Indonesia's globally significant seagrass meadows are under widespread threat

Running head: ***Indonesia's seagrass ecosystems***

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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 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. 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 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.

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.

Methods

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, focussed 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.

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 the time; yes, sometimes; no, not very often; no, not at all) (Grech et al., 2012) (see Appendix 1).

Conservation solutions

To propose potential solutions to conserve seagrass in Indonesia we ran a Delphi process (Linstone and Turoff, 1975) as part of the previously described workshop. Participants were split into three groups (West, East and Central Indonesia) where they listed, debated and agreed on a set of answers to three questions (for questions see Table 2) about the positive and negative aspects of current seagrass conservation in their area of Indonesia. Upon completion of these group sessions all workshop participants voted on their overall priority answers to the three questions.

Literature review

A search of grey and academic literature examining threats to seagrasses in SE Asia was conducted using Google Scholar and Web of Science. The terms "Seagrass", "Halophila", "Thalassia", "Thalassodendron", "Cymodocea", "Enhalus" and "Halodule" were used as search terms relative to each country in SE Asia along with the words "status", "threat", "impact" and "loss". All relevant literature produced between 1970 and 2014 was included and additionally searched the names of countries in SE Asia. Within the literature we found within the search we examined what threats to seagrass the literature contained and any observed associated seagrass loss (see Appendix 2).

Results

Seagrass meadow change (individual expert survey)

Seventy five percent of experts indicated that seagrass spatial extent had decreased in the last five years. Twelve percent of experts considered seagrass area to have stayed the same (Fig 1). Where loss was reported, it was estimated by 20% of participants to be over 1km^2 with 29% of participants reporting an estimated loss of between 0.1 and 1km^2. Seventy percent of participants believed the seagrass in their study area had declined in density, with 46% having observed a decline in seagrass species richness and 58% observing a decline in seagrass health.

Coastal development (17%) was the most commonly cited cause of seagrass loss, with land reclamation (12.5%) and sedimentation as a result of deforestation (8%) also recognised as significant factors. Other major causes of loss included seaweed farming (8%), sand and coral mining (8%) and overexploitation of associated herbivores (4%) in addition to direct physical damage from activities such as anchoring (4%). Most participants observed limited or no seagrass recovery.

When examining current and future threats to seagrass, coastal development (25%) was most frequently cited followed closely by sedimentation (20%), poor water quality (20%), seaweed aquaculture (15%), overexploitation of herbivores (10%) and coastal erosion (10%).

On a scale of 0-5, respondents on average ranked their data at 3.7 ± 1.2 certain implying a high level of personal confidence in their answers. Quantitative data was available to verify some of the opinions presented in this study (five experts had data pertaining to condition and change of the seagrass in their study area and/or its environment) but the majority of conclusions rely on long term qualitative observations by participating experts.

Seagrass faunal changes (individual expert survey)

Seventy nine percent of participants stated that their local seagrass supported both fish and invertebrate fisheries, with 4% stating that seagrass was not a fishery target of any kind. The most commonly targeted taxa were the Siganids (75% of respondents), the Mollusca (33%) and the Scarids (33%), followed by the Lethrinids (29%) and the Crabs (21%). The majority of those respondents recognising Siganids as highly exploited in seagrass specified the species *Siganus canaliculatus*.

Forty one percent of participants believed the density of fish in seagrass meadows at their sites had decreased in the last five years and 46% believe the same for seagrass associated invertebrates. Thirty three percent of experts believed that seagrass associated fishery catch had also declined during that period.

Data triangulation

All workshop participants gave short presentations to the rest of the group about the sites that they were describing (see Appendix 2). This provided opportunity for trends and supporting data to be presented and discussed. Seven experts presented quantitative data on the condition and temporal change of seagrass or their associated fauna, and one participant provided quantitative data evidencing a change in environmental conditions (increasing sedimentation). The majority of this data was weak with limited temporal resolution but provided an opportunity for triangulation and discussion.

Regional threats to seagrass (group vulnerability assessment).

The suite of threats to seagrass meadows in Indonesia changes with respect to region (figure 2, Table 1). Coastal development and sedimentation were the only threats recognised at the country scale. Water quality was considered a threat in central and eastern areas. Coastal development had the highest vulnerability factor (VF) due to the widespread nature of this threat and the inability of seagrass to recover after removal. Oil pollution (Western Indonesia) had the second highest VF followed by sand mining which was considered a threat but only in central Indonesia (Table 1). Seaweed farming was also a threat in the central region, with litter and invertebrate gleaning recognised as threats in the eastern part of Indonesia. Overfishing was seen as a major threat in the west.

Conservation solutions

Successful seagrass conservation initiatives do exist in Indonesia. Primary examples proposed by participants were based around community led projects and laws. The most effective of which was agreed to be the use of customary law where tradition has imbedded the value of marine conservation (e.g. Papua Gili Trawangan referred to as ‘sistem adat’). Community led MPAs (with dugong as flagship species) have been effective in some places as have schemes using community incentives (see Table 2). A novel approach was highlighted from the Wakatobi National Park where a local NGO are leading a successful incentive scheme to restore riparian vegetation and reduce run-off and sedimentation. Numerous barriers to seagrass conservation success were proposed with lack of knowledge about seagrass and its importance highlighted. Lack of seagrass knowledge was considered to have secondary implications in terms of funding priorities and the implementation of national laws. A major problem highlighted for seagrass conservation is the difficulties created by overlapping legal jurisdictions for the marine environment and lack of local and village level autonomy (disempowering local people). Problems of vested interest and corruption were also highlighted as problematic (see Table 2).

Regional literature

Our data-explicit literature review identified studies from 59 locations published between 1989 and 2014 (Appendix 3). At 24 of these locations, estimates of seagrass loss are described but supporting data was not of sufficient temporal extent in those published prior to 2008 to be included in the most recent global review of seagrass (Waycott et al., 2009). Twelve threats to seagrass are identified across these studies, with sedimentation, coastal development and poor water quality described at over 50% of locations and destructive fishing described at 40%. Sixteen of the studies were from Thailand, 12 from the Philippines, ten from Indonesia and Malaysia, eight from Vietnam and three from Cambodia. Of the Indonesian studies published, only one demonstrated primary data collection on seagrass change (Douven et al., 2003).

Discussion

The seagrass meadows of Indonesia are of global significance, here we provide the first widespread assessment indicating the perilous state of this fundamental part of the world's natural heritage. We present evidence from across the Indonesian archipelago that documents widespread and extensive seagrass loss and degradation, placing the long-term viability of these systems in doubt. In contrast we highlight exemplars for how Indonesian community led initiatives can result in successful seagrass conservation.

Seagrass meadows have been described as the powerhouses of our oceans due to the carbon they store (Fourqurean et al., 2012) and the habitat they provide for economically important fauna (Jackson et al., 2001; Unsworth et al., 2014). Recognition of the value of seagrass meadows as ecosystem service providers is growing, but these ecosystems appear to have an "image problem" (Duarte et al., 2008). The result is that seagrass remains marginalised on conservation agendas and remains unfamiliar to the general public and decision makers. Seagrass meadows in Indonesia are impacted by a myriad of threats including, significantly, coastal development and sedimentation from deforestation. These threats are thought to act through the increased suffocation of plant tissue by sediments together with a reduction in light availability due to elevated particulates in the water column (Cabaco et al., 2008; Terrados et al., 1998). This data provides the first evidence in contrast to a recent (and contested) model that proposed deforestation would result in large increases in Indonesian seagrass meadows (Abrams et al., 2016; Unsworth et al., 2016).

Although quantitative empirical data about temporal change of seagrass in Indonesia is limited, data from expert witnesses coupled with the more limited quantitative data available suggests a national problem of seagrass loss that has significant global implications. Seagrass scientists from across Indonesia report extensive seagrass loss in areas from Jayapura Bay in the east to Sumatra in the west. Given the need to rely upon expert witnesses to assess seagrass change in Indonesia our study highlights the need for more research and monitoring into seagrass change across the archipelago to be undertaken. These experts provide valuable information however it is important to consider the potential for an unknown level of bias and error within the data.

Not only are seagrass meadows under threat, but so too are the fishery resources they support. All expert witnesses describe seagrass in their area to be important fishery habitat (Unsworth and Cullen, 2010; Unsworth et al., 2014), but many also describe rapidly declining fish catches and aggressive fishing techniques that are exacerbating seagrass loss. Some witnesses describe over exploitation as threating the integrity of seagrass meadows, presumably due to cascade style top-down impacts upon the resilience of the system (Burkholder et al., 2013).

Indonesia is undergoing rapid economic development (ADB, 2016), with growth expected to average over five percent for the coming decade. Rapid population expansion and coastal development is considered to be a major cause of seagrass loss. As the economy of Indonesia develops, building materials become increasingly in demand. It is not surprising that the extraction of sand and coral excavated from below the seagrass and connected beaches is also having a widespread impact upon seagrass meadows.

While in some cases it is difficult to avoid seagrass loss as a result of coastal development, experiences from around the world suggest that mitigation and appropriate management of impacts can result in improved ecological outcomes (Cullen-Unsworth and Unsworth, 2016). Law enforcement and environmental governance in Indonesia are weak (Afsah and Makarim, 2014) and considered by workshop participants to be insufficient to protect seagrass. This highlights a need to establish appropriate institutions, governance, and behaviours (Rands et al., 2010) sufficient to deal with the threats to seagrass meadows.

Seaweed cultivation, oil pollution, dumping of litter (garbage) and destructive fishing techniques are major concerns (Plate 1). Seaweed cultivation is rapidly expanding across the Indo-Pacific, and studies from East Africa have documented the negative impacts upon seagrass (Eklof et al., 2006; Hedberg et al., 2018; Lyimo et al., 2006). It has been hypothesised that the pathway of this impact is through direct physical disturbances in the farms such as deliberate removal of seagrasses by seaweed cultivators (Lyimo et al., 2006). It has further been hypothesised seaweed farming consequently results in overexploitation of seagrass invertebrate fauna (Moore et al., 2012). The impacts of seaweed farming on seagrass presents an unfortunate juxtaposition as international marine conservation programmes have championed seaweed cultivation as an alternative livelihood to reduce pressure on reef fisheries (DW, 2017). Additionally, there is evidence that seaweed farmers may actually target and favour seagrass for this activity. Participants in the present study highlighted the need for seaweed cultivation to be conducted more sustainably, possibly in deeper waters and away from seagrass.

Threats to seagrass appear to change from west to east, in the west, Coastal development and sedimentation were present and important threats everywhere, however water quality was considered a bigger threat in central and eastern areas.

In the central region sand mining and seaweed farming were key threats and in the west oil pollution and overfishing were also thought to be a problem. These spatial differences may reflect the variable levels of population, development and industry across what is a vast archipelago.

Climate change was not considered a threat to seagrass anywhere in Indonesia. This is in contrast to the growing empirical global evidence that sea level rise and increasing temperatures will have a negative impact upon seagrass (Saunders et al., 2013; Saunders et al., 2014; Short and Neckles, 1999). The present study indicates that more immediate threats are of greater concern in Indonesia. Without addressing these immediate smaller-scale threats it is unlikely that seagrasses will remain sufficiently resilient to cope with the consequences of a changing climate (Unsworth et al., 2015). Seagrass meadows form complex social-ecological systems that require consideration in conservation management (Cullen-Unsworth et al., 2014). Community led conservation initiatives provide a means of incorporating local knowledge of socio-ecological systems into management and are considered to be a useful pathway to positive conservation change. For community led conservation to be a success environmental education must be improved. Incentives schemes are increasingly used to influence individual behaviour toward more biodiversity-friendly actions (Rands et al., 2010). In SE Sulawesi a community-led incentive scheme is being used to protect seagrass by providing land owners with economically valuable plants to incentivise them to plant and maintain riparian vegetation in hot spots of surface run-off.

Community led projects can lead to success but they require solid foundations (Brooks, 2017). In the SE Sulawesi example, the incentive scheme was built upon a decade of co-research (Maclean and Cullen, 2009) between scientists and a small community led NGO. The global value of seagrass in Indonesia provides an opportunity for the nation to take leadership in its conservation. The inclusion of blue carbon in the Paris Agreement has created a platform for Indonesia to put coastal habitat conservation at the heart of climate mitigation and food security policy.

Indonesia's seagrass meadows are under widespread threat with significant implications for local food supply as well as global fisheries production, carbon cycling and biodiversity conservation. The ability for policy and management to reverse these growing threats requires making longer term decisions for the sake of food security for a growing population. Currently short-term trade-offs are being made between the high economic gain associated to industries such as palm oil and aggressive fishing and the what are perceived as the low short-term economic gain of seagrass conservation. Given the wider ecosystem service importance of seagrass conservation policy needs to take a longer term view of mechanisms for their protection. Examples do exist of successful management strategies, with exemplars of community led conservation working towards securing a future for seagrass across this vast archipelago. These exemplars highlight the need for increased local level autonomy in terms of the management of marine resources where decisions can be made to balance the needs of local stakeholders often dependent upon seagrass resources. Evidence presented in our study indicates an urgent need to reprioritise marine conservation efforts in Indonesia, to protect seagrass ecosystem services and maintain their long-term resilience.

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Table 1. Vulnerability (V) and certainty (C) scores for 10 anthropogenic activities across three regions of Indonesia derived from an expert opinion based vulnerability assessment.

	West		Central		East		**Average**	
	V	C	V	C	V	C	**V**	**C**
Coastal Reclamation & Development	3.27	4	3.73	4	3.47	3	3.49	3.67
Oil pollution	3.40	4					3.40	4.00
Sand & coral mining			3.27	4			3.27	4.00
Seaweed farming			3.20	4			3.20	4.00
Sedimentation	3.13	4	3.33	4	3.13	4	3.20	4.00
Deforestation	3.13	4					3.13	4.00
Overfishing	3.07	4					3.07	4.00
Water Quality			3.20	3	2.40	2	2.80	2.50
Garbage/litter					2.40	2	2.40	2.00
Gleaning (physical impacts)					2.07	3	2.07	3.00

Table 2. Factors leading to the success and failure of seagrass conservation in Indonesia together with information on potential future conservation solutions. Factors and ranks are from questions asked to the workshop participants during a discussion on conservation solutions following a Delphi method.

	Current successful seagrass conservation actions in Indonesia
1	Use of customary law (e.g. Papua Gili Trawangan referred to as ‘sistem adat’) including side effect of “Sasi” in Ambon
2	Successful small community led MPAs (e.g. Tolitoli and Baru Baru) including MPAs focused on protecting ‘flagship’ species Dugong (e.g. Bintan)
3	Regions defined as having Conservation Province status (West Papua)
4	Conservation education for children (e.g. community led scheme to in Wakatobi NP)
5	Conservation incentive schemes (e.g. community led scheme to reforest degraded riparian vegetation in Wakatobi NP)
	Current barriers to seagrass conservation actions in Indonesia
1	Low knowledge and recognition (inc economic importance) of seagrass at all levels (community, government, enforcement and legal systems, education, media, etc)
2	Limited funding for seagrass conservation because of 1 and 2 especially from government sources/budgets
3	Poor implementation of national laws aimed at protecting seagrass
4	Overlapping jurisdictions and limited local and village level autonomy (resulting in poor empowerment of local people)
5	Vested interests and corruption resulting in alternative outcomes such as reclamation or destructive activities (e.g. logging, destructive fishing)
	Potential conservation actions for seagrass in Indonesia
1	Inclusion of seagrass in local and national curriculum for primary schools
2	Encourage national and local media outlets to include seagrass in coverage of our oceans
3	Determine the economic value of seagrass ecosystems in Indonesia
4	Enhance the value of seagrass to tourism - provide guides (waterproof leaflets) and highlight charismatic/iconic species (turtles, dugong, seahorse)
5	Encourage environmentaly friendly seaweed farming (especially where bottom line used, also other areas with long-line and other methods)
6	Enable village, district and province level regulations regulations about seagrass conservation (not national) (including use of customary laws)
7	Create targeted Marine Protected Areas to specifically protect key seagrass areas
8	Improved land use control by the central and regional governments to reduce the impacts of poor water quality on coastal seagrass
9	Greater financial support for seagrass conservation and research
10	Better law enforcement to protect seagrass and prosecute those damaging it
11	Improved knowledge sharing amongst scientists involved in seagrass conservation
12	Conduct beach cleans to remove excessive garbage from seagrass
	If you could ask the President of Indonesia to do one simple thing now to help conserve seagrass what would it be?
1	Make a (widely publicised) declaration of commitment to seagrass conservation in Indonesia as climate change mitigation (blue carbon) in the context of implementing the Paris Agreement, stating succinctly why seagrass is important and stressing that Indonesia is globally important for seagrass (in top 5 in terms of area and diversity) - ideally including regional leadership

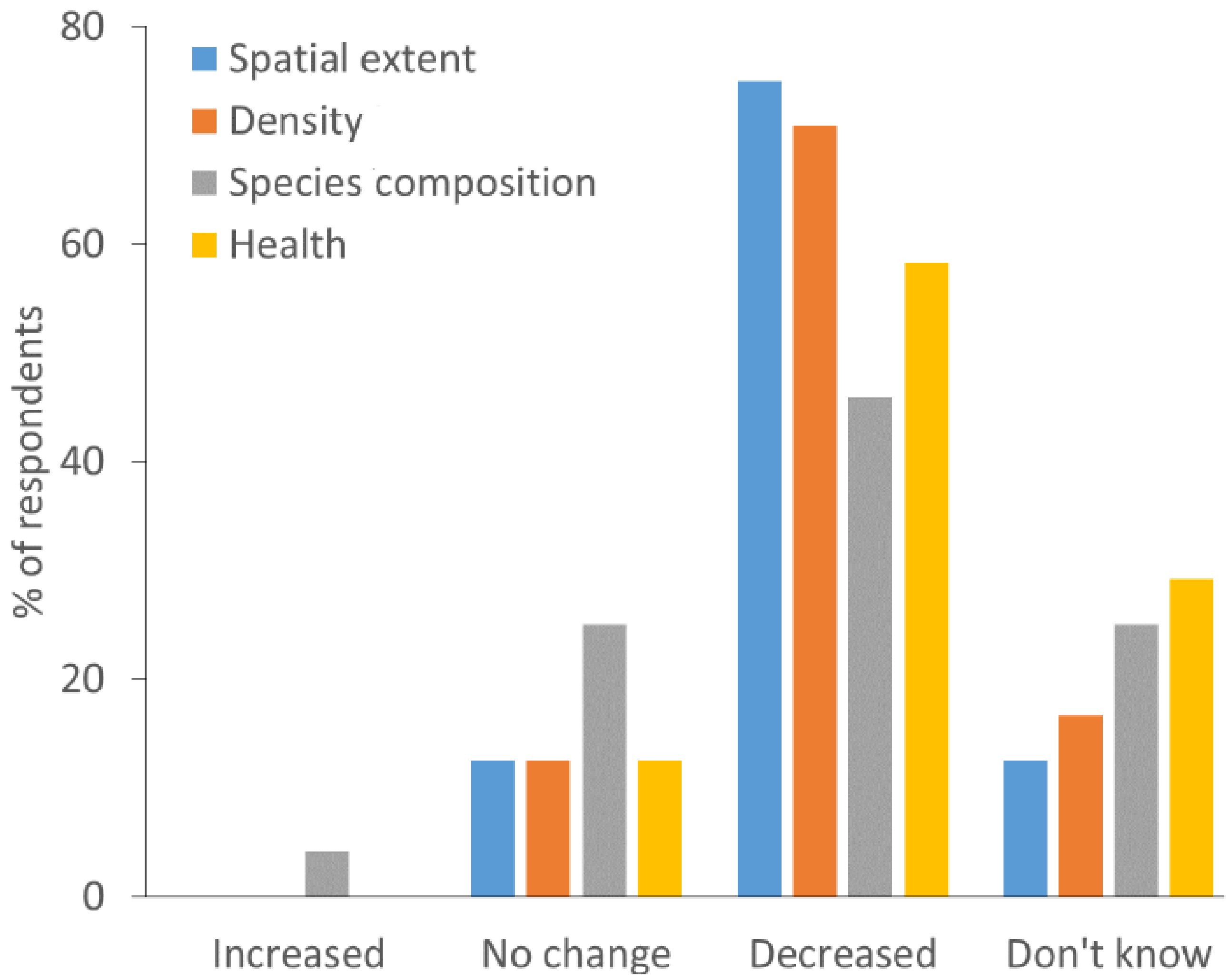

Figure 1. Expert witness information about seagrass change at 23 locations throughout Indonesia during the last 5 years.

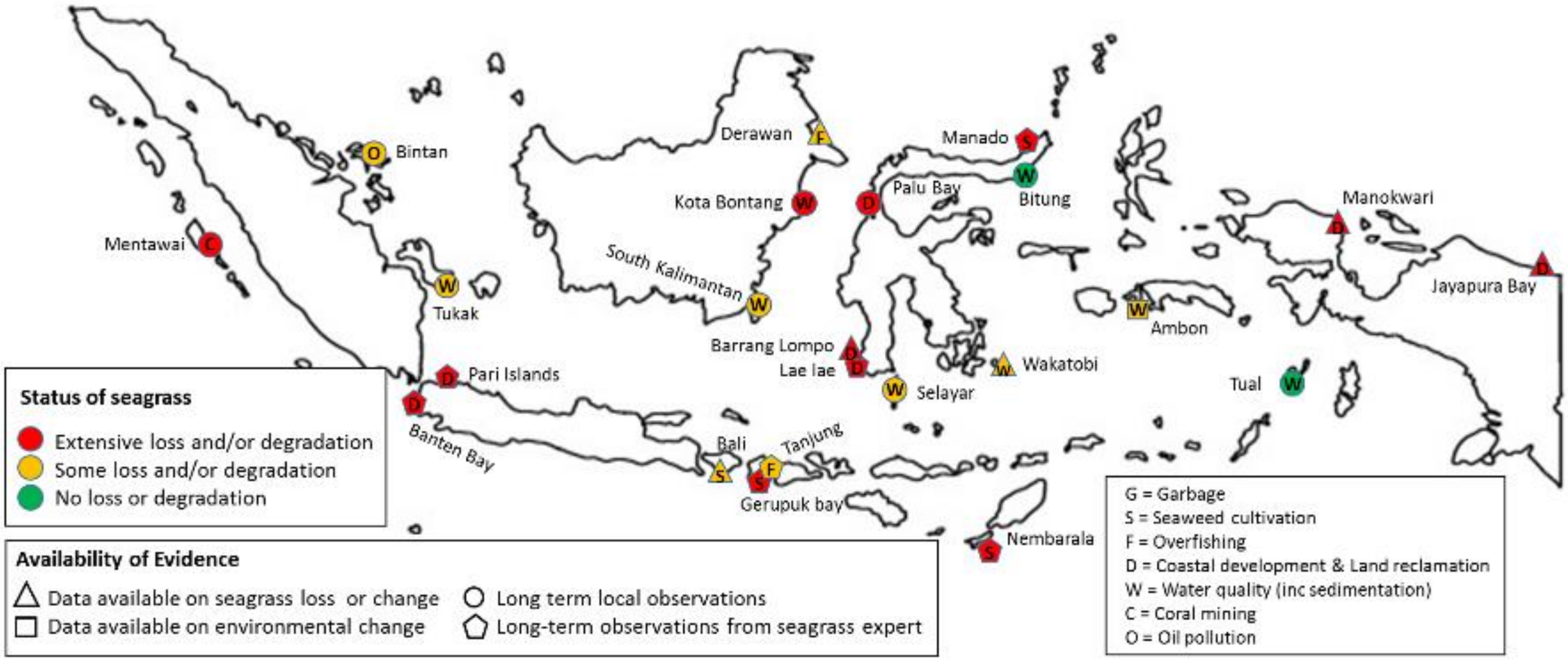

Figure 2. Location of 23 seagrass sites around the Indonesian archipelago, about which expert witnesses have completed questionnaires. The main drivers of seagrass loss at the sites are shown together with the relative change of the seagrass (according to expert witnesses). Additionally we show an indication of the availability of quantitative data to back up the findings presented by the expert witness.

Plate 1. Threats to seagrass throughout the Indonesian archipelago. Clockwise from top left, sedimentation and poor water quality from deforestation (West Papua), boating impacts (Spermonde), seaweed farming (Rote Island), land reclamation (Pari Islands), sand mining (Pari Islands), garbage (Palu Bay), seaweed farming (Bali), oil pollution (Bintan).