ha)	Life history stage			Valuable nursery habitat			
								L/E	J	A	Presence in seagrass	Viability gain to population	Source of juveniles to stock	Key reference
1	<i>Theragra chalcogramma</i>	Alaska (Walleye) Pollock	3,214,422	31.8	44.5	3642.9	1159.1	x			Yes	Yes	Unknown	Sogard and Olla (1993)
6	<i>Clupea harengus</i>	Atlantic Herring	1,631,181	19.6	39.3	747.3	146.8	x	x	x	Yes	Yes	Unknown	Polte and Asmus (2006)
11	<i>Gadus morhua</i>	Atlantic Cod	1,373,460	60.6	41.0	586.3	355.2	x		X	Yes	Yes	Yes	Lilley and Unsworth (2014)
24	<i>Clupea pallasii</i>	Pacific Herring	478,778	50.0	46.0	19540.2	11724.1	x	x	x	Yes	Yes	Unknown	Murphy et al. (2000)
25	<i>Gadus macrocephalus</i>	Pacific Cod	474,498	50.0	44.5	1837.1	918.6	x		x	Yes	Yes	Unknown	Dean et al. (2000)
Catch of FAO top 25 (tons)			33,319,537											
Catch of seagrass associated species in FAO top 25 (tons)			7,172,339											
% catch of seagrass associated species in FAO top 25			21.5%											

Note: Listed are the landings value for these species together with the probability (chance of being recorded in a single research study in seagrass) of recording them in seagrass within their range. Values are also presented of their average recorded density (no/ha) and a density estimate base on their % occurrence. Information is provided as to the life history stage in which they're observed and whether each species fulfills the definition of seagrass being valuable nursery habitat (Lilley & Unsworth, 2014). The food security provided by many of the world's biggest fisheries is supported by seagrass nursery habitats. Over a 5th of the world's top 25 fishery species (including its biggest, the Walleye Pollock) utilize seagrass as valuable nursery habitat, potentially increasing their life chances and the likelihood of individuals reaching reproductive maturity. Seagrass is not always essential nursery habitat (as juveniles are found frequenting many alternative habitats), but information indicates it's favored and probably provides viability gains to the overall population in terms of increased survival, resources, and growth. Data pertaining to these statements exists across numerous locations across the majority of the extent of these species; however, many studies remain spatially and temporally weak. Experimental studies that examine viability increases are especially limited as are those that link nursery populations as sources to adult populations. See Supplementary Information 2.

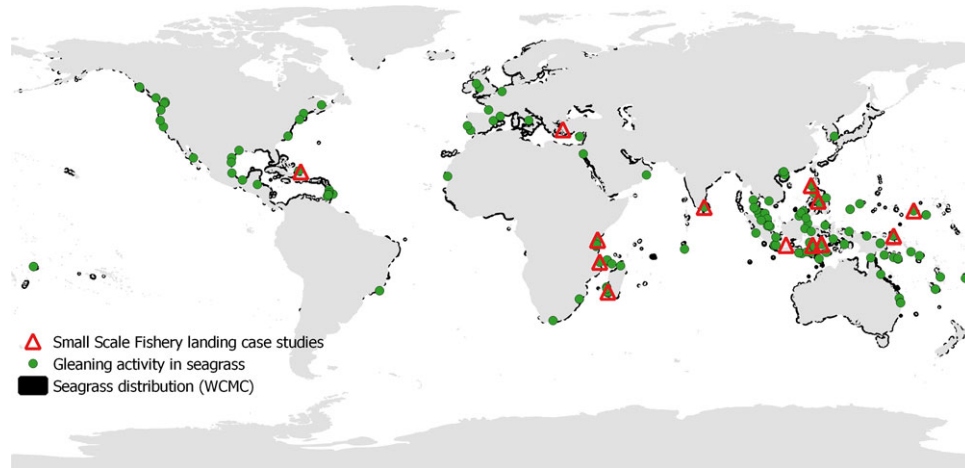


FIGURE 2 Locations of known gleaning activity (low tide walking or wading) in seagrass meadows for invertebrates and fish. Information comes from literature references or expert witnesses. Locations of 13 small-scale fishery landing datasets examined for their association to seagrass are also shown as is the current known distribution of seagrass (WCMC, Cambridge, UK)

from Eastern Indonesia demonstrates that at least 50% of all landed fish (>100 species) in one SSF are seagrass associated (Unsworth, Hinder, Bodger, & Cullen-Unsworth, 2014). A similar SSF study from the Turks and Caicos Islands in the Caribbean documents eight of the most landed species to have seagrass-associated stages within their lifecycles (Baker et al., 2015). Additional studies from other locations across the globe demonstrate a similar pattern with seagrass associated fisheries and fish species consistently important. Cumulative analysis from our database demonstrates that of the 10 most landed SSF fishes (in metric tons) from 13 locations across the tropics and subtropics, $79\% \pm 18\%$ are seagrass associated. SSF provide the major source of protein for millions of people in tropical and subtropical developing regions and the role of seagrass in supporting these fisheries provides strong evidence that seagrass contributes significantly to food security in these areas (Figure 2, Supplementary Material 2).

3 | SEAGRASS AS KEY FISHING GROUNDS

Seagrass meadows host a large variety of fish and invertebrates (Nordlund, Erlandsson, de la Torre-Castro, & Jiddawi, 2010; Unsworth & Cullen, 2010), which provides a fishery resource that is directly exploited by small-scale subsistence and artisanal fishers as well as large-scale commercial enterprises. For example, the Caribbean spiny lobster fishery, one of the region's biggest fisheries, generates >U.S.\$450 million per year (Winterbottom, Haughton, Mutrie, & Grieve, 2012). This fishery productivity is directly supported by seagrass meadows as fishing grounds (Spiny lobster fishers often put up aggregation shelters in seagrass to maximize their catch and indirectly by the nursery role of seagrass meadows (Higgs,

Newton, & Attrill, 2016). Fishing gears used in seagrass fisheries range from simple hand collection to complex large vessel trawls (Nordlund et al., 2018). In many parts of the world, seagrass situated fisheries are often unreported and unregulated.

4 | SEAGRASS FOR LOW-TIDE INVERTEBRATE GLEANING

In many regions (e.g., Indo-Pacific), it is the accessibility (on a daily basis and in most weather conditions) and minimal gear requirements (facilitating those with limited income) that confer a sense of food security derived from seagrass meadows. Seagrass fisheries are targeted by a diverse range of stakeholders using a diverse suite of methods (Nordlund et al., 2018). Seagrass invertebrate fisheries provide a source of essential protein for some of the most vulnerable people in tropical coastal communities (Nordlund et al., 2010). In many localities such fisheries are also conducted in order to catch bait (e.g., polychaete worms or crustaceans) for use in fin-fish fisheries, (McPhee & Skilleter, 2002; Watson, Murray, Schaefer, & Bonner, 2017). Our database (Supplementary Material 1) also includes 108 examples (65 literature reports and 43 expert witness observations) of low-tide seagrass invertebrate harvesting by hand and on foot at low (or very shallow) tide, often referred to as “gleaning.” The distribution of these documented examples demonstrates the widespread nature of gleaning activity, which occurs across the globe in both developed (e.g., prawn hand-netting in the United Kingdom) and developing countries (Figure 2, Supplementary Material 3). In Zanzibar, Tanzania, fishers target over 200 species of macroinvertebrates in just a 2 km² area of seagrass (Nordlund et al., 2010); this example demonstrates the high diversity

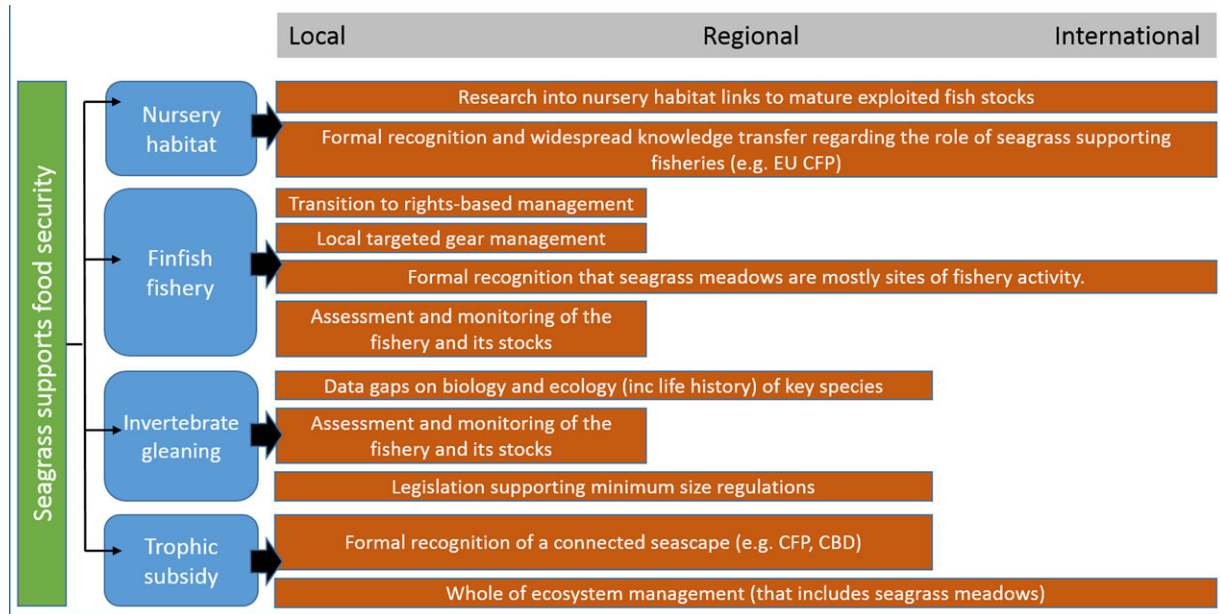


FIGURE 3 Proposed policy changes required to include the value of seagrass as a key fisheries habitat at local, regional, and international levels

of invertebrates accessible to seagrass gleaners. Invertebrate gleaning activity is expanding globally (Anderson et al., 2011) and we speculate that in the tropics increased coral reef degradation is leading to increasing reliance of people on seagrass invertebrate species for food. Although gleaning is a globally significant activity that is often conducted by women and children, it is not usually included in fishery statistics and is rarely considered in resource management strategies (de la Torre-Castro, Fröcklin, Börjesson, Okupnik, & Jiddawi, 2017; Kleiber, Harris, & Vincent, 2015).

Invertebrate gleaning activities are commonly unreported and unregulated, which is problematic given their widespread status and apparent importance to food security in many areas. In some places although management is conducted it is poorly enforced. It is likely that the sustainability of these invertebrate fisheries is compromised with localized evidence of recruitment overfishing, loss of species and associated cascades, as well as concerns regarding the direct impact of fishing activity (e.g., trampling or using small tools) on the supporting habitat. Better information is needed on the characteristics and status of these fisheries, to achieve this monitoring is required as well as policy that recognizes the importance of these fisheries and the need to support their sustainability (Figure 3). The informal nature of this sort of fishery activity and its largely intertidal location necessitates assessments that follow tidal cycles and incorporate fishers' local ecological knowledge. Management of these fisheries is required to ensure they remain secure sources of food. For this to happen, policy related to “informal” and “subsistence” fisheries needs to change and recognize that seagrass meadows are mostly sites of such fishery activity. The common multi-species and complex nature of these fisheries necessitates that

management requires “buy-in” from local communities and their fishers. Transition to rights-based management in other fisheries (e.g., Alaskan Pollock) (Morrison Paul, Felthoven, & Torres, 2010) has contributed significantly to economic performance whilst maintaining stocks. As such we believe that management of these fisheries can be most successful through comanagement, preferably including co-ownership of resources through marine land tenure (Figure 3). Finally, many of the species collected in these largely informal subsistence fisheries are invertebrates about which little biological information is held. For many species (e.g., commonly harvested gastropods), there is insufficient data to make recommendations about minimum size (at maturation) limits.

The substantial and widespread invertebrate gleaning fishery needs to be considered within regional and local marine management planning. Policy is required to acknowledge the significance of this fishery for social and ecological sustainability.

5 | SEAGRASS TROPHIC SUPPORT FOR FISHERIES

The productivity of seagrass meadows rivals that of many terrestrial ecosystems and results in the export of vast quantities of living plant material, organic matter and associated animal biomass (Heck et al., 2008). Organic matter export is to both terrestrial (e.g., grazing by geese and consumption of seagrass detritus by the rodent capybara) and other marine ecosystems in both temperate and tropical environments (Heck et al., 2008). Primary production export estimates range from 0% to 100% of total production (Heck et al., 2008; Mateo, Cebrián,

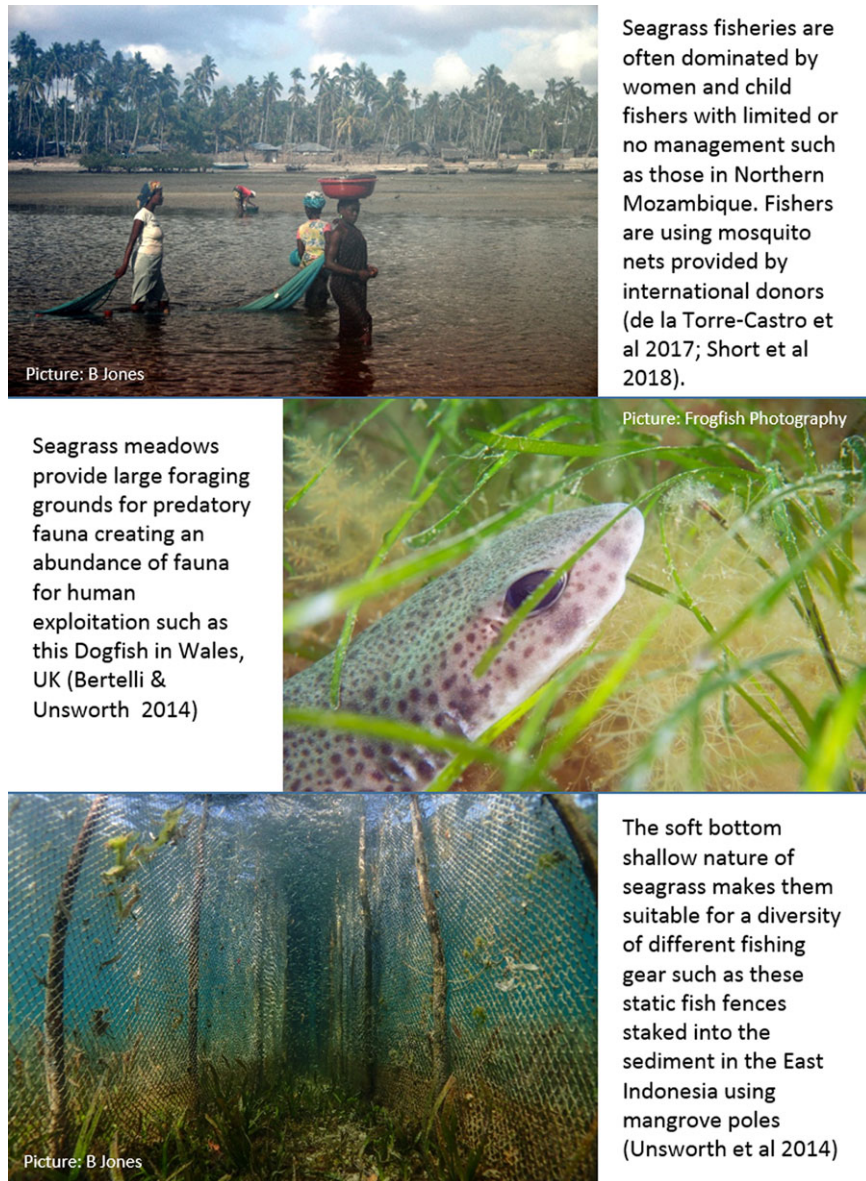


FIGURE 4 Examples of the value of seagrass for supporting fisheries around the world

Dunton, & Mutchler, 2006). On average, around 24.3% of seagrass net primary production is thought to be exported (Duarte & Cebrian, 1996). Coral reef fisheries are a clear example of where plant and algal grazers consuming material in seagrass habitat excrete carbon into an adjacent system. Trophic transfer of seagrass, however, is not restricted to shallow coastal zones with evidence from the Atlantic indicating that seagrass may subsidize whole food webs (and therefore fisheries productivity) in the deep sea (Wolff, 1976, 1980). In addition to the specific carbon production from the seagrass, there is growing evidence of the key role that other biota play within the seagrass ecosystem in terms of support for fisheries productivity. For example, chemosynthetic primary production from specialized clams in seagrass plays a significant role in supporting the Caribbean spiny lobster fishery (Higgs et al., 2016).

6 | RECOGNIZING THE VALUE OF SEAGRASS MEADOWS FOR FOOD SECURITY

The value of seagrass meadows in supporting food security, both directly and indirectly, remains largely underappreciated. In particular there is disparity between the significant economic benefits supplied by the seagrass nursery habitat function (especially for industrial-scale fishing) and the poor levels of funding and management afforded to prevent seagrass degradation (Kritzer et al., 2016; Seitz, Wennhage, Bergström, Lipcius, & Ysebaert, 2013). In some cases, this disparity results from the perception that some fisheries are offshore resources (e.g., Atlantic cod) with limited appreciation of the crucial role that seagrasses play in “stocking”

the offshore resource. There is also a disconnect between our understanding of the ecosystem services provided by seagrass habitats and associated management responses, particularly in the fisheries sector (Jackson et al., 2015). Fisheries modeling and management approaches tend not to consider the functional role of seagrass and other coastal habitats on recruitment to the spawning stock, for example, current U.K. marine protected area policy (Department for Environment, 2015). Policy across scales is required that supports whole of ecosystem management action including targeted action to sustain seagrass meadows as part of a connected seascape. We need to address the apparent mismatch between policy developed to support food security, biodiversity, and productive fisheries and call for clear integration for the purpose of supporting multiple ecosystem services concurrently. Where seagrasses are protected, measures are taken largely in the name of biodiversity support rather than in relation to fisheries support. As a result, information on seagrass degradation does not logically flow back to those stakeholders who are dependent upon this resource. Organizations with statutory responsibility to monitor the status of seagrass (e.g., Indonesian Institute of Sciences in Indonesia) should also be responsible for reporting this information in a targeted manner to fisheries stakeholders and the appropriate sections of government responsible for fisheries management.


Seagrass meadows are experiencing rapid decline with loss estimated at around 7% of their global distribution annually (Orth et al., 2006; Waycott et al., 2009). Poor data availability combined with poor management of seagrass fisheries threatens the ecological balance of the seagrass ecosystem due to the loss of major herbivores and top predators (Unsworth et al., 2014). The coastal distribution of seagrass means it is vulnerable to a multitude of both land- and sea-based threats, such as land runoff, coastal development, boat damage, and trawling (Orth et al., 2006; Waycott et al., 2009). Seagrasses are also subjected to climate associated temperature stress (Hyndes et al., 2016; Thomson et al., 2015). When seagrass is lost, there is strong evidence globally that fisheries and their stocks often become compromised with profound negative economic consequences (Gillanders, 2006).

The chasm that exists between coastal habitat conservation and fisheries management (Salomon et al., 2011) needs to be filled to maximize the chances of habitats, such as seagrass, supporting fisheries so that they can continue to support human wellbeing (Cullen-Unsworth et al., 2014). To maintain the role of seagrass meadows in fisheries support and hence food security, awareness of their role must pervade the policy sphere with resultant and integrated management frameworks targeting the major threats such as declining water quality. The significant role that seagrasses play in global fisheries needs to be formally recognized; this includes recognition of their nursery support for major offshore fisheries as well as their role as fishing ground that provides a sense of food security

for vulnerable people (Figures 3 and 4). The data we have presented here demonstrates that seagrass requires targeted management to maintain and maximize their role in global fisheries production.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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