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Conservation and restoration of mangroves: Global status, perspectives, and prognosis

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ABSTRACT

Mangrove forests provide critical services around the globe to both human populations and the ecosystems they occupy. However, losses of mangrove habitat of more than 50% have been recorded in some parts of the world, and these losses are largely attributable to human activities. The importance of mangroves and the threats to their persistence have long been recognized, leading to actions taken locally, by national governments, and through international agreements for their protection. In this review, we explore the status of mangrove forests as well as efforts to protect them. We examine threats to the persistence of mangroves, consequences, and potential solutions for effective conservation. We present case studies from disparate regions of the world, showing that the integration of human livelihood needs in a manner that balances conservation goals can present solutions that could lead to long-term sustainability of mangrove forests throughout the world.

1. Introduction

Mangroves are found chiefly in the intertidal zones of coastal tropical and subtropical regions of the world (Fig. 1). They can tolerate salinities from freshwater to hypersaline exceeding 100 parts per thousand. They can also thrive under much lower salinities, but their occurrence in terrestrial communities is limited by competition with other species better adapted to the terrestrial environment. Mangroves are physiologically a tropics-adapted group, and frost frequency and severity as well as minimum temperature requirements limit poleward expansion (Twilley, 1998; Saintilan et al., 2014). Mangroves were reported by Spalding et al. (1997) to occupy 18,100,000 ha worldwide, but this estimate of global coverage was revised downward to 13,776,000 ha by Giri et al. (2011), and then to 8,349,500 ha by Hamilton and Casey (2016). The distribution of mangroves, which includes 118 countries, is described in detail by Tomlinson (1986).

At least 35% of mangrove forest area was lost worldwide during the 1980s and 1990s alone (Valiela et al., 2001), with losses of 50–80% in some regions (Wolanski et al., 2000). The global loss of mangroves can be attributed largely to human population growth and development in the coastal zone. Specific reasons are urban development, aquaculture, conversion to agriculture such as rice farming, and overexploitation of timber.

These losses matter, as mangroves provide numerous services and benefits to nature and to people. Mangroves play an important role in buffering coastlines against storm surges and tsunamis through wave attenuation (Kathiresan and Rajendran, 2005; Wolanski, 2007; Barbier et al., 2008; Teh et al., 2009). Studies have shown that the flooded area produced by Hurricane Wilma in 2005 in southwestern Florida would have extended 70% further inland without the protection of the 6–30 km zone of mangroves (Zhang et al., 2012a; Liu et al., 2013, Fig. 2), and mangroves reduced the loss of human life from the 1999 cyclone that struck Orissa, India (Barbier, 2016). Loss of mangroves will result in less protection from both flooding and high winds. Some countries, such as Guyana, have engaged in educational outreach to alert the public about the potentially catastrophic consequences to mangrove deforestation (Fig. 3). Numerous studies show that mangroves provide nursery habitat for juvenile coral reef fishes of many species (Nagelkerken et al., 2000). Laegdsgaard and Johnson (2001) showed that mangroves, especially the prop roots of *Rhizophora*,

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Fig. 1. Map showing the global distribution of mangroves (in black).
Source: United Nations Environment World Conservation Monitoring Centre (UNEP-WCMC); Giri et al. (2011); version 1.3, http://data.unep-wcmc.org/datasets/4.

provide structural heterogeneity that is favorable both to prey attempting to avoid predators and to predatory fish searching for invertebrate prey hiding within the root structure. Mangroves also serve as sinks for carbon, not only through accumulation of living biomass, but also through litter and dead wood deposition, including the trapping of sediments delivered from the uplands. Carbon in mangrove sediments does not turn over in the same way it does in terrestrial soil, but builds up vertically in response to sea level rise (SLR) (McLeod et al., 2011). Another service provided by mangroves is that of a nutrient sink. Denitrification in the anaerobic environment (Ewel et al., 1998) and nitrogen-fixation by certain bacteria and cyanobacteria associated with mangrove mud and with above-ground root systems (Kimball and Teas, 1975; Pelegri and Twilley, 1998) can improve water quality from wastewater inputs.

Worldwide, natural resources fall under various levels of management and ownership, ranging from private to government ownership (Berkes, 2004). Because of the recognized importance of mangroves and the continuing threats to their persistence, actions have been taken internationally and for the conservation and sustainable use of wetlands. Protective authorities include the United Nations Forum on Forests (UNFF), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Convention on Biological Diversity (CBD), United Nations Framework Convention on Climate Change (UNFCCC), Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention), Convention for the Protection of World Cultural and Natural Heritage, and the Convention on the Conservation of Migratory Species of Wild Animals. These agreements have resulted in the protection of large areas of mangrove forests globally. In addition to conservation agreements at the international level, efforts by individual nations to protect or restore these forests have varied from mandated protection by governments to locally-initiated efforts. Human use of those resources varies depending on the level of protection. Overall, the global decline of mangroves has slowed, but additional actions need to be taken to ensure their long-term survival (Alongi, 2002).

In this review we provide overviews of (1) Status of & Current Threats to Mangroves, (2) Threats for the Future (3) Failures of Current Conservation Approaches, and (4) Innovation and Success in Mangrove Conservation.

2. Status of and current threats to mangroves

Mangroves exist on every continent except Antarctica. In this section, we will limit our discussion to Asia (Fig. 4) and the United States of America (U.S.; Fig. 5). Asia encompasses the largest land area of mangroves and the U.S. has been the focus of many decades of published research on mangrove forests. Although the status of mangrove forests varies by country and region, many mangrove forests experience similar threats to their persistence from urban development and timber harvest to conversion for other land uses such as agriculture and aquaculture, which we describe in more detail in this section.

2.1. Asia

Asia has the largest land area of mangrove forest, encompassing 42% of the world's mangroves (Giri et al., 2011). Within Asia, Indonesia and Malaysia have the largest mangrove areas. We focus on Malaysia and China as representative of examples of status and change.

Malaysia has about 575,000 ha of mangrove forest (Fig. 4), reduced from 695,000 in the 1970s; that is, reduced by 17%, due to land conversion/reclamation for agriculture, aquaculture, urbanization, infrastructure development and natural causes mainly from coastal erosion. Located in the State of Perak, Matang Mangrove Forest is the largest mangrove forest in Malaysia. Covering an area of about 40,000 ha, the Matang Forest was designated as a Permanent Forest Reserve since 1904 with efforts to preserve the forest dating back to 1902, making it the oldest mangrove reserve in Malaysia. Although Matang Forest is not designated as a Ramsar site, it is a sustainable and well-managed forest system that produces a constant yield of renewable forest resources while maintaining ecosystem biodiversity and richness. There are currently seven Ramsar sites in Malaysia—four in Peninsular Malaysia, two in Sabah and one in Sarawak. The three Ramsar sites, Pulau Kukup, Sungai Pulai and Tanjung Piai, are located in the State of Johor. These sites are particularly rich in mangroves and intertidal mudflats. Located about 1 km offshore from the southwestern region of Johor, Pulau Kukup is an uninhabited and intact mangrove island of approximately 650 ha surrounded by extensive (800 ha) intertidal mudflats. The island is important for flood control and protection from storm events and coastal erosion. Sungai Pulai, over 9000 ha, is Peninsular Malaysia's largest estuarine mangrove system, which also includes seagrass beds, intertidal mudflats and an inland freshwater riverine forest. It provides