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Governance and the mangrove commons: Advancing the cross-scale, nested framework for the global conservation and wise use of mangroves

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ABSTRACT

Mangroves provide critical ecosystems services, contributing an estimated 42 billion US dollars to global fisheries, storing 25.5 million tons of carbon per year, and providing flood protection to over 15 million people annually. Yet, they are increasingly threatened by factors ranging from local resource exploitation to global climate change, with an estimated 35% of mangrove forests lost in the past two decades. These threats are difficult to manage due to the intrinsic characteristics of mangrove systems and their provisioning services, and their transboundary and pan-global nature. Due to their unique intertidal ecological niche, mangroves are often treated as a "common pool resource" within national legal frameworks, making them particularly susceptible to exploitation. Moreover, they form ecological connections through numerous biotic and abiotic processes that cross political boundaries. Because of these qualities a cross-scale nested framework of international, regional, and local coordination is necessary to successfully sustain mangrove ecosystems and their valuable services. Although coordination across the geopolitical spectrum is often cited as a need for effective management of common resources such as mangroves, there has been no formal analysis of mangrove multiscale governance. In this paper we address this gap by providing a comprehensive analysis of interactions between and within international, regional, and local mangrove management regimes and examine the challenges and opportunities such multiscale governance frameworks present. We highlight Costa Rica as a case study to demonstrate the universal relevance and potential of multi-scale governance and explore its downscale potential. Using Elinor Ostrom's principles for self-governance of the commons as our touchstone, we identify where improvements to the status quo could be implemented to increase its effectiveness of the current frameworks to meet the ongoing challenge of managing mangrove-derived resources and services in the face of a changing climate and human needs.

1. Introduction

Multi-scale governance is necessary for the sustainable use and management of mangrove systems given their pan-global and transboundary ecology as well as the current and future anthropogenic threats to mangroves stemming from international, regional, and local levels. Many major multilateral agreements either explicitly or implicitly address mangroves, and efforts to increase cross-scale governance have been both formally and informally addressed through synergistic interactions among these agreements, as well as the regional and domestic governance frameworks that support the multilateral initiatives. However, even with these synergies and the acknowledgement of the need for coordination between multiple scales, there has been a lack of formal analysis of the larger the cross-scale nested framework surrounding mangrove governance. Within this paper we characterize the way in which global mangrove governance is incorporated into regional and domestic legal systems. For illustrative purposes, we focus on Costa Rica as a case study to demonstrate one example in which domestic legal

Abbreviations: MEAs, Multilateral Environmental Agreements.

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systems incorporate regional and international law, how they address land tenure in the intertidal zone, and how they govern mangrove systems more generally. We draw upon this case study to discuss the improvements that could be made in support of the current legal frameworks at each scale to meet the threats to mangroves.

2. Importance of mangrove ecosystem services and global and regional interconnectivity of mangroves

Mangroves are a diverse group of >70 different species of wetland trees, all sharing similar adaptations that allow them to thrive in the tropical intertidal zone (Mitsch and Gosselink, 2000; Polidoro et al., 2010). Mangroves cover 75% of tropical coastlines between 25° N and 25° S latitude, spanning 123 countries across the globe (Iii and Jensen, 1996; Spalding et al., 2010). Similar to other intertidal wetlands, mangroves are exposed at low tide and inundated at high tide, placing them at the interface of terrestrial and marine environments. As such, they serve an important ecological role of providing habitat and resources to numerous species from both biomes in addition to those that are unique to mangroves. The complex root structures of mangroves that allow for their survival in waterlogged soils also provide stable substrate for the attachment of other species such as algae, mollusks, and sponges, and create refugia habitat for crabs, fish and other free-swimming organisms (Kon et al., 2010; Mumby et al., 2004). The dense forest canopy created by mangroves is of similar ecological importance, serving as vital habitat for terrestrial species (Spalding et al., 2010). A survey of terrestrial vertebrates across the globe tallied 853 species, including 6 mammals, 48 birds, 14 reptiles, and 1 amphibian, as endemic to mangroves (Luther and Greenberg, 2009). Further, many species that rely on mangrove ecosystems are listed as endangered or vulnerable, including iconic species such as the Hawksbill sea turtle, Atlantic goliath grouper, manatees, and dugongs (IUCN, 2020). With the reliance of many species of commercial and conservation value on mangrove ecosystems, they have been distinguished as critical systems for maintaining global biodiversity.

In addition to providing habitat to many species, mangroves also support neighboring ecosystems. Mangroves form at the land-sea interface and are connected at the regional level to adjoining habitats through cross-habitat and cross-ecosystems flow of materials, energy, and organisms. Because mangroves form at the base of watersheds, they receive water, sediment, and nutrients from upstream catchment basins and are widely recognized as natural filters that reduce turbidity and nutrient runoff from terrestrial systems, benefiting connected marine ecosystems that form downstream and offshore (Fig. 1) (Gillis et al., 2014; Valiela and Cole, 2002). In doing so, mangroves create favorable conditions for coral reefs by enhancing light availability for photosynthesis and mitigating algal blooms through their water quality improvement services (Gillis et al., 2014). Seagrasses, which serve as a secondary filter to coral reefs, similarly benefit from mangroves' natural filtering. Mangroves, seagrasses and coral reefs are also interconnected through the exchange of organisms and resources. For example, many fish species utilize mangroves as juveniles before migrating to seagrasses and then reefs at later life stages, leading to a higher abundance of reef fishes on reefs where these habitats co-occur (Gillis et al., 2014).

In addition to the regional connections between mangroves and other habitats, these intertidal forests are globally linked via atmospheric processes (Fig. 1). Mangroves, like other wetlands, are an important component of the global carbon cycle, taking up atmospheric carbon and sequestering it in plant biomass and depositions of soil that are rich in organic carbon (Alongi, 2016; Simpson et al., 2019). Because of their high level of productivity and the slow decomposition of litter in the anaerobic waterlogged soils where they grow, mangrove sequester 25.5 million tons of that carbon per year, over half the total for all wetlands which are the largest terrestrial carbon sink (Chmura et al., 2003; Dixon and Krankina, 1995; Eong, 1993). The high productivity of mangroves and the associated benefits to other marine systems make them economically valuable, contributing 42 billion US dollars to global fisheries alone (Hutchison et al., 2014). When considering their provisioning of fisheries and other ecosystem services, such as carbon sequestration, pollution control, and coastal storm protection, mangroves are particularly important contributors to the global economy (Costanza et al., 1997).

3. Threats to mangrove ecosystems

Due to an estimated 20–35% of global mangrove forests lost in the

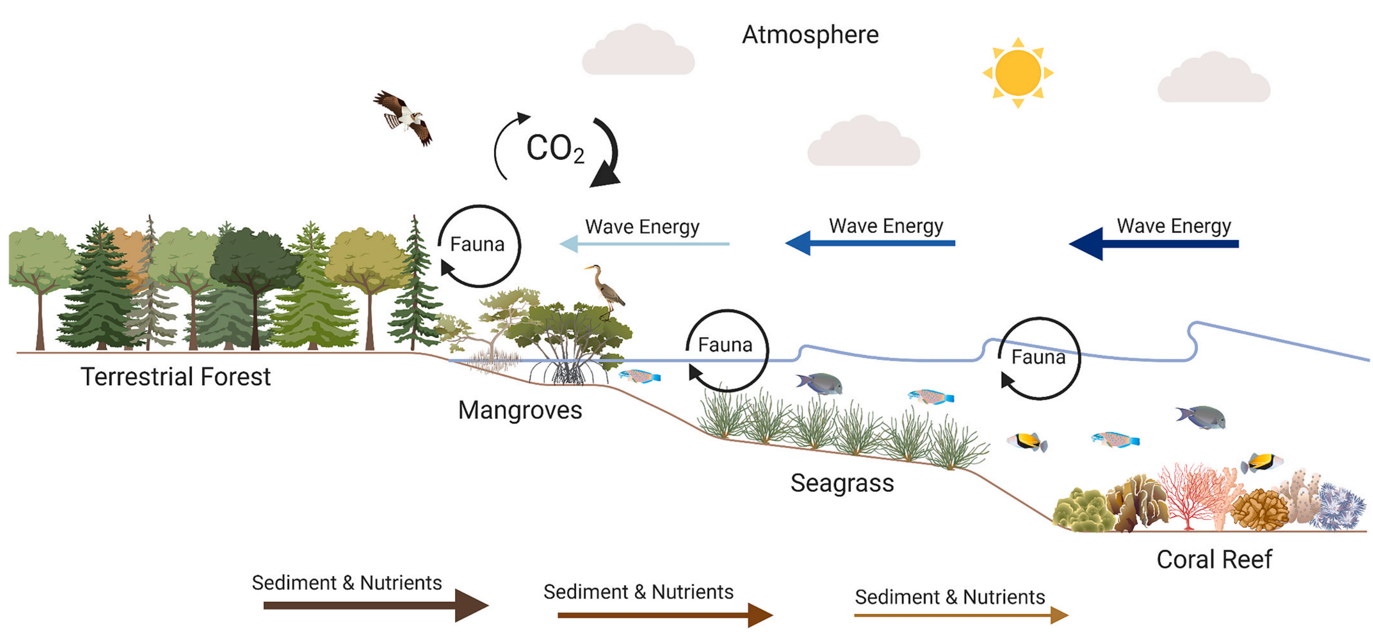

Fig. 1. Connections between terrestrial forests, coastal mangroves, seagrass beds, and coral reefs. Arrows indicate strength of connection (strength increases with increased width and color saturation) and direction of exchange. Clipart courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/) and created with Biorender.com.(For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

past two decades alone, all the services mentioned above are threatened (Polidoro et al., 2010; Valiela et al., 2001). While the rate of mangrove loss has declined since the 1980s, the current rate remains higher than the average rate for tropical and subtropical terrestrial forest losses and would lead to mangrove extinction within 100 years (Duke et al., 2007; Gardner and Finlayson, 2018; Goldberg et al., 2020; Worthington and Spalding, 2018). Losses of mangroves can be attributed to multiple stressors at all governance scales, ranging from localized threats of resource exploitation to global threats from climate change.

At the local scale, mariculture, or the farming of fish and shrimp in constructed ponds, is a common use of mangroves. Although it can support local food security and economies, the deforestation required for mariculture makes it the most destructive use of mangrove forests, impacting 52% of mangrove habitat globally (Valiela et al., 2001). Furthermore, mariculture ponds typically last only 5–10 years before becoming overrun with diseases and toxins, thus propelling the further destruction of mangrove forest to sustain fish and shrimp production (Aslan et al., 2021; De Silva, 1998; Matsui et al., 2014; Wolanski et al., 2000). Because mangrove recovery rates are slow relative to the rate of deforestation and pond destruction, communities with spent mariculture ponds can no longer derive other vital benefits produced by mangroves, including reducing the ability to harvest of non-maricultural species (Primavera, 1997; Valiela et al., 2001).

Other local stressors include the harvesting of forest products for firewood, charcoal, and wood chips as well as deforestation to meet increased demand for coastal real estate (Saenger et al., 1983; Valiela et al., 2001). Removal of mangroves makes communities less resilient to the effects of climate change. Coastal communities without mangroves are more vulnerable to the effects of storms and sea level rise by exacerbating shoreline subsidence due to peat collapse and removing their ability to increase elevation through sediment trapping (Macintyre et al., 2009). To create more coastal infrastructure and raise developed land out of the intertidal zone, the removal of mangroves is usually accompanied by the dredging of nearby benthic habitats for fill material, causing either direct damage to mangrove associated ecosystems, such as corals and seagrasses, or indirect damage through increased sediment suspension (Gillis et al., 2014; Guannel et al., 2016). These damages to adjacent habitats can reduce their capacity to attenuate wave energy and decrease erosion, resulting in negative feedback on mangroves (Fig. 1) (Gillis et al., 2014; Guannel et al., 2016; Macintyre et al., 2009).

Regionally, development of upland forest or conversion of mangrove forests to agriculture also threaten mangroves. Land use change is often associated with increased runoff of excess sediments that smoother mangrove roots, as well as chemical pesticides and herbicides causing decreased survival and productivity of mangroves (Bell and Duke, 2005; Ellison, 1999; Lewis et al., 2011; Walsh et al., 1973). Changes to regional hydrology can also decrease coastal mangrove habitat, with activities such as freshwater divergence (e.g., upstream damming) resulting in coastline erosion due to decreased sediment supply, increased saltwater intrusion, and nutrient depletion (Lacerda, 2002; Lovelock et al., 2015).

At the global scale, mangroves are threatened by the effects of climate change, such as sea level rise, increased storm events, and changes in precipitation patterns. Globally, sea levels have risen 12–22 cm within the 20th century and are continuing to rise at an average pace of ~3.4 mm per year with projections of 10 mm per year under high-emissions scenarios by 2100 (Gilman et al., 2008; Saintilan et al., 2020; Solomon et al., 2007). Increased flooding can exceed the physiological thresholds of mangroves, causing dieback and conversion to open water (Lovelock et al., 2015; Woodroffe, 1995). Although mangroves and other coastal wetlands have the potential to naturally gain elevation through soil accretion, mangroves, on average, are projected to be unable to keep pace when the annual rate of sea level rise exceeds 6.1 mm per year, a rate already exceeded in many tropical areas around the globe (Saintilan et al., 2020; Woodroffe et al., 2016). The greatest losses of mangroves are likely to occur in coastal areas lacking space for mangroves to migrate to a higher tidal elevation as well as in areas with insufficient sources of upland and riverine sources of sediments that provide the basis for substrate (Solomon et al., 2007; Woodroffe, 2002; Woodroffe et al., 2016). The changing climate is also projected to increase the frequency and intensity of storm events (Solomon et al., 2007). As a result, there is likely to be greater direct damage to mangroves via defoliation and increased mortality, as well as increased flooding resulting in sulfide soil toxicity, and soil erosion (Gilman et al., 2008; Woodroffe, 2002). Changes in global climate will also result in regional changes in precipitation, with decreased rainfall likely in the subtropics (Gilman et al., 2008). This decreased input of freshwater, combined with increased evapotranspiration rates will increase salinity in the intertidal zone, resulting in decreased mangrove growth and seedling survival, and potential conversion of mangrove forests to salt flats (Saintilan et al., 2020).

The multiple spatial scales at which mangrove threats and services operate at necessitate that mangrove management also act at these different scales. However, each level of this cross-scale nested framework has its own unique challenges (Fig. 2). Within the following sections we will discuss the existing policies at each of these scales and the challenges that arise at each of these levels.

4. Challenge to effective governance of mangrove ecosystems

4.1. Local challenges: the "mangrove commons"

Mangroves' susceptibility to local anthropogenic threats is largely a consequence of the intertidal zone they occupy. The intertidal zone and the resources within it are treated as a commons in most countries. The resources within a commons, such as mangroves, are known as "common pool resources." The commons and common pool resources are those that are not owned by any individual person but are instead owned communally by all the people within a sovereignty. The legal tradition of treating the intertidal zone as a commons was first codified by the Romans in the Institutes of Justinian, stating, "*by the law of nature these things are common to all mankind; the air, running water, the sea and consequently the shores of the sea*" (Institutes of Justinian A.D. 530) (Fenn, 1925). The Institutes went on to declare that this area included all the foreshore area up to the highest point reached by the waves in winter storms. This concept has been passed on, and refined, through the widespread adaptation of Roman law into the two major modern day legal systems: the civil law of Europe and its former colonies and the common law of Britain and its former colonies (Fenn, 1925).

The most famous argument regarding the management of common pool resources is Garrett Hardin's "Tragedy of the Commons" (Hardin, 1968). Hardin explains that this tragedy occurs when individual users acting in their own self-interest exploit a shared resource, leading to the loss of the resource for all parties. Under this assumption, the only way to ensure that a common resource is maintained is through either restriction of use from an outside authority or transforming commons to private property. However, contemporary critics of Hardin's theory have proposed that the tragedy of the commons is not inevitable. Nobel prize-winning political scientist Elinor Ostrom suggests that Hardin's tragedy of the commons cannot be a universal truth by identifying several case studies in which self-management of a commons resource has been successful (Ostrom et al., 1999).

Notably, most case studies proposed by Ostrom involve managing resources that are smaller in scale and contained within an individual country (Ostrom et al., 1999). However, as highlighted above, mangroves and other intertidal wetlands are susceptible to the effects of global changes in climate and to changes to adjacent habitats and contributing watersheds, sources of stress that are not neatly constrained by geopolitical boundaries. Instead, these threats often span large geographic areas that cross jurisdictional boundaries, making them difficult to holistically manage at local scales (Fig. 2, see Box 1). For such common resources, Ostrom recommends "nested" cooperation among local, national, regional, and international institutions to

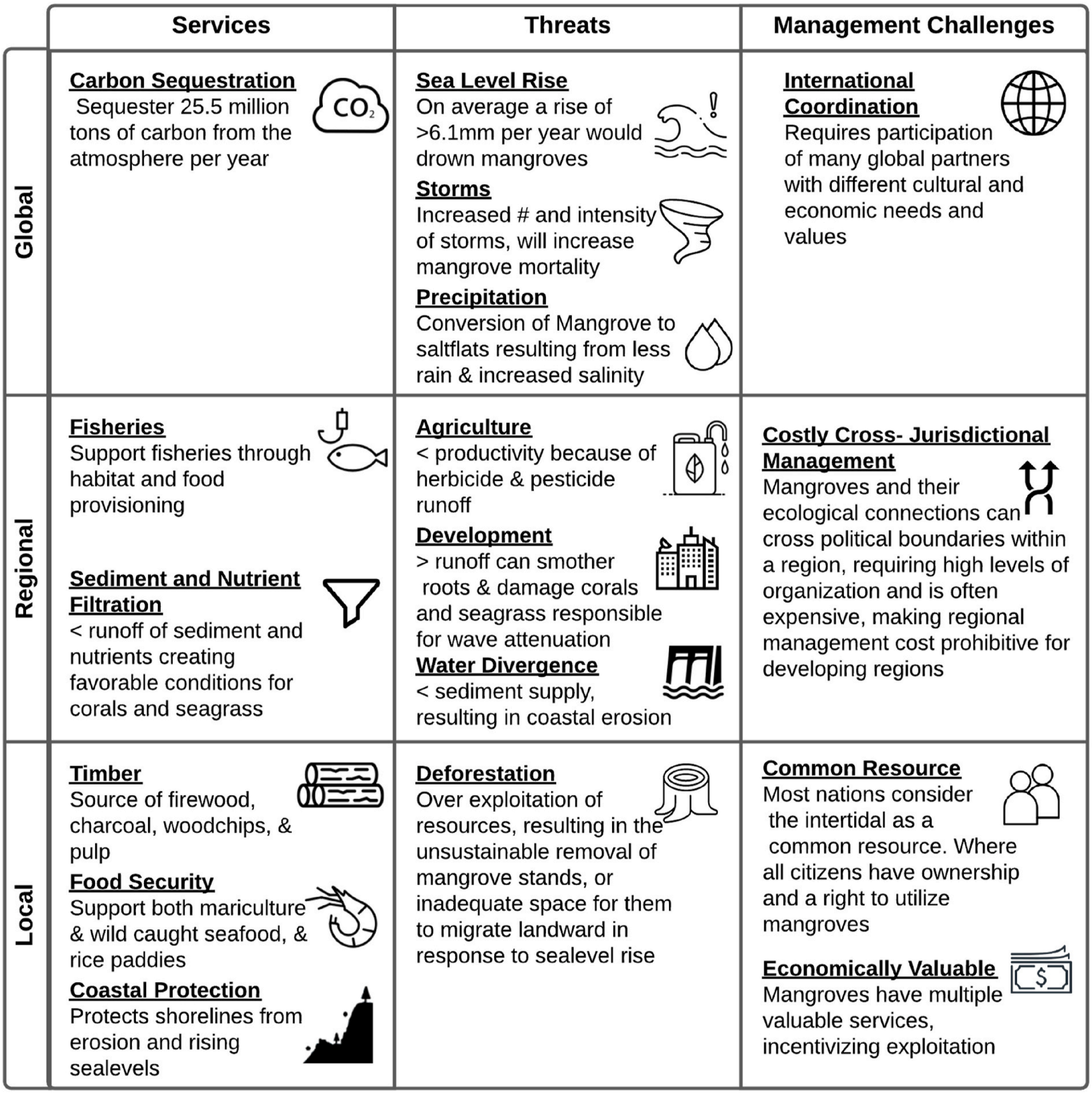

Fig. 2. Ecosystems services, threats, and management challenges of mangroves at the global, regional, and local scales. Clipart courtesy of Lucidchart (lucidchart.com).

develop the best possible management strategies (Ostrom et al., 1999). Within the following sections, we examine how nested scales of management strategies have been applied to mangroves and explore the potential effectiveness of such hierarchical management for the sustainability of mangroves as a common pool resource.

4.2. Global environmental governance structure and management challenges

Because of the pan-global, transnational nature of mangroves, effective management of these systems requires extensive coordination on the international level. Despite being a relatively new field, international environmental law has grown and matured rapidly in the past several decades. There now exists a rich tapestry of international agreements, international jurisprudence, and "soft law" instruments that together create the governance framework within which international approaches to mangrove management rest. Although there is no specific international instrument devoted to mangrove ecosystems, binding or otherwise, there are many global agreements that create commitments that may apply to mangroves. This section focuses on the most pertinent global agreements that, working together, could create an international framework for mangrove governance. Thereafter, we examine some of the most important regional and subregional instruments. Together, international, regional, national, and sub-national legislation and management create the basis for the sort of nested governance hierarchy that Ostrom suggests provides the path forward for sound management of a commons that is at once global and local. First, we will preface the discussion with an overview of some of the relevant principles of International Environmental Law.

4.2.1. Applicable principles and concepts of international environmental law

The core principle that defines international environmental law was first formalized in Stockholm, Sweden in 1972, at the first United Nations sponsored gathering of heads of state devoted to the global environment. Principle 21 of the Stockholm Declaration provides:

Box 1
Transnational challenges: A commons of common concern.

The need for regional transnational coordination around the protection of mangroves can be clearly derived from the number of countries that are connected by mangrove forest. To quantify the level of sharedness of mangroves across political borders, and to highlight regions where these agreements may be particularly impactful, we looked at two indicators: a) the relative percentage of global mangrove cover for each ecologically linked stretch of coast (Giri et al., 2011; Spalding et al., 2010), and b) the total number of countries sharing boarders or river basins in each ecologically linked stretch of coast (TWAP, n.d.). We used Large Marine Ecosystems (LMEs) as the unit of analysis. Half of the world's LMEs (i.e., 33) have mangroves, and one-third (i.e., 22) of those LMEs are shared by more than one country. In terms of area, this distribution translates to about 90% of global mangrove cover being found in transboundary watersheds, ~9% in watersheds (LMEs) belonging to a single country such as Australia or Brazil, and ~1% in isolated territories such as the small island states of the Pacific. The average number of countries sharing LMEs where mangroves occur is 6.5 and over 8 if including countries connected through upstream river basins. Fig. 4 shows the world's 66 LMEs categorized by their share of mangrove extent (panel A) and number of countries involved (panel B). The two indicators reveal that there are regional hot-spots for potential transnational management challenges for mangrove ecosystems. For example, the Guinea Current LME (#26) in West Africa ranks highest in terms of mangrove area but also in terms of countries within an LME. The Bay of Bengal (#34) in South Asia also ranks highest in terms of mangrove area but not in terms of countries, where it is surpassed by the Arabian (#32) and Caribbean Sea (#12) LMEs. The Pacific Central-American Coastal LME (#11) that is relevant for our analysis of Costa Rica ranks second highest in both indicators. These are transboundary areas that would benefit the most from regional support for the management of mangroves. A list of all mangrove-harboring LMEs, bordering countries and upstream countries crossing adjacent transboundary river basins is provided in Table 1 within the appendix along with the Regional Seas to which they are associated.

> "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."(UNEP, 1972).

In short, countries may do what they want with their own resources as long as it does not negatively affect other countries' resources. This principle was reiterated twenty years later as Principle 2 of the Rio Declaration on Environment and Development at the Rio Conference on Environment and Development in 1992 and continues to serve as the hallmark of modern international environmental law.

At the same time, other overarching international legal principles and concepts support a global approach to the protection of mangroves. Three of these are particularly salient: the concept of "equitable utilization of shared resources," the concept of "common concern of humankind," and the principle of "common but differentiated responsibilities."

"Equitable utilization of shared resources" refers to the use of resources that do not wholly fall within the territorial jurisdiction of one country but straddle common political borders (Morgera, 2017). International rivers represent one such example, with the common watershed of international rivers, including marine and coastal areas also being viewed as a shared resource. The U.N. Watercourses Convention defines "watercourse" as "a system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus"(Rieu-Clarke et al., 2012). The Convention further provides: "Watercourse states shall, individually and, where appropriate, in cooperation with other states, take all measures with respect to an international watercourse that are necessary to protect and preserve the marine environment, including estuaries, taking into account generally accepted international rules and standards."(Rieu-Clarke et al., 2012). Thus, countries must agree to coordinate to preserve shared resources.

The concept of "common concern of humankind" emerged during the runup to the Rio Conference as an alternative to the "common heritage of mankind" principle that applies to areas beyond national jurisdiction, such as the high seas and outer space (Bowling et al., 2016). The drafters of the 1992 Framework Convention on Biological Diversity (CBD) were looking for a term that did not suggest an incursion into national sovereignty yet reflected the significance of biodiversity protection as a shared resource among nations, and thus settled on "common concern." As one scholar has noted, "despite the emphasis on nationally created strategies and plans in the CBD …, the designation of biodiversity as a common concern ensures that States are aware of their responsibility to humankind and provides for global involvement and interest, particularly through reporting and other requirements,"(Bowling et al., 2016). This interpretation requires that nations act as global citizens and participate in initiatives that address challenges shared by all of humanity.

The principle of "common but differentiated responsibilities" also found its way into international law during the Rio Conference. It is enshrined as Principle 7 of the Rio Declaration on Environment and Development and is a core principle undergirding the Climate Convention (United Nations, 1992a). This principle asserts that nations have a common responsibility as environmental stewards, but because nations contribute differently to global environmental degradation, their responsibilities also differ (Stone, 2004). For example, higher levels of development and wealth of some nations is correlated to historically higher contributions to environmental degradation, and as such they should bear more of responsibility than countries that are currently developing.

Mangroves are confined to the tropics and subtropics, where most of the developing world lies. Only 15 countries make up 73% of the global total of mangrove distribution, of these 15 nations, only one, Australia, is regarded as a "developed nation." (Giri et al., 2011). As a result, the "common but differentiated responsibilities" principle suggests that there is a greater responsibility on developed countries to assist mangrove range states that are in the process of development (developing nations containing mangroves) with the financial resources and technology transfer needed to conserve mangroves. The "common but differentiated responsibilities" principle is typically operationalized through bilateral and multilateral aid, and often channeled through existing international agreements.

These foundational principles offer a conceptual framework for consideration of a global approach to mangrove governance, and result in more detailed implementation strategies through existing international environmental agreements, often referred to as Multilateral Environmental Agreements or MEAs. Although these MEAs have historically been developed independently, there has been a recent recognition of the value of collaboration among MEAs to streamline the implementation and success of all agreements (Davidson, 2016). Moreover, international legal frameworks that might not be considered "environmental" also have a role to play in any effort to achieve global mangrove governance.

4.2.2. Ramsar Convention

The foremost MEA for the protection of wetlands, including mangroves, is the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat, which dates to 1971, and hence is often described as a "first generation" MEA (Davidson and Coates, 2011). Ramsar's mandate consists of three pillars, the first being to designate suitable wetlands for the List of Wetlands of International Importance (Ramsar List) serving as a mechanism to establish an international network of protected wetlands. Through the Ramsar Convention, 294 mangrove sites in 75 countries, totaling roughly 38 million ha, have been placed on the List of Wetlands of International Importance (Ramsar, 2014). Nevertheless, mangroves are viewed by Ramsar as an "underrepresented" wetland type on its list of wetlands of international importance (Ramsar, 2002).

However, as the convention has evolved, the latter two pillars have taken on increased importance as Ramsar broadens its focus on all wetlands, and not just listed sites (Gardner and Davidson, 2011), The second pillar calls for the Convention to ensure the effective management of wetlands and to work towards the wise use of wetlands through national land and resource use planning, appropriate policies and legislation, management actions, and public education and awareness. The third pillar promotes international cooperation concerning transboundary wetlands, shared wetland systems, shared species, and development projects that may affect wetlands.

Pillar two, addressing the "wise use" of wetland resources as the underlying mechanism for wetland conservation has become the primary focus of the Convention. In giving early meaning to the term "wise use", Ramsar became the first convention of its kind to link the conservation of natural resources to the sustainable use of those resources (Finlayson et al., 2011; Matthews, 1993). The Ramsar Convention defines wise use as the "sustainable utilization for the benefit of humankind in a way compatible with the maintenance of the natural properties of the ecosystem." The Convention further defines 'sustainable utilization' as the "human use of a wetland so that it may yield the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations." This interpretation of wise use further evolved to dovetail more closely with "next generation" MEAs like the Biodiversity Convention and the Climate Change Convention, discussed below, to mean the "maintenance of ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development" (Ramsar Res. IX.1, 2005, Annex A, supra note 8) (Finlayson et al., 2011).

This philosophical convergence between Ramsar and other MEAs around the overarching contextual principle of wise use supports the third pillar of Ramsar – international cooperation. It is this pillar that undergirds efforts by Ramsar to formally engage with other MEAs with substantive overlap and that drives international policy to support wetland protection.

4.2.3. Convention on Biological Diversity

Another MEA of significance to the international governance of mangroves is the United Nations Framework Convention on Biological Diversity (CBD), one of the three treaties that emerged from the 1992 Rio Conference on Environment and Development. The objective of this convention is the "conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of benefits arising out of the utilization of genetic resources and by appropriate transfer of relevant technologies."(Coates, 2016). Although the CBD itself does not specifically target the conservation of wetlands, it does focus on the preservation of biodiversity that wetlands support. Further, it has made coastal wetlands a priority through the adoption of the Jakarta Mandate on Marine and Coastal Biological Diversity in 1995. Within the Jakarta mandate, the CBD further addresses the wise use of wetlands indirectly, with a particular emphasis on mangrove systems in connection with the development of sustainable fisheries and mariculture operations (sensu Ramsar Res. IX.1, 2005, Annex A, supra note 8) (Gardner and Davidson, 2011).

4.2.4. UNFCCC - United Nations Framework Convention on Climate Change

One of the most well-known MEAs is the United Nations Framework Convention on Climate Change (UNFCCC), which is relevant to mangroves due to their significance to the global climate system. UNFCCC also arose from the Rio 1992 Conference on Environment and Development and entered into force in 1994. The ultimate objective of the UNFCCC is to "achieve… Stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Sands, 1992). Embedded within the UNFCCC is the Paris Agreement. The Paris Agreement "aims to strengthen the global response to the threat of climate change" by halting the increase in global temperature, the resultant sea level rise, and increasing the nation's ability to adapt to the impacts of climate change (UNFCCC, 2015).

The Climate Change Convention focuses on both mitigation and adaptation. As mentioned above, mangroves play an important role in climate change mitigation through carbon storage and sequestration, particularly in soils and as blue carbon in coastal waters (Howard et al., 2017; Taillardat et al., 2018). A key feature of the Paris Agreement is the requirement that countries submit "Nationally Determined Contributions (NDC)," essentially a description of the mitigation measures that the country will take to meet the Convention objective of stabilizing greenhouse gas emissions. Protecting and restoring mangrove forests represent one way that a mangrove range country can reach its NDC (Ramsar, 2018).

In addition to their value in carbon sequestration, mangroves can buffer storm surges, and increase shore elevations by trapping and accumulating sediment, potentially mitigating the risk of climate induced sea level rise. However, as previously mentioned, research suggests that mangroves would not be able to keep pace with an annual sea level rise greater than 6.1 mm per year (Saintilan et al., 2020). The most recent Intergovernmental Panel on Climate Change (IPCC) report, which triggered the Paris Agreement, found that projected global mean sea level rise for 1.5 °C of global warming has an indicative range of 0.26–0.77 m, well above the tolerance level for mangroves (Pachauri and Meyer, 2014). Thus, the UNFCCC is an important MEA for ensuring that mangroves can continue to perform their climate regulation function as well as providing protection of mangroves from the increasing future threats of climate change.

4.2.5. Sendai Framework for disaster risk reduction 2015–2030

The Sendai Framework for Disaster Risk Reduction was adopted in 2015 at the United Nations World Conference on Disaster Risk Reduction (Sebesvari et al., 2019). It succeeds the Hyogo Framework for Action (HFA) 2005–2015: 'Building the Resilience of Nations and Communities to Disasters'. The Sendai Framework differs from the MEAs discussed above in two significant ways; it is not a binding agreement in the same sense as a treaty, and it is not per se an environmental agreement. Instead, the Sendai Framework serves as a quasi-legal instrument, sometimes referred to as "soft law," encouraging, but not requiring, parties to adopt the principles laid out in the framework. Parties to the Sendai Framework are UN member nations that attend the meetings, agree to the Framework principles, and express commitments to further the goals of the Sendai Framework (UNDRR, 2015a). The United Nations Office for Disaster Risk Reduction serves as its administrative body and is charged with implementing a "Plan of Action." (UNDRR, 2020). The Sendai Framework outlines four priorities for "action to prevent new and reduce existing disaster risks" which include: 1) Understanding disaster risk; 2) Strengthening disaster risk governance to manage disaster risk; 3) Investing in disaster reduction for resilience and; 4) Enhancing disaster preparedness for effective response, and to “Build Back Better”' in recovery, rehabilitation and reconstruction (UNDRR, 2015b).

Recent research has estimated that mangroves annually reduce globally property damage by more than 65 billion USD and protect over 15 million people from flooding (Menéndez et al., 2020). However, Sendai only fleetingly addresses the role of natural systems in disaster risk reduction by encouraging “mainstreaming disaster risk assessment, mapping and management into rural development planning and management of, inter alia, mountains, rivers, coastal flood plain areas, drylands, wetlands and all other areas prone to droughts and flooding, including through the identification of areas that are safe for human settlement, and at the same time preserving ecosystem functions that help to reduce risks” within Priority 3 of the framework (UNDRR, 2015b).

4.2.6. Synthesis and synergies

Although all the above-mentioned multilateral treaties and initiatives originated with different aims, significant overlaps in their goals and methodologies have led to several synergies among the four agreements (Fig. 3). For example, parties to Ramsar and the CBD have signed a memorandum of understanding (MOU) and established joint work plans to achieve common goals within the CBD 2011–2020 strategic plan (Slobodian and Badoz, 2019). Ramsar and the CBD have agreed on a similar goal of promoting the wise use of environmental resources. Through a joint liaison group as well as with the Sendai Framework, CBD signatories have also coordinated efforts with the signatories of the UNFCCC to develop voluntary guidelines for implementing ecosystem-based approaches to combat climate change and disaster risk, such as coastal buffering and carbon storage capacity of wetlands (CBD COP decision XIII/4) (Lo, 2016). Similarly, Ramsar, via Resolution XII.13 on Wetlands and Disaster Risk Reduction, encourages parties to integrate wetland-based disaster risk management and climate change adaptation into development policies and planning at all levels of government (Kumar et al., 2017). The Sendai Framework and the UNFCCC also highlight the potential role of wetlands in ecosystem-based adaptation to combat climate change. As mentioned previously the Sendai Framework identifies preserving ecosystem functions that help to reduce risks, such as wetlands through their storm-surge mitigation capabilities within its priorities for action (Priority 3:G). Likewise, the UNFCCC Paris Agreement states: “Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases.” (Art4,1 d) (Horowitz, 2016).

4.2.7. Sustainable development goals

However, despite the significant overlap in scope, formal coordination between MEAs is somewhat limited, with most of these synergies being undertaken outside of the MEAs themselves. One example is the United Nations Sustainable Development Goals (SDG) which operate above the MEAs and play a vital role in unifying global efforts around common themes. Predecessors to the Sustainable Development Goals date back to the groundbreaking Stockholm Conference on Environment and Development, discussed above. Sustainable development then became the central organizing principle of the 1992 Rio Conference on Environment and Development and was enshrined as Principle 1 of the Rio Declaration. In 2012, at the “Rio +20” conference marking the 20th anniversary of the Rio Conference, a set of seventeen broad, “integrated

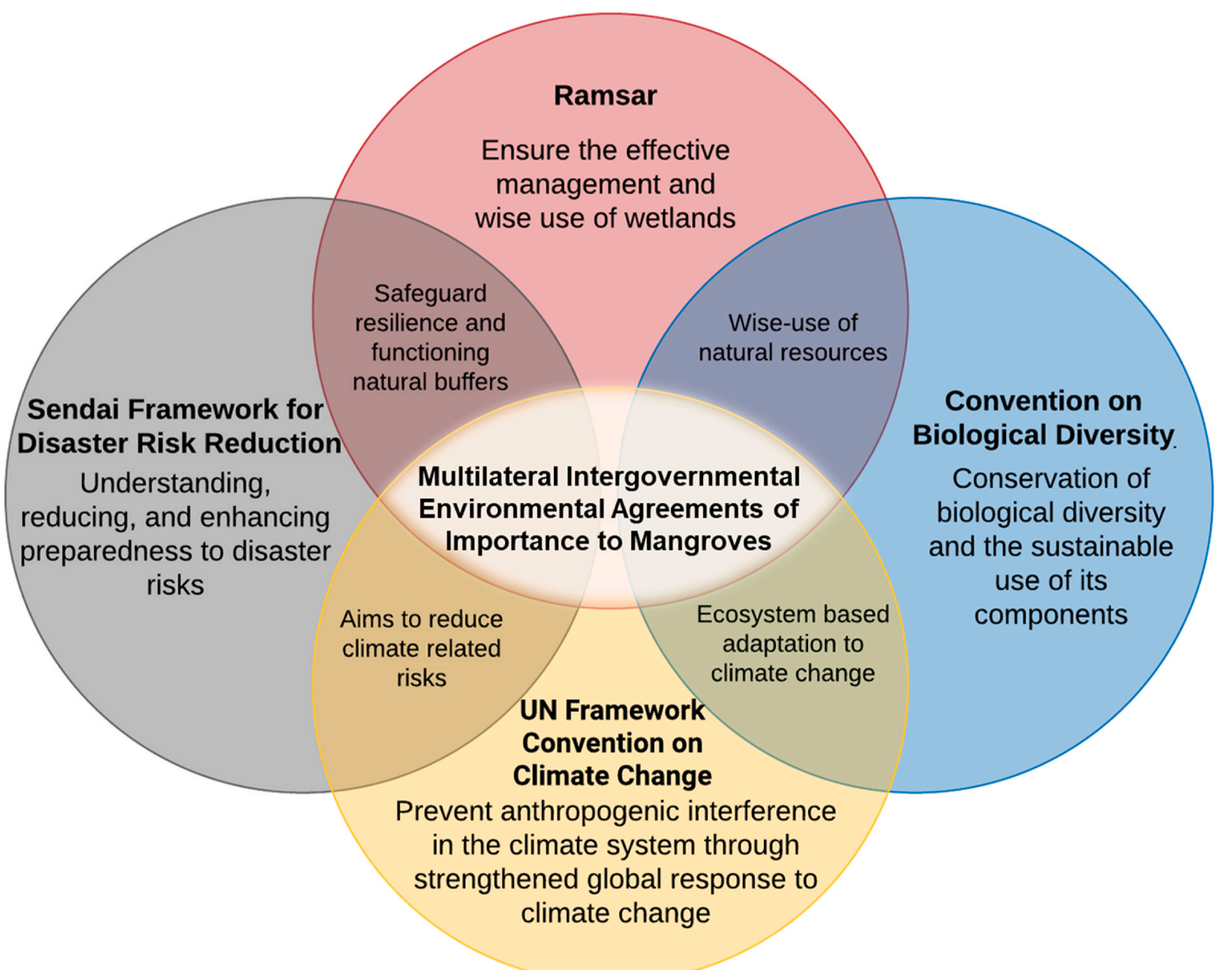

Fig. 3. The focus of multilateral intergovernmental environmental agreements and overlaps in these agreements that are relevant to mangrove management.

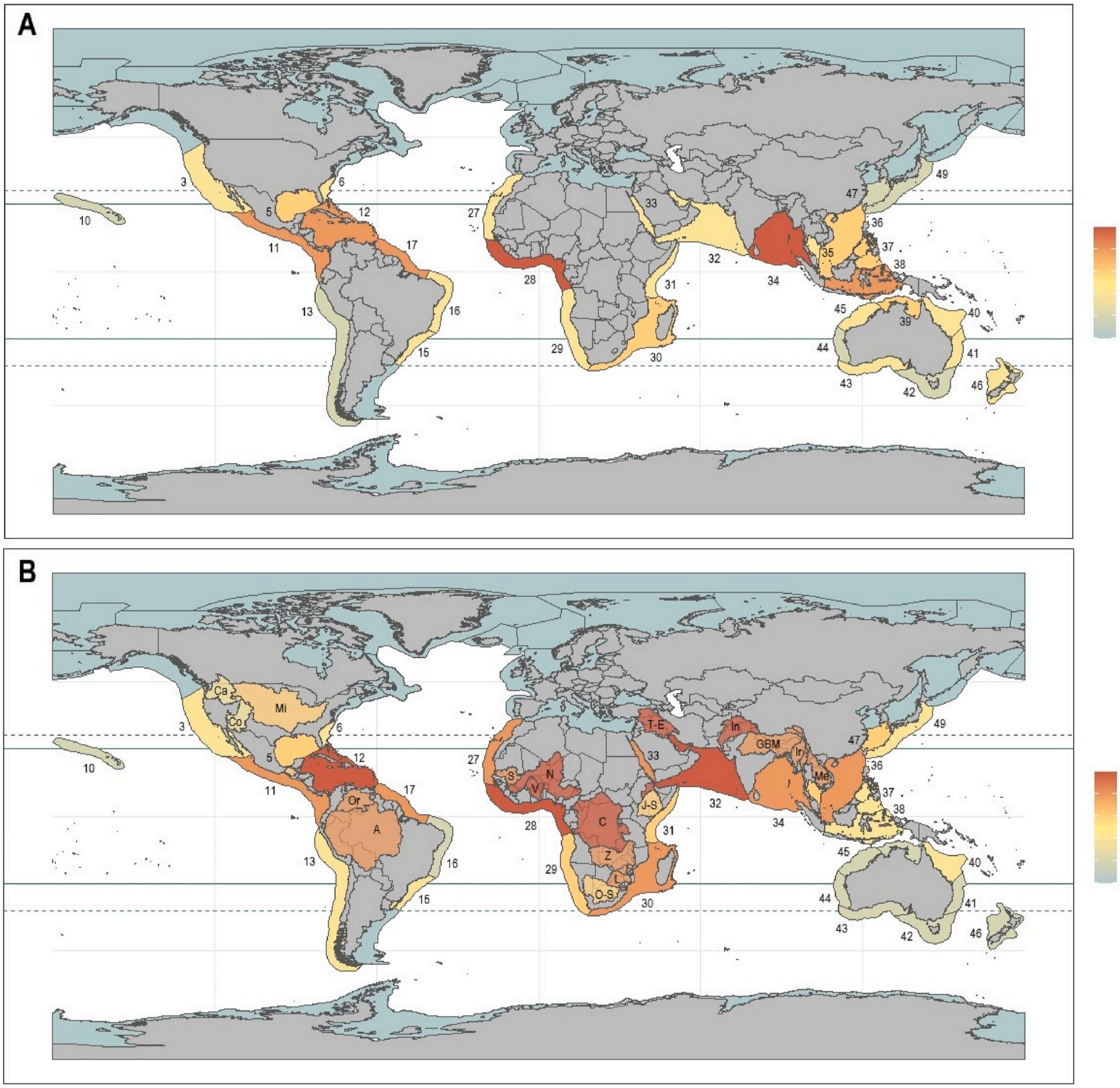

Fig. 4. A: quintile distribution, indicated by color (from 1st green - 5th red quintile) of relative mangrove cover per LME (km^2); B: quintile distribution, indicated by color (from 1st green - 5th red quintile) of the number of mangrove-sharing countries per LME (only transboundary river basins crossing additional upstream countries are shown). Green lines denote the latitudinal range of mangroves with a 5°N and 10°S buffer. Numbers refer to LME regions, see key in appendix Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

and indivisible" Sustainable Development Goals (SDGs) were agreed upon. These goals were approved in 2015 by the United Nations General Assembly as part of the 2030 Agenda. In 2017, targets and indicators were set for each goal, to be achieved by 2030.

Arguably, the SDGs create the overarching policy paradigm beneath which lies the aggregate of global efforts to chart the future. Thus, existing MEAs and related agreements should all relate back to the SDGs as they pursue their international obligations, a goal formalized within the SDGs themselves with target 17.14 championing the need for "policy coherence for sustainable development." The SDGs can also be downscaled to successively create nested levels of policy, resulting in a through-line from a local community action all the way back through state, regional and global policy to one or more relevant SDGs. While an audacious goal, identifying such a through-line would coincide with Ostrom's theory of successful management of common pool resources.

Several of the SDG's are relevant to the global effort to conserve mangroves. Yet, goal 14, which calls for the international community to "conserve and sustainably use the oceans, seas and marine resources for sustainable development" is the most directly relevant to mangroves. Even then, the intertidal nature of mangroves, and their status as both forests and marine ecosystems, challenge neat categorization. Furthering Goal 14 has become the charge of the United Nations Conference on the Oceans which convened first in 2017, where they released a joint statement entitled "Our Ocean, Our Future: Call for Action" including a call to "strengthen cooperation, policy coherence and coordination amongst institutions at all levels, including between and amongst international organizations, regional and subregional organizations and institutions, arrangements and programmes." (United Nations, 2018). However, the statement's only direct reference to mangroves came in the context of its role in climate change mitigation and adaptation.

Yet, mangroves were extensively addressed in the voluntary commitments solicited by the Oceans Conference from the governmental and non-governmental community to make progress toward the Goal 14 targets. These commitments were grouped into nine thematic areas described as "Communities of Ocean Action" included one specific to mangroves (IUNC and Ramsar, 2020). This effort has resulted in the first inter-governmental coordinating entity specific to mangrove conservation: "The Community of Ocean Action for Mangroves."(IUNC and Ramsar, 2020). The Secretariat to the Ramsar Convention, and the International Union for Conservation of Nature (IUCN; an international consortium of governmental and non-governmental organizations), were tasked to serve as focal points for the Mangrove Communities of Ocean Action and required to report to the UN's Special Envoy for the Ocean and to the UN Department of Social and Economic Affairs (IUNC and Ramsar, 2020). However, the progress of this effort has been delayed with the postponing of the 2020 Oceans Conference due to the global coronavirus pandemic.

4.2.8. Multinational non-governmental approaches

As alluded to above, many of the voluntary commitments around the SDGs and, in turn, coordination between common goals of MEAs are undertaken by non-state actors, including non-governmental organizations (NGOs). Since the 1992 Rio Conference, the role of NGOs in international environmental policymaking has grown dramatically (Partelow et al., 2020). International NGOs are routinely admitted as observers to the Conference of the Parties and interim meetings for MEAs, are assigned follow-up actions resulting from these meetings, and in the case of resource-starved developing nations they can sit as part of governmental delegations at these meetings (Martens, 2003). NGOs have played a significant, if not leading, role in promoting both international and domestic mangrove governance. This is particularly evident when looking at commitments submitted to the Sustainable Development Goals, with the greatest percentage (33%) of commitments to SDG14 coming from NGOs (IUNC and Ramsar, 2020). Because of the wide reach of NGOs activities surrounding mangrove management, NGOs have addressed many of the synergies between MEAs informally throughout their work. Yet, several international NGOs with the largest global reach, the World Wildlife Fund, The Nature Conservancy, and Conservation International, Wetlands International, and one quasi-governmental NGO, the IUCN, have gone even further and formed the Global Mangrove Alliance a formal collaboration among themselves aimed at advancing mangrove conservation initiatives (Global Mangrove Alliance, n.d.).

Through both formal and informal coordination, these MEA, SDG, and NGO efforts play an important role in addressing the threat to mangroves across the globe. What seems to be missing is an effort among these governmental and non-governmental institutions to converge around a common theme for a targeted purpose. Given the significance of mangroves to each of their missions, biophysical uniqueness, pan-global nature, and common pool status of mangroves, there is a need for an independent arrangement or a formalized embrace of the Ocean Action for Mangroves among the four MEA agreements. Such coordination, in addition to the support of NGOs, would set stage for downscaling commons governance in the manner Ostrom suggests.

4.3. Regional environmental governance and management challenges

Ostrom's principle of nested scales of governance, is partially realized under the current legal structure with governance differentiating at the regional, sub-regional and bilateral level. Global MEAs and related agreements often rely on regional cooperation and integration to achieve their objectives. According to the International Environmental Agreement database (as of 2013), there are 2227 MEAs globally (Mitchell, 2021). Of these, nearly 1096 have been characterized as "regional," which includes bilateral agreements, of which there are 589 (Balsiger and Prys, 2016).

A very small percentage of these regional/bilateral agreements can be considered primarily oceanic or coastal and marine. In the oceanic and marine context, these agreements can be international commissions for a geographically or taxonomically specific fishery, transboundary river basin agreements that include river mouths and estuaries, or a coastal and marine component to more broad-based environmental agreements. Even given the smaller number of regional agreements that specifically address or include the marine and coastal environment, the diverse range and subject matter of these agreements offer a daunting prospect for vertical coordination with MEAs and national and subnational programs. More than one commentator has referred to the plethora of regional environmental agreements and their relationship to MEAs as 'an ad hoc and fragmented institutional architecture' (Kim and Bosselmann, 2013; Oberthür, 2002; Steiner et al., 2003).

A more targeted and systematic approach to achieving a regional governance framework for mangroves can be found in the United Nations Environment Programme's (UNEP) Regional Seas Programme. The Regional Seas Programme breaks up the world's oceans into 18 different regions where UNEP supports activities. Virtually all mangrove range states lie within a Regional Sea, with most of these regions buttressed by regional agreements or action plans institutionally supported by the UNEP Secretariat. However, these Regional Seas are often large, and since these regions are geopolitically determined (and not ecologically based) the regional agreements can be very broad. This has been remedied in part by the Regional Seas Programme embrace of the Large Marine Ecosystems (LMEs) tool. The Large Marine Ecosystems tool was developed by the US National Oceanic and Atmospheric Administration (NOAA) and is a biogeographically based tool for enabling ecosystem-based management through a multilateral approach to management of shared natural resources within ecologically-bounded transnational areas (Billé et al., 2017).

Much of the work within the LMEs is done through projects funded by the Global Environment Facility (GEF). The GEF is the financial mechanism for the CBD and UNFCCC among other conventions and aids eligible countries in managing LMEs. The GEF supports the development of Transboundary Diagnostic Analyses (TDA), which are scientific assessments of the water-related issues of a region, and their environmental and economic impacts (Whalley, 2011). TDAs help to specify sources, locations, and sectors as well as the spatial scale and the socio-economic context within which they occur. Based on the TDA, LME countries negotiate a policy document known as the Strategic Action Plan (SAP) to create operational resource management agreements among environmental, fisheries, energy, and tourism ministers of neighboring countries. This is both a regional framework detailing the legal and institutional changes needed to address the priority actions identified in the TDA and an agreement among countries to take their own sets of actions necessary to implement the Strategic Action Plan at the national level. Participating countries therefore commit to share knowledge and resources pertaining to local LMEs to promote longevity and recovery of fisheries and other industries dependent upon LMEs (GEF et al., 2015).

However, even with the formalized framework of the LME and Regional Seas Programme, these initiatives create few substantive obligations, but instead rely largely on voluntary compliance, making the effectiveness of these agreements dependent on how they are interpreted into national law. In the following section we will explore Costa Rica as a case study as an example of how international and regional agreements can be translated, and downscaled, into domestic policies.

5. Costa Rica case study

With greater reliance of developing nations on foreign economic assistance, often tied to international agreements, the nested governance framework is likely to materialize to the furthest extent in these countries with international policy driving domestic reforms. Costa Rica was chosen as our national case study, because its development status and extensive environmental policy make it a good candidate for generalizing a paradigm for successful integration of national policy with regional and international agreements within developing countries where the majority of mangrove coverage lie (Giri et al., 2011; United Nations, 2020).

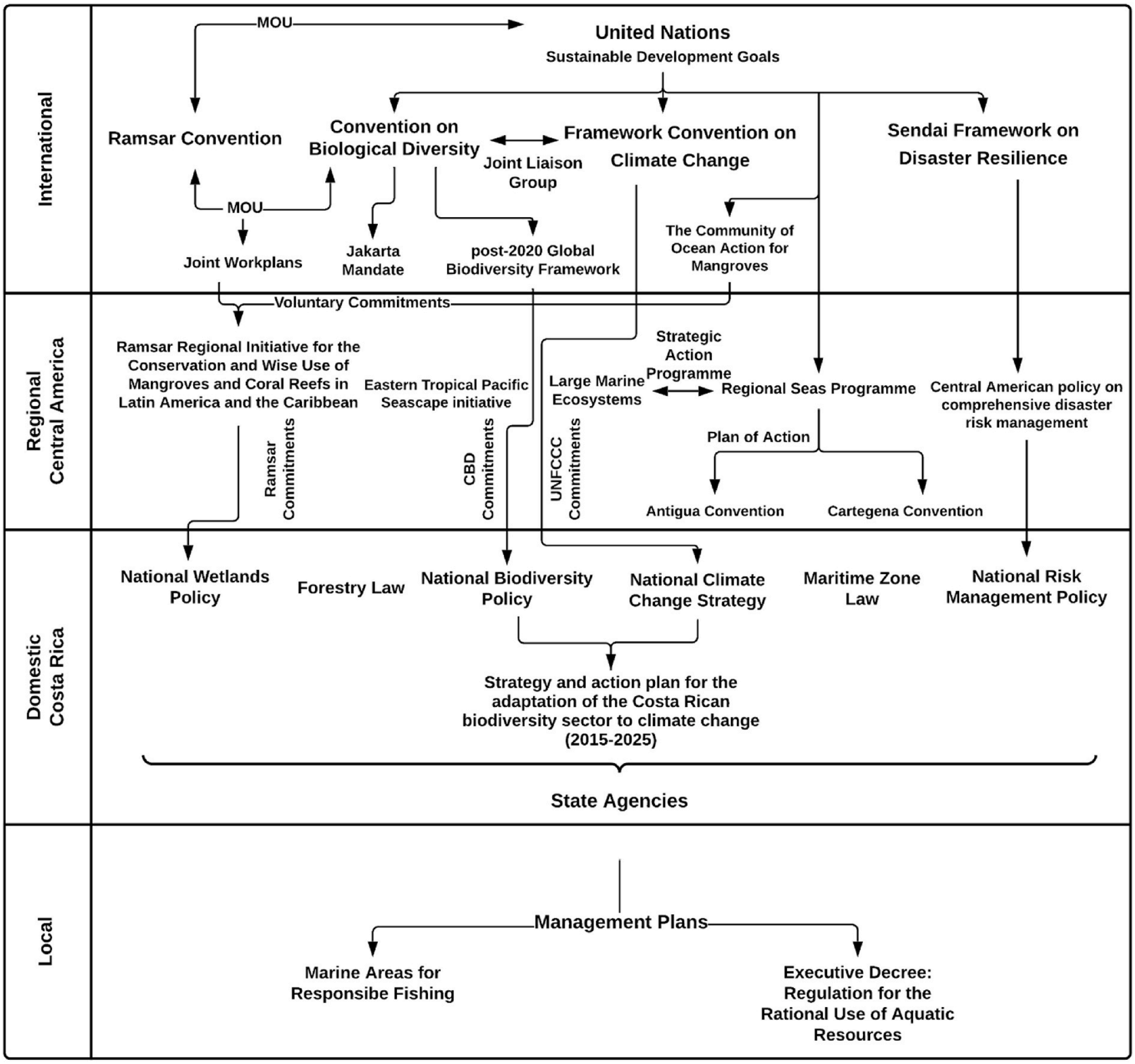

Fig. 5. A subset of the governance framework of policies pertaining to mangroves in Costa Rica. Arrows indicated direction of influence; arrow labels indicate formal connections.

5.1. Global and regional mangrove governance relevant to Costa Rica

Costa Rica is a global leader in promoting environmental policy being a signatory to each of the MEAs discussed above as well as a participant in most of the relevant regional agreements that are key to downscaling mangrove governance, such as the Regional Seas Programme and LME SAPs. Specifically, Costa Rica is a signatory to the 2002 Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment (the Antigua Convention), which serves as the governance platform for the Northeast Pacific Regional Seas Programme (UNEP, 2017). The Antigua Convention includes a "Plan of Action," that contains a number of specific objectives that address regional mangrove governance, including support for mangrove management at the national and sub-national levels (UNEP, 2017). This region also includes a corresponding LME initiative for the Pacific-Central American Coast, including Costa Rica, but it is relatively new with project development beginning only three years ago in 2018 (GEF, 2018a). At the NGO level, Costa Rica participates in the Eastern Tropical Pacific Seascape initiative, which also places considerable emphasis on mangrove management (GEF, 2021a).

On the Caribbean-Atlantic, Costa Rica is a party to the Cartagena Convention for the Protection and Development of the Marine Environment in the Wider Caribbean (IUCN, 2002). This regional Convention includes three sub-agreements, termed "protocols," that address oil spills, land-based sources of pollution, and protected areas and wildlife known as the SPAW protocol. The SPAW protocol, to which Costa Rica is not a party, is the most biodiversity-oriented protocol. Red and white mangroves are listed under Annex III of the SPAW Protocol, calling for regulation on exploitation (IUCN, 2002). The broader Cartagena Convention has a direct linkage to the UNEP Regional Seas Programme through the Secretariat to the UNEP Caribbean Environmental Programme. In addition, pursuant to the Caribbean LME initiative, a series of regional and subregional Transboundary Diagnostic Analyses were completed in 2011(GEF, 2021b). This, in turn, led to a "Strategic Action Programme," completed in 2013 and endorsed by 35 of the region's sectoral ministries, including Costa Rica, with mangrove governance as a key strategic objective of the document (GEF, 2021b).

5.2. Costa Rica's internationalist approach to international law

Two factors considerably influence how a country internally operationalizes MEAs and regional agreements pertaining to mangroves. The first is domestic implementation of international law, with countries ordinarily following either the "monist" or the "dualist" approach. Monist countries are countries which directly accept international law as part of their domestic law, with no further domestic legislative action required (Bruch, 2005). In many cases, where there is conflict in a monist system, international law is either accorded superior legal status to a domestic law or it is given equal weight. This can also mean that in some cases an international agreement can be directly actionable through the judicial branch. When applied to international law this can be beneficial as it allows for MEAs to take immediate effect. However, since MEAs often use broad and vague language, they are unlikely to address the specific needs of the country. In contrast, dualist countries treat international law and domestic law separately. This means that an international agreement will require domestic legislation for implementation, and judicial recourse will only occur through that domestic legislation. This can allow for the policies to specifically address the environmental needs of the nation, but domestic policies may take significantly longer to enact into legislation, if they are enacted at all.

Costa Rica is a monist country. International agreements fall only beneath the national constitution in the hierarchy of legal authority. Judicial cases can and have been brought directly under a treaty, including the treaties discussed here that are most relevant to mangroves, e.g. Ramsar, CBD and UNFCC. Moreover, administrative agencies have asserted an international treaty as authority to take an action that would otherwise violate a statute or regulation. This occurred in the case of an internationally important wetland where the Ramsar principle of "wise use" conflicted with a protected areas statute that prohibited the "active management" of national parks, such as cattle grazing (MINAE, 1998).

Costa Rica's internationalist and monist approach to governance makes it particularly receptive to receiving and embracing policies, principles and concepts that flow from international law such as the MEAs such as those described above. In essence, Costa Rica offers a laboratory to test Ostrom's "trickle down" theory of governance of the commons (Fig. 5).

The most overarching of all mangrove governance in Costa Rica is the National Wetlands Policy, which draws its inspiration directly from the MEAs Costa Rica has ratified, especially Ramsar and the UNFCC. Costa Rica recently updated its nationally determined contributions under the Paris Agreement to include many mangrove related action items including protecting all of the coastal wetlands recorded in the National Wetland Inventory, including 22,000 ha of mangroves, restoring priority coastal wetlands areas by 2025, developing management plans that enable sustainable community stewardship of mangrove areas, and exploration of innovative conservation financing mechanisms (Gobierno del Bicentenario et al., 2020).

5.3. The mangrove commons: the status of mangroves under domestic law in Costa Rica

The second factor influencing translation of international agreements pertaining to mangroves is the treatment of mangroves as a common pool resource in many countries. Although the status of mangroves as a commons resource can lead to exploitation as a result of the "tragedy of the commons", it also affords nations great authority over the policies determining the wise use of mangroves.

Costa Rica characterizes the intertidal zone as "*dominio publico*," or public dominion, and incapable of alienation (Cabrera, 2010). The application of *dominio publico* to the coastal zone in Costa Rica is formalized within the 1977 maritime zone law, *la Ley sobre La Zone Maritimo-Terrestre,* that establishes a public zone encompassing the intertidal zone as well as 50 m from the high tide line. The legal concept of *dominio publico* grants significant legal protection to this public zone, is ordinarily interpreted in favor of maintaining the zone's environmental character and its character as a commons (Instituto Costarricense de Turismo, 1977).

In addition to the protections provided to mangroves as *dominio publico*, Costa Rican law protects mangroves as a common pool resource under a legal doctrine termed *Patrimonio Natural del Estado* (1996). This doctrine applies to several categories of forested lands, including those that have been declared "inalienable," such as the intertidal zone discussed above (1996). The types of protection mangroves receive, however, depend on the management category within which they fall. In some cases, mangroves fall within National Parks and come under the jurisdiction of the National Park Service. These are accorded the greatest protection and extractive use of any kind is prohibited, with other management categories allow varying degrees of extractive and non-extractive use, allowing for differentiated management practices on the subnational level (González-Maya et al., 2015).

5.4. Ostrom's last mile: community-based mangrove management in Costa Rica

Costa Rica' fealty to international law and its domestic embrace of that law, coupled with the treatment of mangroves as "dominio publico" and "patrimonio naticional" create the enabling conditions for community-based management of the mangrove commons; the last step in Ostrom's nested sequence of successful commons governance. Costa Rica enables community-based management in several ways. In 2009, Costa Rica created a new form of protected area, termed Marine Areas for Responsible Fishing (Carrillo et al., 2019). These areas are designed to promote small scale fisheries, and the boundaries typically extend to the high tide line along the coast, thus incorporating mangroves. As of 2019, there were at least 7 such areas, mostly along the Northwest Pacific Coast in and around the Gulf of Nicoya, where extraction of mangrove dependent mollusks is a common artisanal fishery (Carrillo et al., 2019).

In addition, by Executive Decree (No. 39.411), Costa Rica authorizes the rational use (wise use) of natural resources within mangrove wetlands by communities more generally, if they are outside of specifically designated protected areas (InforMEA, 2015). A condition precedent to this authorization is a "general management plan" prepared by the Ministry of the Environment, and where fishing or aquaculture activities are involved, approval by the Costa Rican Institute of Fisheries (INCOPESCA) (InforMEA, 2015). Moreover, the executive decree is limited to legally constituted community associations and cooperatives that come from local communities that have traditionally harvested from the mangrove wetlands. Authorized community-based organizations must still seek a concession, use permit, license, or other form of administrative authorization to conduct extractive activities within mangroves. In keeping with Costa Rica's internationalist approach, the Executive Decree makes specific references to the Biodiversity Convention and Ramsar and requires that management plans conform to technical parameters adopted by both conventions (InforMEA, 2015). These community initiatives allow for Costa Rica to determine protections on a site-by-site basis and permit the determination of what constitutes wise use of mangrove resources on the local level based on ecological and societal needs.

6. Discussion

Costa Rica offers a robust case study for downscaling governance from the international to local level, as suggested by Ostrom's principles. Although Costa Rica is a monist country, making the international agreements that they sign binding, they have also tailored the often-broad statements in international laws to meet their national needs by complementing MEAs with domestic policies applying directly to mangroves and containing explicit requirements. For example, the National Wetland Policy contains specific provisions to incorporate Ramsar site management plans into the planning cycle of the Ministry of National Planning and Economic Policy, MIDEPLAN, the institution responsible for the multi-sectoral development strategies of the government

(Gobierno de la Republica de Costa Rica et al., 2017).

This participation in international agreements, combined with supporting domestic policies, provides a more robust environmental governance framework than in other countries, especially countries with a dualist approach to international law. Dualist countries, which require MEAs to be passed as domestic laws to be binding, may adopt and interpret the broad language in international environmental agreements differently. These domestic interpretations may make international agreements more specific to local threats and needs but can also dilute the force and effect of a unified front of international agreements. Dualist nations are also often subject to delays in implementation due to politicization of environmental issues and may result in international commitments being met with more temporary policies or compliance that is limited to setting voluntary actions. Lack of binding policies can lead to countries failing to meet their MEAs commitments. For example, Davidson (2016) found that there is inadequate implementation and compliance regarding the mechanisms established for countries to report the status and change in the ecological character of their wetlands under article 3.2 of the Ramsar Convention. This work highlights the need to pass substantive laws at both the national and local levels to fully participate in international agreements.

Many nations have attempted to overcome this obstacle by incorporating environmental protections into their constitutions. Integrating these rights into the highest levels of domestic policy makes it easier for these countries to justify national policies that support international environmental agreements. Although this may seem challenging, particularly in nations that are historically hesitant to amend their constitutions, constitutional provisions for the environment are fairly common with 75% of national constitutions already incorporating some sort of environmental protections (Boyd, 2014). Eighteen of those nations added constitutional protections in 1992, the year of the United Nation's Rio Conference on Environment and Development marking the inception of the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change, providing evidence that many nations added these provisions as a tool to meet the commitments made within these agreements (Boyd, 2014). However, there are still many populous, industrialized, dualist countries, such as the United States, United Kingdom, Australia, and Canada, that do not include such provisions, making implementing environmental policies particularly challenging (Boyd, 2014; Hollis, 2020).

At the regional level, tailoring the broad statements found in international law may require targeted institutional capacity building and operational guidance on MEA implementation. Both technical and financial assistance are often critical to develop and thoroughly implement strategies and management plans on the regional level. Despite efforts at coordination, such as the formalized framework of the LME and Regional Seas program, many regional programs are still unable to come to full fruition. For example, a 2018 internal review of GEF International Waters projects found that areas of concern remain, including the level of integration with biodiversity and climate change projects, connection between the freshwater river basins and land-based impacts to the coastal zone, and private sector engagement to leverage financial contributions in the long run (GEF, 2018b).

Additional assistance from international MEAs, through grant systems such as those undertaken by GEF on behalf of CBD and UNFCCC, is particularly important for regional agreements pertaining to mangroves. With 90% of the global area covered by mangroves found in countries not classified as "developed" or "economies in transition", and 17% of these countries considered "least-developed countries", resources for regional scale environmental management is often lacking within mangrove range states (Bunting et al., 2018; United Nations, 1992b). To overcome inequities in the challenges of undertaking regional protections of mangroves, it is important that the concept of "common but differentiated responsibilities" is applied at the MEA level, allowing developed nations that do not contain mangroves but benefit from mangrove services and contribute to their global threats, to bolster regional protections of mangroves. Increased operational guidance from MEAs would allow regional agreements to move from being ad-hoc with little coordination to more comprehensive ecosystem level management between multiple regional agreements.

Yet, even with the increased capacity of global MEAs, there are still shortcomings to implementing ecosystem level management. For example, regional and international policies both fall short in addressing upland land use influences on mangroves. Ramsar recognizes the importance of wetlands as the buffer between terrestrial and aquatic environments but defines wetlands as areas of static or flowing water the depth of which at low tide does not exceed 6 m (Gardner and Davidson, 2011). This includes aquatic environments well off the coastlines but excludes the entire terrestrial environment which drains into these environments. Despite it being championed within many MEAs and associated regional policies, the best way to implement ecosystem level management is still unclear. The scientific community can help fill this knowledge gap by conducting further research on the influences of the terrestrial environment on wetlands to complement the extensive research conducted on the connectivity between wetlands and marine environments.

Additionally, on the international level, increased coordination among MEAs is necessary to achieve their common goals. As previously mentioned, there has been a concerted effort to coordinate strategies to achieve overlapping objectives through the efforts of NGOs, convergence around the SDGs, and the new Community of Ocean Action for Mangroves. However, MEAs could achieve a greater level of synergy. One example that was evident through our case study of Costa Rica was the relative lack of coordination of disaster and risk policies with other mangrove related policies on every geopolitical scale, highlighting the lack of recognition of mangroves role in disaster resilience (Fig. 5). Disaster and risk policies could more directly acknowledge the role of mangroves in coastal resilience through an expansion of the definition of critical infrastructure. Critical infrastructure - such as physical structures, facilities, and networks that provide essential services to the functioning of society - term in disaster science and policy. Typically, critical infrastructure refers to "grey infrastructure" such as roads, power lines, utilities, etc. However, more recently the notion of green infrastructure, such as fringing mangroves, have been considered as critical infrastructure, and there is ample room to adopt the same definition of critical infrastructure within the Sendai Framework and its downscaled polices (Sebesvari et al., 2019). A green infrastructure approach to the Sendai Framework would more closely align it with the MEAs that address the conservation of ecosystems and ecological processes and climate change. Increased coordination between the Sendai Framework and other MEAs around mangrove initiatives could lay the groundwork for increased synergies on all scales. In addition, the increased awareness of the services of mangroves for risk management can help to properly value mangroves. As foreseen in Hardin's tragedy of the commons, the benefit of exploiting mangroves is typically higher than the penalty for degradation (Slobodian and Badoz, 2019). Recognizing the true value of services provided by mangroves incentivizes wise-use practices and ensures that the full cost of damage is paid by those benefiting from their deterioration.

7. Conclusion

Within this paper we have shown that there is a legal framework for achieving successful management of mangroves, but with several remaining challenges. The first of which is the challenge of managing mangroves on multiple spatial scales. Mangrove threats and resources operate on the global to local level, necessitating corresponding management strategies to be conducted at these scales to ensure their effectiveness. Because of the multiple scales that are required to manage mangroves, countries must be fully participatory in not only international agreements but also be willing to pass substantive laws at both the national and local levels to be effective.

Yet another challenge is to ensure that the policies put in place are scientifically sound. With the recognition that ecosystem level management is necessary to manage the many services provided by mangroves, it is important that management plans reflect that mangrove are highly connected systems, as opposed to placing them in a silo of either the terrestrial or marine realm. Successful ecosystem level management also requires extensive scientific knowledge for implementation, especially regarding the connections of mangroves to upland systems, and translation of these scientific findings into laws. To secure funding necessary to support this research and build the support to implement management on this scale, mangroves will need to be properly valued, ecologically, economically, and culturally. The challenges facing the sustainable management of mangroves may seem daunting, yet they are challenges that we will need to meet as mangroves become increasingly important to protect both society and nature as we enter the Anthropocene.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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8. Appendix

Table 1

Regional Seas and corresponding Large Marine Ecosystems (official numbers) and jurisdictions (countries and territories where no mangroves are found in square brackets; upstream countries and corresponding river basins in braces)

Regional Sea	Large Marine Ecosystem	Countries
North-East Pacific	California Current (3)	Mexico
		{United States and Canada via Columbia (Ca)}
	Gulf of California (4)	Mexico
		{United States via Colorado (Co)}
	Pacific Central-American Coastal (11)	Colombia
		Costa Rica
		Ecuador
		El Salvador
		Guatemala
		Honduras
		Mexico
		Nicaragua
		Panama
South-East Pacific	Pacific Central-American Coastal (11)	Ecuador
	Humboldt Current (13)	Peru [Chile]
		{Argentina via 12 different river basisn in the Andes}
	Insular Pacific-Hawaiian (10)	United States of America
Wider Caribbean	Southeast US Continental Shelf (6)	Bahamas
		United States of America
	Gulf of Mexico (5)	Mexico
		United States of America
		{Canada via Mississippi (Mi)}
		{Belize and Guatemala via Grijalva (G)}
	Caribbean Sea (12)	Anguilla (UK)
		Antigua and Barbuda
		Aruba (NL)
		Bahamas
		Barbados
		Belize
		Bonaire (NL)
		British Virgin Islands (UK) Cayman Islands (UK)
		Colombia
		Costa Rica
		Cuba
		Curaçao (NL)
		Dominica

(continued on next page)

Table 1 (*continued*)

Regional Sea	Large Marine Ecosystem	Countries
		Dominican Republic
		Grenada
		Guadeloupe (FR)
		Guatemala
		Haiti
		Honduras
		Jamaica
		Martinique (FR)
		Mexico
		Montserrat (FR)
		Nicaragua
		Panama
		Puerto Rico (US)
		Saint Kitts and Nevis
		Saint Lucia
		Saint Vincent and the Grenadines
		Trinidad and Tobago
		Turks and Caicos Islands (UK)
		United States Virgin Islands (US) Venezuela
		Saint Martin (FR)
	North Brazil Shelf (17)	Brazil
		French Guyana (FR)
		Guyana
		Suriname
		Venezuela
		{Colombia, Ecuador, Peru and Bolivia via Orinoco (Oo) and Amazon (A)}
	East Brazil Shelf (16)	Brazil
	South Brazil Shelf (15)	Brazil
		{Uruguay via Lagoon Mirim}
West Africa	Canary Current (27)	[Canary Islands (ES)]
		Gambia
		Guinea-Bissau
		Mauritania [Morocco]
		Senegal [Western Sahara]
		{Mali via Senegal (S)}
	Guinea Current (28)	Angola
		Benin
		Cameroon
		Congo
		Democratic Republic of Congo
		Equatorial Guinea
		Gabon
		Ghana
		Guinea
		Guinea-Bissau
		Ivory Coast
		Liberia
		Nigeria
		Sao Tome and Principe
		Sierra Leone [Togo]
		{Algeria, Burkina Faso, Burundi, Central African Republic, Mali, Malawi, Niger, Rwanda, South Sudan, Sudan, Tanzania, Uganda and Zambia via Volta (V), Niger (N) and Congo (C)}
	Benguela Current (29)	Angola [Namibia]
		[South Africa]
		{Botswana and Lesotho via Orange-Senqu (Oe)}
Western Indian Ocean	Agulhas Current (30)	Comoros
		Madagascar
		Mayotte (FR)
		Mozambique
		South Africa
		Swaziland
		Tanzania
		{Botswana, Namibia, Democratic Republic of Congo, Swaziland, Zambia and Zimbabwe via Limpopo (L), Maputo, Sabi, Buzi, Pungwe and Zambezi (Z)}
		Mauritius
		Seychelles
	Somali Coastal Current (31)	Kenya
		Somalia
		Tanzania
		{Ethiopia via Juba-Shibeli (JS)}
Red Sea and Gulf of Aden	Red Sea (33)	Djibouti
		Egypt
		Eritrea [Israel]
		[Jordan]
		Saudi Arabia

(*continued on next page*)

Table 1 (*continued*)

Regional Sea	Large Marine Ecosystem	Countries
		Sudan
		Yemen
	Arabian Sea (32)	Djibouti
		Somalia
		Yemen
		{Ethiopia via Awash}
Persian Gulf	Arabian Sea (32)	Bahrain [Kuwait]
		[Iraq]
		Iran
		Oman
		Qatar
		Saudi Arabia
		United Arab Emirates
		{Jordan, Syria and Turkey via Tigris-Euphrates (TE)}
Southeast Asian	Arabian Sea (32)	Iran
		Pakistan
		India
		{Afghanistan via Indus (In)}
	Bay of Bengal (33)	Bangladesh
		India
		Sri Lanka
		{Bhutan, China and Nepal via Ganges-Brahmaputra-Meghna (GBM)}
East Asian Seas	Bay of Bengal (33)	Indonesia
		Myanmar
		Thailand
		{China via Irawaddy (Ir) and Salween}
	Gulf of Thailand (34)	Cambodia
		Malaysia
		Thailand
		Vietnam
	South China Sea (36)	Brunei Darussalam
		China [Honk Kong (China)]
		Indonesia [Macao (China)]
		Malaysia
		Philippines
		Singapore
		Taiwan (China)
		Vietnam
		{Laos via Mekong (Me)}
	Sulu-Celebes Sea (37)	Indonesia
		Malaysia
	Indonesian Sea (38)	Indonesia
		Timor Leste
	North Australian Shelf (39)	Australia
	Northwest Australian Shelf (45)	Australia
	South West Australian Shelf (43)	Australia
South Pacific	Northeast Australian Shelf (40)	Australia
		Papua New Guinea
	New Zealand Shelf (46)	New Zealand
		American Samoa (US)
		Fiji
		Micronesia
		New Caledonia (FR)
		Palau
		Samoa
		Solomon Islands
		Tonga
		Vanuatu
North West Pacific	East China Sea (47)	China
		Japan
		South Korea
		Taiwan (China)
	Kuroshio Current (49)	Japan
		Philippines
		Taiwan (China)

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