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A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions

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Abstract
Global seagrass habitats are threatened by multiple anthropogenic factors. Effective management of seagrasses requires information on the relative impacts of threats; however, this information is rarely available. Our goal was to use the knowledge of experts to assess the relative impacts of anthropogenic activities in six global seagrass bioregions. The activities that threaten seagrasses were identified at an international seagrass workshop and followed with a web-based survey to collect seagrass vulnerability information. There was a global consensus that urban/industrial runoff, urban/port infrastructure development, agricultural runoff and dredging had the greatest impact on seagrasses, though the order of relative impacts varied by bioregion. These activities are largely terrestrially based, highlighting the need for marine planning initiatives to be co-ordinated with adjacent watershed planning. Sea level rise and increases in the severity of cyclones were ranked highest relative to other climate change related activities, but overall the five climate change activities were ranked low and experts were uncertain of their effects on seagrasses. The experts' preferred mechanism of delivering management outcomes were processes such as policy development, planning and consultation rather than prescriptive management tools. Our approach to collecting expert opinion provides the required data to prioritize seagrass management actions at bioregional scales.

Keywords: expert elicitation, marine planning, prioritisation, seagrass, threat assessment, vulnerability assessment, management

S Online supplementary data available from stacks.iop.org/ERL/7/024006/mmedia

1. Introduction

Seagrasses are one of the most productive ecosystems on earth (Duarte and Chiscano 1999) and provide a variety of ecosystem services including fisheries habitat, coastal protection, and nutrient recycling (Cullen 2007). Seagrasses have been damaged and destroyed in many parts of the world (Short and Wyllie-Echeverria 1996, Larkum *et al* 2006) as a result of anthropogenic activities (Cambridge and McComb 1984, Coles *et al* 2003, Waycott *et al* 2009). Globally, 15% of seagrass species are threatened (Randall Hughes *et al* 2009, Short *et al* 2011) and seagrass habitats have declined

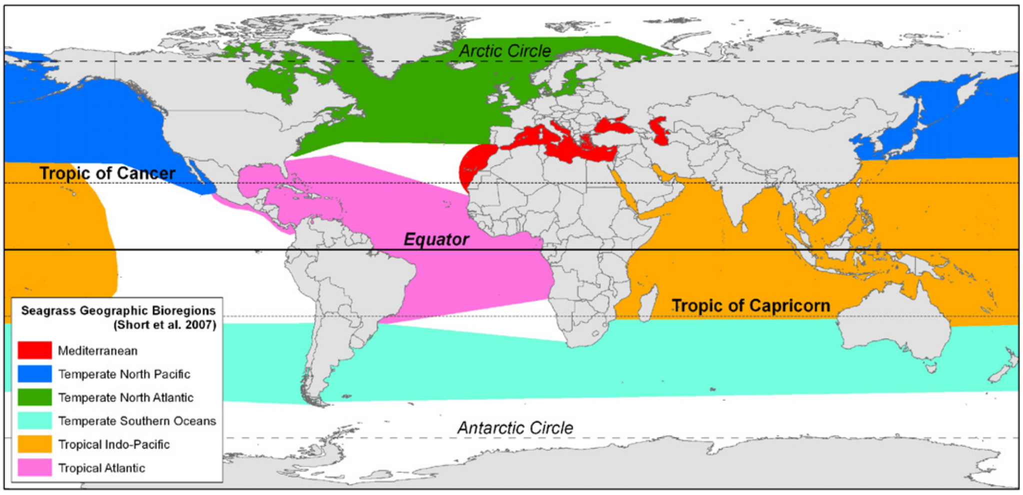

Figure 1. The six seagrass specific geographic bioregions of Short *et al* (2007) used to segregate workshop participants and survey respondents into sub-groups that corresponded to their knowledge and expertise.

worldwide at a rate of 110 km^2 yr^{-1} between 1980 and 2006 (Waycott *et al* 2009). The causes of this decline vary globally (Orth *et al* 2006) due to multiple factors including local species resilience, the nature of anthropogenic activities, and the frequency and scale of exposure to those activities.

Quantitative data on the relative impact of anthropogenic activities is vital to the management of seagrasses as it can direct the strategic deployment of limited resources (Cleary 2006). Wilson *et al* (2007) found that targeting management intervention to activities with the highest impact can be more beneficial to achieving conservation goals than other management approaches. However, information on how multiple activities impact on seagrass habitats and species are rarely available, especially at broad spatial scales such as for global bioregions (Wilson *et al* 2005). A major cause of this data deficiency is the limited ability of empirical studies to evaluate the impact of multiple activities due to time, expertise and cost constraints (Crain *et al* 2008). The commonly reported lists of anthropogenic activities that have an impact on seagrass are from compilations of different studies (Short and Wyllie-Echeverria 1996, Short *et al* 2001, Orth *et al* 2006) and are referenced routinely without questioning the relevance of that list or the order of importance of the activities. The data supporting that order, and whether the list that is referenced is applicable to a particular location, scale or issue is often not available. When stated as an overarching global effect, for example, nutrient over-enrichment and sediment loads have been described as the most important anthropogenic cause of seagrass decline in coastal waters (Short *et al* 2001, Orth *et al* 2006). The scale and detail of data to support that assertion and how well the data represents all locations in the world where seagrasses are found remains undefined. The literature is also biased to shallow coastal seagrasses within developed regions which are readily accessible and where there are more resources available for research and monitoring (Fonseca *et al* 2008).

Expert knowledge is fundamental to conservation decision making (Burgman 2005, Martin *et al* 2012), especially when actions are required before uncertainties can be resolved (Sutherland 2006, McBride and Burgman 2011). Structured approaches to expert elicitation provide a transparent and explicit process to identify and compare diverse anthropogenic activities in data-poor scenarios (e.g. Halpern *et al* 2007, Selkoe *et al* 2008, Donlan *et al* 2010, Teck *et al* 2010). Our objective was to inform seagrass management needs across all seagrass bioregions using a structured approach to bring together expert knowledge on the relative impact of multiple anthropogenic activities. The assessment was conducted at the scale of seagrass bioregions (Short *et al* 2007) so that the outputs of our assessment were applicable at the regional (management) scale. We used the outputs of the assessment and a follow-up expert workshop to explore regional similarities and differences in seagrass management approaches.

2. Methods

2.1. Expert workshop

We hosted an expert workshop to identify the anthropogenic activities that threaten seagrasses at the 8th International Seagrass Biology Workshop (ISBW8) in September 2008 at Bamfield, Canada. The workshop was attended by 122 participants from academic institutions, government agencies and non-government organizations with expertise in seagrass ecology, biology, monitoring, threats and management. The workshop participants were divided into groups based upon their regional knowledge of seagrasses in accordance with the six seagrass bioregions identified by Short *et al* (2007). Temperate North Atlantic, Tropical Atlantic, Mediterranean, Temperate North Pacific, Tropical Indo-Pacific and Temperate Southern Oceans (figure 1). The groups were asked to: (1) identify the anthropogenic activities that threaten seagrasses within their bioregion; and (2) rank the activities in order of their relative impact. Experts from different parts of the world used different nomenclature for the same

Table 1. Ranking system for the five vulnerability factors (Halpern *et al* 2007, Selkoe *et al* 2008).

Score	Scale	Frequency	Functional impact	Resistance	Recovery time	Certainty
0	No impact	Never occurs	No impact	Not applicable	No impact	Not at all certain
1	<1 km^2	Rare	$<25\%$ of species	High resistance	<1 year	Low certainty
2	1–10 km^2	Occasional	25–50% of species	Medium resistance	1–10 years	Moderate certainty
3	10–100 km^2	Annual or regular	50–100% of species	Low resistance	10–100 years	High certainty
4	100–1000 km^2	Persistent			>100 years	Very certain
5	1000–10 000 km^2					
6	$>10\,000$ km^2					

anthropogenic activity (e.g. coastal development, construction and coastal structures were used to describe the threat of urban/port infrastructure development). We devised a common nomenclature to identify anthropogenic activity categories and used this common identifier for ease of comparison across bioregions (supporting material 1 available at stacks.iop.org/ERL/7/024006/mmedia).

2.2. Web-based vulnerability assessment

Following ISBW8, we assessed the relative impact of anthropogenic activities using the approach of Halpern *et al* (2007). The approach requires experts to provide a rank value (score) for five attributes that determine the vulnerability of seagrasses to anthropogenic activities, and an estimate of their uncertainty (table 1). In comparison with the simple ranking exercise of the ISBW8 workshop, this process encourages evaluation of the components that contribute to seagrass vulnerability. We collected scores from experts using a web-based survey tool. The survey included questions on the anthropogenic activities identified at the ISBW8 expert workshop and an additional three climate change related threats from Orth *et al* (2006) and Waycott *et al* (2007). Invitations were emailed to the 122 participants from the ISBW8 workshop. An additional 10 individuals with expertise in bioregions that were not adequately represented at the workshop were also invited to participate in the survey to ensure representation of the whole expert community (Armstrong 2006). 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. Survey respondents were asked to stipulate their affiliation (academic institution, government agency and non-government organization) and the seagrass bioregion that their answers applied to (Short *et al* 2007, figure 1). 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).

A hierarchical cluster analysis was used to detect outliers in the survey respondents. The standard error and coefficient of variation (CV) in vulnerability scores across responses was used to assess the degree of consensus among experts. We assessed differences in the mean vulnerability scores of experts when grouped by their institutional affiliation and bioregion (ANOVA) and gender (t-test) and evaluated the effect of sample size on the vulnerability scores within bioregions using a linear regression.

The rank values for the vulnerability factors of scale, functional impact and resistance (table 1) were rescaled to a 0–4 range by multiplying each by 4/6, 4/3 and 4/3 respectively, so that all factors had the same range of values. Each vulnerability factor was assumed to have equal weighting (after Halpern *et al* 2007, Selkoe *et al* 2008). We combined the mean of the expert-derived scores of the five vulnerability factors to create a single vulnerability score for each anthropogenic activity in each bioregion and at a global scale. The scores of experts were not weighted according to age, experience, qualification etc as such approaches do not provide better results than simply averaging scores across all respondents (Clemen 1989). We used t-tests to assess differences in vulnerability scores of individual activities both within and across bioregions. Anthropogenic activities were ranked by their vulnerability scores to allow a comparison between the results of the web-based survey and the rankings derived at the ISBW8 expert workshop.

2.3. Follow-up expert workshop

We hosted a follow-up workshop in November 2010 at the 9th International Seagrass Biology Workshop (ISBW9) in Trang Province, Thailand to identify management options to mitigate the impact of four anthropogenic activities. At this follow-up workshop, the participants were divided into their sub-regional groups. The location of the workshop in South-East Asia had mostly scientists and managers from the tropical Indo-Pacific bioregion (Australia, Indonesia, Singapore and Malaysia, Thailand, the Philippines and China).

3. Results

The web-based vulnerability survey received an above-average response rate of 45% (total = 59) relative to similar surveys (Halpern *et al* 2007) and to online surveys overall (Cook *et al* 2000). Forty-two responses were from the staff of academic institutions, nine were from government agencies and eight were from non-government organizations (table 3). The number of survey responses varied among bioregions, with the Tropical Indo-Pacific receiving the most responses ($n = 22$) and the Temperate North Pacific receiving the least

Table 2. Rankings of the relative impact of multiple anthropogenic activities on seagrasses in six bioregions derived from the expert workshop (EW) at ISBW8 and the vulnerability assessment (VA) (1 = most threatening activity). A dash (—) indicates that the anthropogenic activity was not identified as a threat to seagrasses at the expert workshop.

	Temperate North Atlantic		Tropical Atlantic		Mediterranean		Temperate North Pacific		Tropical Indo-Pacific		Temperate Southern Oceans		Global
Anthropogenic activity	EW	VA	EW	VA	EW	VA	EW	VA	EW	VA	EW	VA	VA
Agricultural runoff	1	1	1	3	6	4	2	9	3	7	5	2	3
Aquaculture	8	6	—	13	4	5	3	8	7	5	4	5	6
Boat damage (commercial)	—	12		8	—	10	—	12	10	8	7	8	7
Boat damage (recreational)	7	9	5	6	5	7	4	15	8	12	8	9	8
Changes in air temperature	—	13	—	15	—	14	—	5	—	14	—	13	14
Changes in sea surface temperature	—	7	—	12	—	13	6	2	—	10	—	12	10
Desalination plants	—	17	—	18	9	12	—	18	—	15	3	10	17
Dredging	5	4	2	2	7	6	—	11	4	3	9	3	4
Elevated CO_2 and ocean acidification	—	15	—	16	—	16	—	7	—	17	—	11	16
Fishing (other than trawling)	4	11	—	10	—	11	—	14	5	9	—	16	11
Increase in severity of tropical cyclones	—	16	6	5	—	18	—	17	—	6	—	17	13
Invasive/introduced species	—	10	—	14	8	9	8	10	11	18	2	14	15
Sea level rise	—	3	—	9	—	17	—	3	—	16	—	15	12
Seagrass harvesting	—	18	—	17	—	15	—	16	12	13	—	18	18
Shipping accidents (e.g. oil spills)	—	14	4	7	—	8	—	6	9	11	—	6	9
Trawling	6	5	3	11	2	3	7	13	2	4	1	7	5
Urban/industrial runoff	3	2	—	1	3	2	5	4	6	1	6	1	1
Urban/port infrastructure development	2	8	—	4	1	1	1	1	1	2	10	4	2

($n = 5$; table 3). However, we found no significant effect of sample size on the vulnerability scores ($F = 0.655$, $p = 0.464$). The majority of respondents found the survey easy to understand and complete (76%) with no effect of affiliation, gender or bioregion.

The hierarchical cluster analysis revealed five clusters (see supporting material 2 available at stacks.iop.org/ERL/7/024006/mmedia). Four clusters represented the survey respondents from four bioregions (Temperate North Atlantic, Tropical Indo-Pacific, Mediterranean and Tropical Atlantic), indicating a high similarity in scores from experts within those bioregions. Survey respondents from the Temperate North Pacific were within two clusters and respondents from the Temperate Southern Ocean were scattered throughout the five clusters.

We found no significant differences in vulnerability scores among the three categories of affiliation (academic, government and non-government; $F = 1.080$, $p = 0.393$). There was also no significant relationship between gender and the vulnerability scores of experts ($F = 0.04$, $p = 0.346$). As indicated by the hierarchical cluster analysis, the bioregion of survey respondents had a significant effect on vulnerability scores ($F = 1.615$, $p = 0.006$). The values of the coefficient of variation (CV) across the scores for the five vulnerability factors (supporting material 3 available at stacks.iop.org/ERL/7/024006/mmedia) revealed high variation in the scores for climate change related activities and the vulnerability factor 'scale'.

The vulnerability assessment identified urban/industrial runoff as the greatest threat to seagrasses in three bioregions, urban/port infrastructure development in two bioregions, and agricultural runoff in one bioregion (tables 2 and 4). At a global scale, the vulnerability scores for urban runoff, urban/port infrastructure development, agricultural runoff and dredging were significantly higher than the vulnerability scores of the remaining anthropogenic activities ($p < 0.05$); the vulnerability scores for seagrass harvesting and desalination plants were significantly lower ($p < 0.05$). The major differences in rankings between the vulnerability assessment approach and the simple ranking approach of the expert workshop were the elevation in rank of urban/industrial runoff and the reduction in rank of trawling (table 2).

Table 3. Number of survey respondents in each bioregion and their affiliation and gender category. NGO = non-government organization.

	Affiliation			Gender	
Bioregion	Academic	Government Agency	NGO	Male	Female
Temperate North Atlantic	4	3	0	5	2
Tropical Atlantic	8	1	2	6	5
Mediterranean	6	0	1	3	4
Temperate North Pacific	3	1	1	3	2
Tropical Indo-Pacific	16	3	3	14	8
Temperate Southern Ocean	5	1	1	4	3
Total	42	9	8	35	24

Of climate change related impacts the highest mean vulnerability scores were a rank of 2 for changes in sea surface temperature in the Temperate North Pacific and a rank of 3 for changes in sea level rise in the Temperate North Pacific and Temperate North Atlantic (tables 2 and 4). The highest ranks for other climate change factors were ranks of 5 and 6 for increases in tropical storm severity in the Tropical Atlantic

Table 4. Vulnerability and certainty scores for 18 anthropogenic activities across six bioregions derived from expert opinion and a web-based vulnerability assessment. VS = vulnerability score; C = certainty score; CV = coefficient of variation. Activities are organized from the highest to lowest VS scores based on the global scale results.

	Global		Temperate North Atlantic		Tropical Atlantic		Mediterranean		Temperate North Pacific		Tropical Indo-Pacific		Temperate Southern Oceans	
Anthropogenic activity	VS	C	VS	C	VS	C	VS	C	VS	C	VS	C	VS	C
Urban/industrial runoff	2.78	2.49	2.65	2.00	2.95	2.50	3.02	2.14	2.91	2.20	2.60	2.94	2.86	2.40
Urban/port infrastructure development	2.67	2.71	2.17	2.43	2.61	2.20	3.20	2.57	3.17	3.00	2.52	3.12	2.73	2.60
Agricultural runoff	2.62	2.37	2.99	2.43	2.87	2.60	2.86	2.00	2.72	1.60	2.16	2.59	2.86	2.40
Dredging	2.56	2.76	2.60	2.43	2.89	3.11	2.31	2.29	2.57	2.00	2.38	3.12	2.78	2.80
Trawling	2.39	2.22	2.55	2.00	2.18	2.44	2.93	2.17	2.33	2.00	2.37	2.65	2.01	1.00
Aquaculture	2.32	2.30	2.33	2.86	1.99	1.56	2.74	2.29	2.74	1.80	2.25	2.71	2.30	2.00
Boat damage (commercial)	2.13	2.54	2.05	3.14	2.35	2.67	1.84	1.57	2.34	2.40	2.13	2.76	2.00	2.20
Boat damage (recreational)	2.12	2.69	2.17	2.86	2.47	3.00	2.21	2.29	2.26	2.00	1.85	2.88	1.99	2.40
Shipping accidents (e.g. oil spills)	2.10	1.86	1.76	1.57	2.41	2.67	2.12	0.57	2.78	2.00	1.87	2.12	2.07	1.60
Changes in sea surface temperature	2.03	1.65	2.30	1.86	2.17	2.00	1.18	0.29	3.17	1.80	1.90	2.07	1.89	1.20
Fishing (other than trawling)	1.98	2.27	2.07	2.43	2.22	2.20	1.69	1.71	2.30	1.80	1.98	2.76	1.52	1.80
Sea level rise	1.84	1.43	2.62	1.57	2.26	1.80	0.74	0.71	3.05	1.60	1.50	1.59	1.53	0.80
Increase in severity of tropical cyclones	1.74	2.06	1.13	2.57	2.52	2.80	0.56	0.71	1.50	2.00	2.21	2.35	1.16	0.80
Invasive/introduced species	1.72	1.51	2.00	1.71	1.62	1.56	1.17	0.71	2.81	1.60	1.55	1.81	1.82	1.20
Changes in air temperature	1.72	1.80	2.10	1.86	1.73	1.80	2.08	1.86	2.67	2.20	1.23	1.76	1.59	1.40
Elevated CO_2 and ocean acidification	1.59	1.20	1.57	1.43	1.51	1.33	1.05	0.29	2.75	0.80	1.42	1.71	1.90	0.60
Desalination plants	1.31	1.48	0.54	1.50	0.99	1.40	1.66	1.57	1.03	2.20	1.54	1.35	1.97	1.20
Seagrass harvesting	1.22	2.45	0.42	3.00	1.14	2.33	1.16	1.83	1.62	2.20	1.60	2.76	0.82	1.80
Score mean	2.05	2.10	2.00	2.20	2.16	2.22	1.92	1.53	2.48	1.96	1.95	2.39	1.99	1.68
CV	22.2	23.4	35.0	24.9	26.4	24.7	43.0	50.1	23.6	22.6	20.9	23.0	28.6	40.9

and Tropical Indo-Pacific emphasizing regional differences and differences between the temperate and tropical biomes (table 2). The greatest range in mean vulnerability scores was for climate change factors; sea level rise ranging from 3 to 17; and increases in the severity of tropical storms of 5–18 (table 2).

The Temperate North Pacific bioregion had the highest mean vulnerability score across all anthropogenic activities (2.5, CV 23.6), followed by the Tropical Atlantic (2.2, CV 26.4) and Temperate North Atlantic (2.0, CV 35.0; table 4) bioregions. In addition, the Temperate North Pacific bioregion had the highest vulnerability score for seven of the eighteen activities (table 4) and was the only bioregion whose vulnerability scores were significantly higher than the global average ($F = 2.736$, $p = 0.014$).

There was a significant, positive relationship between the vulnerability and certainty scores of anthropogenic activities across all bioregions ($p = 0.01$). Survey respondents had low levels of certainty in their estimates of vulnerability scores for climate change related impacts and desalination plants (table 4).

At the follow-up workshop in 2010, 55 seagrass experts were asked to identify management approaches to mitigate the four top threats identified in the vulnerability survey: urban/industrial runoff, urban/port infrastructure development, agricultural runoff and dredging. 49% of the responses were in favour of non-prescriptive approaches (i.e. policy development, consultation, community awareness and good planning; Coles and Fortes 2001). 26% of responses suggested prescriptive options such as enforcement, compliance and fines; and 25% reactive solutions e.g. restoration, monitoring and mitigation.

4. Discussion

Seagrass communities are considered to be one of the most highly threatened marine habitats along with coral reefs, mangroves and salt marshes (Waycott *et al* 2009). In this study, we assessed the relative impact of multiple anthropogenic activities on seagrasses at the scale of global bioregions by bringing together the expert knowledge of seagrass researchers and managers. We used a vulnerability assessment approach and a web-based survey in order to reduce the biases associated with ranking exercises and to capture the knowledge of experts across the globe.

Qualitative assessments of the relative impact of anthropogenic activities are dependent on the subjective judgements of the responding experts. Those judgements are influenced by multiple factors including personal experience and beliefs, cultural differences, and cognitive and judgement bias (Carey *et al* 2005). These biases were demonstrated in the ranking exercise at the expert workshop as participants perceived anthropogenic activities with a high visual impact such as trawling and dredging to have a greater impact on seagrasses relative to other activities (table 2). When asked to consider the components of risk (i.e. table 1) more diffuse (and less visual) impacts such as urban/industrial runoff were ranked higher. Systematic surveys of experts such as the one used here better inform management as they are able to overcome some of the problems associated with expert bias (e.g. Donlan *et al* 2010) and can identify key regional differences that may need to be taken into account.

Seagrass scientists commonly use terms such as ‘modified sediment dynamics’ or ‘nutrients’ to identify a threatening process (supplementary material 1 available at stacks.iop.org/ERL/7/024006/mmedia; Short and Wyllie-Echeverria 1996.) These terms may be useful in a biological sense but are difficult to analyse in a risk-based management approach as they are not clearly linked to the source of the threatening activity. The common nomenclature developed in this study (supporting material 1 available at stacks.iop.org/ERL/7/024006/mmedia) links the threatening process with the source of that process. This approach allows management responses to target the specific anthropogenic activity and to identify the industries and practices where intervention is required (e.g. commercial shipping, land-based agriculture, urban planning); and to identify the government and/or management agencies with the power to implement change.

Seagrass meadows globally are found in shallow inshore waters to a maximum depth of approximately 70 m (Coles *et al* 2009). However most meadows are found in inshore waters less than 10 m deep where their health and survival is influenced by complex natural and human induced processes. It is in this zone, where the land and sea meet, that seagrasses are under pressure from their greatest threats: urban/industrial runoff, urban/port infrastructure development, agricultural runoff and dredging (tables 2 and 4). These activities are largely terrestrially based, and our results highlight the need for marine planning initiatives to be co-ordinated with adjacent watershed planning (Alvarez-Romero *et al* 2011). Programmes have been designed for land–sea planning to control the effects of agricultural runoff (Gordon 2007). However, urban and industrial land-use planning is rarely co-ordinated with adjacent marine spatial planning initiatives and this may be to the detriment of coastal species such as seagrasses.

Our analysis showed only minor differences in the top four ranked anthropogenic activities among the six bioregions (tables 2 and 4). This agreement is remarkable considering the diversity of countries, seagrass species and threatening activities globally. The global consensus was not fully shared by the Temperate North Pacific seagrass experts who ranked seagrasses more vulnerable overall than other bioregions and ranked climate change related activities as a greater threat to seagrass than other regions. The difference in perceived vulnerabilities may be related to regional topography and species (the bioregion is unusual as having a predominance of *Phyllospadix* (an outer coast, rocky substrate species) and *Zostera* with a narrow depth range) but the true source of these differences remains unclear, and should be explored in future studies.

Most experts outside of the Tropical North Pacific bioregion were uncertain about the impact of climate change pressures, but perceived the likelihood of climate change having an impact on seagrasses as low (table 4). There were regional differences. Increased severity for tropical cyclones was ranked fifth and sixth in the Tropical Atlantic and Tropical Indo-Pacific regions respectively against a global average rank of 13. Tropical storms are a regional issue for the tropics and repeated impacts from cyclones are seen as an important threat. Sea surface temperature rise and sea level rise are ranked higher in the temperate regions than elsewhere. The seagrass community sees climate change impacts as having a variable impact on seagrasses around the world. Climate interacts in complex ways with biophysical factors and plant species ecology and this is reflected in vulnerability scores. There are other regional differences such as the high vulnerability score for trawling in the Mediterranean that are likely to be related to specific seagrass species vulnerability. Fishing activities (e.g. net-fishing) in the Tropical Indo-Pacific were ranked higher than other bioregions, reflecting the regional differences in the exploitation of seagrass fisheries (Unsworth and Cullen 2010) and the nature of the fishing activities (e.g. frequency and scale of the threat events). These differences in relative vulnerabilities across species, activities and regions are important to understand as otherwise expertise on approaches for managing and protecting seagrass may not easily transfer from one part of the world to another.

There was a greater degree of consensus among experts on the relative impact of anthropogenic activities that are easily measured and detected compared with complex influences such as climate change related activities (supplementary material 3 available at stacks.iop.org/ERL/7/024006/mmedia). There is probably a bias towards the understanding of local issues where those issues are familiar to experts (e.g. effects of dredging; Erftemeijer and Lewis 2006) and a bias away from understanding impacts at a global scale (i.e. climate change). This is supported by the CVs for the vulnerability factor ‘scale’ which were higher than for other factors. There is unfamiliarity with the concept of scale, and being asked to evaluate processes at very large (global) scales is a novelty for most scientists. This poor understanding of how anthropogenic activities affect seagrasses across changing spatial scales and the conceptual difficulties in comparing the relative impact of large scale diffuse processes with small scale high impact process is rarely analysed in seagrass literature or taken in to account in coastal management decisions.

There are bioregional, political, cultural and seagrass species specific factors that determine the best methods to influence decision makers (both private and government) to modify terrestrial activities and reduce impacts on adjacent seagrass ecosystems (Coles and Fortes 2001). It is not possible to provide a single recipe for coastal and watershed managers that would be applicable for protecting seagrasses globally. Translating a complex, government sponsored and expensive marine monitoring and marine planning programme (that includes farmers, landholders and reef lagoon users as stakeholders as well as scientists and government land and marine managers) that is effective for Australia’s Great Barrier Reef (Brodie *et al* 2012) to a small Pacific Island nation is unlikely to be productive. Most effective is likely to be a package of approaches that includes a mix of methods tailored to the local political, social and biological environment. However we found a clear preference based on experience within the seagrass community for transparent consultative processes such as policy development, planning and consultation as an approach rather than a legal enforcement/compliance approach, and this should be taken into account. Our follow-up workshop had a participant bias to South-East Asia but it is also likely that this region will have an increasing influence on the global approach to coastal management in the coming decades.

5. Conclusions

This study is the first to assess the relative impact of multiple anthropogenic activities on seagrasses in the six global bioregions of Short *et al* (2007). The rank outputs improve on the accepted seagrass management paradigms (e.g. Short and Wyllie-Echeverria 1996, Short *et al* 2001, Orth *et al* 2006, Waycott *et al* 2009) as they were derived using a vulnerability assessment and the expert opinion of seagrass researchers and managers across the globe. We found that the major threats to seagrasses are largely terrestrially based, highlighting the need for seagrass management to be co-ordinated with adjacent watershed planning. Seagrass experts emphasize the need for planning and consultative approaches to achieve terrestrial management change. The outputs of our approach can be integrated with spatial data in cumulative impact assessments that identify sites for management action across multiple spatial scales (Halpern *et al* 2008, Selkoe *et al* 2009, Grech *et al* 2011). Future research should focus on regional differences in vulnerability, especially in disturbance hotspots.

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