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Indonesia's globally significant seagrass meadows are under widespread threat

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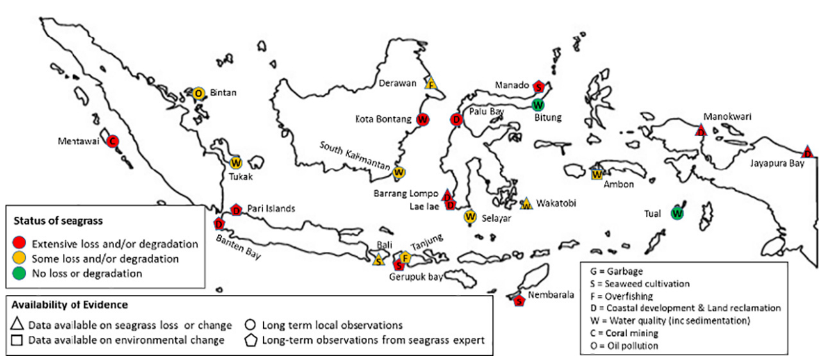
HIGHLIGHTS

- Seagrass meadows in Indonesia of fundamental importance for biodiversity and ecosystem service provision.
- *In lieu* of available data, experts provided information about seagrasses and their ecosystem services around Indonesia.
- Seagrasses and the ecosystem services they support across the Indonesian archipelago are in a critical state of decline.
- Coastal development, land reclamation, deforestation, seaweed farming, overfishing and garbage dumping cause seagrass loss.
- The perilous state of Indonesia's seagrasses compromises both resilience to climate change and ecosystem service provision.

GRAPHICAL ABSTRACT



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ABSTRACT

Indonesia's marine ecosystems form a fundamental part of the world's natural heritage, representing a global maxima of marine biodiversity and supporting the world's second largest production of seafood. Seagrasses are a key part of that support. In the absence of empirical data we present evidence from expert opinions as to the state of Indonesia's seagrass ecosystems, their support for ecosystem services, with a focus on fisheries, and the damaging activities that threaten their existence. We further draw on expert opinion to elicit potential solutions to prevent further loss. Seagrasses and the ecosystem services they support across the Indonesian archipelago are in a critical state of decline. Declining seagrass health is the result of shifting environmental conditions due largely to coastal development, land reclamation, and deforestation, as well as seaweed farming, overfishing and garbage dumping. In particular, we also describe the declining state of the fisheries resources that seagrass meadows support. The perilous state of Indonesia's seagrasses will compromise their resilience to climate change and result in a loss of their high ecosystem

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service value. Community supported management initiatives provide one mechanism for seagrass protection. Exemplars highlight the need for increased local level autonomy for the management of marine resources, opening up opportunities for incentive type conservation schemes.

1. Introduction

Indonesia's marine ecosystems are fundamental to the world's natural heritage, creating a global maxima of marine biodiversity (Tittensor et al., 2010) and supporting the world's second largest production of seafood (FAO, 2016). Consequently Indonesia's marine environment plays a major role in global fisheries supply. Seagrass meadows are a key part of Indonesia's marine environment providing significant ecosystem service provision such as fisheries support. Seagrasses support fisheries productivity by providing nursery and foraging grounds for commercially important fish and invertebrate species (Unsworth et al., 2014). They provide trophic subsidy to adjacent fisheries (Heck et al., 2008) and act as direct fishery habitat (Nordlund et al., 2018). Indonesian seagrasses also support the health of adjacent coral reef fisheries by limiting the release of coral disease causing pathogens through water filtration (Lamb et al., 2017).

Indonesia has mapped 30,000 km^2 of seagrass, representing at least 5% of the world's total seagrass area (Kuriandewa et al., 2003). However, comparisons with nations of similar geography suggest this figure is a gross underestimation. It is likely that Indonesia contains the largest expanse of seagrass of any nation. Indonesia's seagrasses support high fish species richness (Unsworth et al., 2014), vulnerable Dugong (Schipper et al., 2008) and turtle (Heithaus et al., 2014) populations, and potentially store at least 2% of the Worlds Blue Carbon (Alongi et al., 2016). Additionally, Indonesian seagrasses likely support resilience of seagrass throughout the Indo-Pacific by enhancing genetic diversity (Hernawan, 2016; Hernawan et al., 2017).

Indonesian marine ecosystems are threatened from a diverse range of factors such as overfishing and pollution (Burke et al., 2011), but marine conservation funding largely focuses on coral reef and mangrove systems. Despite increasing recognition for their valuable ecosystem services, seagrasses remain a nonpriority to the big international NGO's and to government. Consequently, their status and threats are poorly understood (Unsworth et al., 2016). In the only global review of seagrass change, no data was available from the Indo-Pacific (Waycott et al., 2009). Another review highlights general poor knowledge of the ecology of Indo-Pacific seagrasses (Ooi et al., 2011). Estimates suggest that as much as 40% of Indonesia's seagrass may have been lost (Nadiarti et al., 2012; Tomascik et al., 1997) and other reviews suggest these systems are stressed (Fortes, 1988; Kirkman and Kirkman, 2002). Given the lack of large scale or long term monitoring and the recognition that there are a myriad of threats facing Indonesia's seagrass meadows, there is an urgency to understand the drivers of these threats in order to support development of appropriate management strategies to maintain seagrass ecosystem services.

Local ecological knowledge (LEK) about status and mortality events for threatened species is a useful source of information (Johannes, 1998; Moore et al., 2010; Pilgrim et al., 2008) that, particularly when integrated with scientific expert knowledge, provides opportunity for well-informed conservation decision-making (Burgman, 2005; Grech et al., 2012; Martin et al., 2012). The use of structured approaches to eliciting scientific knowledge (Maclean and Cullen, 2009) provides a transparent process to identify and compare diverse anthropogenic activities in data-poor scenarios (Grech et al., 2012). In localities where conservation resources are limited and baseline data lacking, scientific expert witnesses may be the only available source of information.

Here we use local scientific expert opinion from across the Indonesian archipelago to provide the first qualitative assessment of the threats, status and temporal trends of seagrass ecosystems and their fisheries ecosystem services. We also use experts to propose potential solutions to the threats to seagrass in Indonesia and provide examples of good practice in seagrass conservation.

2. Methods

2.1. Workshop structure and questionnaire

Expert opinion was elicited through a workshop which included 25 experts from 21 locations across the Indonesian archipelago. The workshop was held over four days at Hasanuddin University in Makassar, South Sulawesi, in July 2016. Participants were all invited to contribute to the writing of the research paper, those who took up this offer are authors. Experts were selected and invited from academic institutions, government agencies and non-government organizations, this was conducted by searching for evidence of seagrass research and management activity across the major islands of the Indonesian archipelago. All participants had at least 3 years' experience in seagrass ecology, biology, monitoring, threats and management (evidenced by availability of research papers and reports about seagrass in their locality). At the workshop, participants were divided into groups according to their regional seagrass knowledge across the Indonesian archipelago (West, East and Central Indonesia) and conducted regional seagrass vulnerability assessments.

Prior to the workshop, participants completed a questionnaire about seagrass in their municipality (individual expert survey). The questionnaire (see Appendix 1) was split into three sections: 1) Seagrass change, focused on the current status, health and temporal change of seagrass, 2) seagrass fauna, and 3) seagrass fisheries. The workshop and questionnaire combined were used to assess the status and threats to seagrass as well as the importance of these habitats for fisheries and biodiversity. At the individual expert level (prior to the workshop) the vulnerability component (see below) of this questionnaire was conducted, but the data is not presented here.

2.2. Vulnerability assessment

Seagrass vulnerability assessments were then conducted by each of the three regional groups within the workshop (group vulnerability assessment). This followed questions 1–7 in the questionnaire (Appendix 1). To do this they examined the relative impact of anthropogenic activities on seagrass using an approach (Halpern et al., 2007) that has previously been adapted for use in seagrass meadows (Grech et al., 2012). The approach requires experts to provide a rank value (score) for five attributes that determine seagrass vulnerability to anthropogenic activities, and an estimate of their uncertainty (Table 1) (Grech et al., 2012). A list of all possible threats was pre-identified based on evidence from the local and regional seagrass literature. This removes sources of subjective and psychological biases that effect an expert's capacity to identify potentially threatening activities occurring within their region of interest (Drescher et al., 2013; Martin et al., 2012).

We collected scores from experts using an MS Excel™ based survey tool. The survey contained information on the aims and objectives of the study and a description of the five vulnerability factors, uncertainty estimates and scoring approach (Grech et al., 2012). Survey respondents (all workshop attendees) were asked to stipulate their affiliation (academic institution, government agency and non-government organization) and research location. At the end of the survey, respondents were asked to indicate if the survey was easy to understand (yes, all of