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PRACTITIONER'S PERSPECTIVE

Strategies to enhance the resilience of the world's seagrass meadows

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Introduction

Urgent action is required to stem the loss of the world's seagrass meadows, prioritize their protection and recognize the array of ecosystem services (ES) that they provide. The reasons for continued decline are complex, driven by an array of cross-sectoral forces with solutions consequentially difficult to conceptualize.

Across most of their range, seagrass meadows are mostly soft sediment intertidal to subtidal benthic habitats comprised of marine angiosperms. Seagrasses occupy six distinct bioregions across the globe and form one of the world's most widespread habitats in shallow coastal waters found on all of the world's continents except Antarctica. Current documented distributions include 125 000 km^2 of seagrass meadows; however, some estimates suggest they could cover up to 600 000 km^2 of the coastal ocean (Duarte *et al.* 2010).

Seagrass meadows provide multiple ecosystem services to humanity, yet they remain in decline and largely marginalized on conservation agendas (Orth *et al.* 2006; Duarte *et al.* 2010; Cullen-Unsworth *et al.* 2014). Here, we provide a succinct overview of evidenced successful strategies used to improve the resilience of seagrass meadows and propose 'bite-sized' actions to assist a variety of stakeholders in taking practical steps to help reverse the decline of our seagrass meadows.

Global threats to seagrass meadows

Although some large-scale and local losses of seagrass habitat can be attributed to natural events and cycles, direct anthropogenic impacts are the most serious cause of decline (Waycott *et al.* 2009). Loss is commonly associated with coastal development, including land reclamation, poor land management, overexploitation and localized physical disturbance (Orth *et al.* 2006; Grech *et al.* 2012). In addition, seagrasses are increasingly threatened by climatic change, with increased sea surface temperatures resulting in physiological stress, burning and mortality, and sea level rise resulting in light limitation (Short & Neckles 1999). Associated increased frequency and intensity of extreme weather events exacerbate local disturbance (Short & Neckles 1999). Snowballing anthropogenic inputs to the coastal oceans and destructive activities in coastal regions have resulted in world-wide deterioration and loss of seagrasses, with poor water quality consistently highlighted as the most significant and widespread threat (Waycott *et al.* 2009; Marbà, Díaz-Almela & Duarte 2014). Water quality is of particular concern for seagrasses due to their high light requirements relative to competitive marine macroalgae (Waycott *et al.* 2009), but the impact of multiple stressors (although poorly understood) is cumulative and synergistic (creating an impact that is greater than the sum of individual stressors) (Unsworth *et al.* 2015). Seagrass meadows, due to their geographical positioning at the interface of multiple human–environmental interactions (Kenworthy *et al.* 2006), are particularly vulnerable to multiple anthropogenic stressors. The cumulative effect of these stressors reduces the resilience (i.e. the capacity to resist and recover from stress) of seagrass to predicted future environmental change (Unsworth *et al.* 2015).

Lack of recognition for the value of seagrass ecosystem services also plays a part in their demise, with a general disregard for seagrass meadows fuelled by a bias of popular media attention towards other marine ecosystems. This disregard for seagrasses is particularly counterintuitive given that seagrasses provide and ecological supporting role to adjacent ecosystems as part of a connected seascape (Unsworth *et al.* 2015). From local to regional scales, threats are typically consistent, but their magnitude and relative impact changes, reflecting varying human pressures (Grech *et al.* 2012).

Seagrass decline

The best available estimate suggests that seagrass meadows are declining at a rate of around 7% globally

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(Waycott *et al.* 2009). Losses are continuing to be reported and quantified world-wide indicating the need for urgent action to halt further loss.

Strategies for action

More effective management (including mitigation) is required across spatial scales to protect seagrass meadows and promote resilience to long-term and global-scale change (Orth *et al.* 2006; Unsworth *et al.* 2015). Improved resilience requires that environmental managers and regulators use the most appropriate strategies for seagrass conservation that reflect the most up-to-date science. This includes consideration of the processes and feedbacks that promote resilience in seagrass meadows. Seagrass status, threats, drivers and level of protection vary across scales; therefore, appropriate protective strategies are site and context specific. Here, we outline eleven practical strategies (applicable at different scales) to help reverse the decline of seagrass meadows and bolster their resilience. The strategies largely consist of 'bite-sized' actions, the appropriateness of which will likely be site and context specific, and so they are not presented as a hierarchy but more a series of potential options. Some of the strategies overlap, addressing multiple threats.

CATCHMENT MANAGEMENT FOR IMPROVED WATER QUALITY

Poor water quality caused by urban, industrial and agricultural run-off is highlighted as the greatest threat to seagrasses (Orth *et al.* 2006; Waycott *et al.* 2009; Grech *et al.* 2012) and the primary reason for reduced resilience within seagrass systems. Seagrasses are sensitive to elevated nutrients, high sediment loads and chemical herbicides (Orth *et al.* 2006), which are conditions of increasing prevalence in coastal waters globally. Improved water quality can reduce light limitation by decreasing turbidity and/or algal biomass. It also improves the resilience of seagrass to elevated sea surface temperatures (Unsworth *et al.* 2015).

Water quality issues are complex due to the multiple stakeholders and scales involved, but improvement can be achieved through the cumulative effects of simple actions shared across stakeholders including industries, catchment authorities or other jurisdictions and local communities (Coles & Fortes 2001). Tampa Bay in Florida is an exemplar of how cooperation between public and private sectors can lead to the setting of voluntary but attainable water quality targets that resulted in a significant reduction in nitrogen loading to the coast. Increased nitrogen loads can decrease light availability due to algal overgrowth; consequently, nitrogen reduction can improve seagrass health by decreasing algal overgrowth (Greening *et al.* 2014). The Tampa Bay cooperative network included several catchment jurisdictions enacting residential fertilizer ordinances during the summer months to help reduce nutrient loading to the coast (Greening *et al.* 2014). In other locations, community-driven schemes are trading nutrient credits within catchments as a means of reducing nutrient loading and increasing the health of seagrasses. Another successful initiative to improve water quality in the catchments affecting the Great Barrier Reef lagoon has focused on small readily implementable changes that reduce the rate of nutrients reaching the coast such as better farm management to control erosion, controlled use of fertilizer, replanting riparian vegetation and reduction in soil mobilization by excluding feral animals from waterways though fencing and eradication. Prevention of soil compaction by managing vehicle movement can also reduce the loss of soils. In these examples, the 'management unit' is the catchment and actions are guided by evidence from empirical research and models designed to drive changes that cumulatively improve coastal water quality.

MAINTAINING THE KEY FUNCTIONAL BIOTA OF A RESILIENT ECOSYSTEM

Maintaining biodiversity and the functional balance of the fauna within a seagrass meadow food web is critical to prevent detrimental trophic cascades (Unsworth *et al.* 2015). A reduction in grazer biodiversity, such as a decrease in green turtles in Indonesia (Christianen *et al.* 2012), has been shown to reduce the resilience of seagrass meadows to poor water quality. Creating marine protected areas (MPAs) that consciously include and prioritize seagrass conservation can contribute to the aim of supporting seagrass-dependent functional biota. In some cases, specific measures may be required to restore populations of functional species previously abundant at a site. Habitat configuration (i.e. spatial arrangement of different habitat types) and fragmentation are key determinants of functionally important associated faunal species in shallow water habitats (Gullstrom *et al.* 2008). Appropriate MPA placement therefore needs to consider this spatial variability for improved chances of success. It should be noted, however, that in some cases, although increasing the density of functionally important species through MPA creation can help increase ecosystem resilience, unintended consequences, such as resultant overgrazing, can become problematic (Christianen *et al.* 2014). Again, decisions should be site and context appropriate. Such decisions need to consider not just the presence or absence of seagrass, but its functional value and its life-history traits so that management is tailored appropriately (Kilminster *et al.* 2015). Inclusion of seagrass into MPA networks needs to take into account that both present and historical (hence potential future) seagrass distribution and restoration measures may be appropriate (see section Investing in strategic restoration). Creation of MPAs, restoration action or implementation of fisheries management strategies, however, should be coupled with water quality improvement initiatives for longer-term benefit (see section Catchment management for improved water quality). Our understanding of how removal of key functional fish groups affects seagrass (through potential cascades) requires further research, but where data exist it can be used to evidence the need to maintain the trophic balance within seagrass ecosystems.

REFINING IMPACT ASSESSMENT PROCESSES

Coastal development (including land reclamation) continues to degrade nearshore seagrasses (Grech *et al.* 2012). Environmental impact assessments (EIAs) (a term that varies geographically) largely underpin the planning decisions for such developments, but these are plagued by inconsistent methods, limited data and a lack of independent evaluation, leading to perceptions of inadequate scientific rigour (Sheaves *et al.* 2015). Improved government–science–industry partnerships can facilitate evidence-based decision-making and the design of low to no net impact coastal developments (such as ports, channel creation, marina development, aquaculture facilities). Projects that require environmental impact assessment (EIA) are often designated insufficient time to determine geographical extent, local drivers and temporal variability of seagrass and its associated environment. Decisions are therefore made based on highly limited data potentially exacerbating the threat to seagrass meadows. In areas with rapid coastal development, or in those earmarked for future development, bringing together stakeholders (e.g. regulators, NGOs, industry bodies, private companies, academics) in a cooperative framework to assess, map and monitor seagrass systems will support creation of a temporal and spatial data set to inform the EIA process (Taylor & Rasheed 2011) that can be based on consistent methodologies adhering to high scientific standards (Sheaves *et al.* 2015). Collaboration of this kind results in cost sharing, rapid and accurate EIA, and allows early engineering decisions to be made that minimize impacts. Availability of data can help streamline environmental approvals and result in management plans that rely on accurate temporal and spatial data. Collaborative data banking can also assist in disaster action plan development for the management, understanding and offsetting of impacts on seagrass meadows in the event of environmental incidents (Taylor & Rasheed 2011). In addition to improving data sharing and increasing scientific rigour, better independent peer review of the EIA process may also improve the chances of avoiding type II errors (i.e. failing to detect the potential for damage to seagrass) (Sheaves *et al.* 2015).

In the process of managing the impacts of coastal development, there is increasing use of biodiversity offsets to mitigate for unavoidable loss (Bell *et al.* 2014). However, given the poor success rates in seagrass restoration, offsets should only be used where no alternative exists. Furthermore, a recent review of the use of offsets for seagrass meadows in Queensland Australia concluded that this option first requires development of seagrass-specific offset guidelines (Bell *et al.* 2014).

PROMOTING SUSTAINABLE FISHING PRACTICES

Overexploitation of seagrass-associated fauna and the use of destructive fishing methods within seagrass meadows are global problems (e.g. trampling, bleach fishing in the Caribbean, bait digging and illegal dredging in the Atlantic, seagrass cutting in Indonesia), all reducing the resilience of seagrass meadows and all issues requiring local action (Unsworth & Cullen 2010). The successful control of destructive fishing gears in seagrass (e.g. rakes, digging and dredges) by fisheries authorities on the south coast of England (UK) illustrates the potential for local action to reduce seagrass damage. Regulations, however, require enforcement as well as changes in the law. Fishing need not be at odds with seagrass protection, and some fisheries techniques can be altered to remove or reduce the direct physical impacts of certain gears whilst maintaining fishery productivity, for example replacing dredging with hand collection (hand, rake, dip nets) for scallops.

The use of 'ecolabelling' such as Marine Stewardship Council (MSC) certification, particularly when such labelling secures a higher priced commodity, can incentivize fishers to use more sustainable (less destructive) collection methods. These initiatives, however, need to be accessible to more fishers.

Where fishing techniques are inherently destructive and unsustainable (e.g. bleach, poison or blast fishing), legislation and enforcement to ban these practices need to go hand in hand with education and awareness-raising initiatives with alternatives presented where available and appropriate.

POLICY AND LEGISLATION TO SUPPORT LOCAL AND REGIONAL MANAGEMENT

Policy and legislation to protect seagrass meadows do exist in some countries and regions (Kenworthy *et al.* 2006). Management plans also exist, but as is well illustrated by the ineffectiveness of the majority of the world's MPAs these plans remain 'paper-bound'. Policy and legislation to support implementation, together with local stakeholder support, policing and enforcement, are key to ensuring conservation action that improves the health and resilience of seagrass meadows. For example, where damage to seagrass has been made illegal (e.g. seagrass is legally protected in England as habitat for seahorses under the Wildlife and Countryside Act 1981), mechanisms are required to deter or assess and report damage that can result in proportional penalties. In the European Union (EU), seagrasses are protected under the habitats directive but direct loss from anchor and mooring damage and the impacts of fish farms are commonplace due to a lack of enforcement. Importantly, although the EU habitats directive specifically names *Posidonia oceanica,* other species widespread across the EU and also under threat do not receive recognition.

Mechanisms are needed that can provide top-down support for bottom-up action (i.e. development of policy to support community-based management and action). For example, legislation in Florida provides a mechanism for prosecution and financial penalties following boat-based seagrass damage. Maritime states often have limited capacity or contrivance for damage to seagrass to lead to legal action and appropriate mitigation, even when damage is extensive and has been deliberate and methodical [e.g. widespread mechanical clearance of seagrass to provide bare white sands for tourists in the Caribbean (author observation)]. Clear policies, legislation and mechanisms need to be in place so that regulators have clear pathways to action in the event of an incident. However, this also requires political will in the first instance.

REDUCING IMPACTS FROM BOATING

Static moorings and anchors can cause 'scarring' of seagrass in the sheltered bays favoured by boaters. Further damage accrues due to boat groundings, propeller contact and boat-related pollution. Seagrass density can be reduced to zero, creating 'scars' around weighted chains that tear and uproot seagrass shoots and rhizomes within the circular footprint of the mooring (Demers, Davis & Knott 2013). These scars are often pronounced enough to be observed though aerial imagery. Conflict between boaters and seagrass can be diffused by providing clearly designated 'low-impact' anchoring or mooring areas or through the use of 'eco-mooring' systems that prevent or minimize damage. These systems use rigid and positively buoyant sections at the base of the mooring to replace weighted chains and are so effective that seagrass density around the eco-moorings is similar to that of reference areas (Demers, Davis & Knott 2013). Scar recovery is possible when moorings are exchanged, and in otherwise healthy seagrass systems, recovery is likely when seagrass-friendly eco-moorings are installed. However, for slow-growing seagrass species (e.g. *Posidonia* spp.), the use of seagrass-friendly alternatives may not result in a net benefit to the seagrass due to the poor recovery rate of this species. This further highlights the need for site- and context-specific protection and/or restoration strategies. Where new system installation is not feasible or beneficial, alternative mitigation measures include the use of subsea floats, replacing chains with rope or installing protective covers over chains, or replacing concrete blocks with helical anchors.

Damage from portable and fixed anchor systems can also reduce seagrass shoot density over wide areas. Where anchoring is a problem, installation and use of publically available seagrass-friendly moorings is an option, as is zonation to direct anchoring pressure into predominantly sandy areas away from seagrasses. Additional signage in sensitive areas can reduce physical damage from boats.

REDUCING OPPORTUNITIES FOR THE SPREAD OF INVASIVE SPECIES

Invasive alien species are increasingly prevalent within seagrass meadows, with evidence that disturbance or altered environmental conditions create niches advantageous to rapidly growing, fast-colonizing species. Once seagrass is displaced by an invasive algal species, such as *Caulerpa racemosa* in the Mediterranean (Ceccherelli *et al.* 2014), it is unlikely that it will return to dominance without costly intervention. Therefore, reducing direct physical disturbance will reduce the opportunities available for invasive species to colonize as a primary measure.

INVESTING IN STRATEGIC RESTORATION

There is growing evidence of the viability and successful use of simple low-tech methods for seagrass restoration through the collection and semi-controlled release of seeds using BuDS (Buoy-Deployed Seeding). The simplicity of these methods can empower volunteers to assist with habitat rehabilitation at degraded sites. Seagrass restoration projects globally have had variable levels of success (van Katwijk *et al.* 2016). Restoration efforts need to be better informed to maximize benefits and avoid misplaced action, and guidance is required to strategically direct restoration activity (van Katwijk *et al.* 2016), but with sufficient guidance volunteer scientists can undertake or assist with restoration projects with much improved chances of success. Consideration of seagrass restoration is an opportunity to rethink historical baselines, consider the potential availability of future habitat and propose ambitious targets that reflect actual long-term seagrass loss.

EDUCATION AND AWARENESS RAISING

We need to alter the indifferent or negative public perception of the value of seagrass meadows. It is not sufficient to simply emphasize that seagrass meadows support iconic species' such as green turtle *Chelonia mydas*, dugong *Dugong dugon* or long-snouted seahorse *Hippocampus guttulatus*. In general, a greater appreciation of the ecological role and ecosystem service value of seagrass meadows is required with education and awareness-raising initiatives covering the role of seagrass in food security provision (Cullen-Unsworth *et al.* 2014) and carbon storage. Existing seagrass conservation education, awareness raising and media coverage are insufficient. Seagrass meadows are, generally speaking, off the public radar as a habitat of any significance for those people not directly dependent on them for their livelihoods. Formal and informal educational programmes coupled with proactive science–media partnerships are needed to improve public awareness and generate positive perceptions of seagrass meadows. Promotion of and stakeholder engagement in organized citizen science programmes such as 'Seagrass-Watch' can instil a sense of resource pride whilst training develops skills, and monitoring activities add to a global data base documenting seagrass status and change over time. Better mainstream communication is required that highlights the importance of seagrass and motivates positive action towards protection.

PLANNING FOR MANAGEMENT OF A CONNECTED SEASCAPE

Integrated coastal zone management that supports connectivity within and between habitats is essential, not just to support seagrass meadows but to support the productivity and resilience of the seascape (Unsworth *et al.* 2015). We need managers and governments to recognize the role of seagrass in providing nursery and feeding grounds and other ecosystem services so that marine protected areas intentionally target seagrass habitats (Orth *et al.* 2006) rather than the current status quo of generally relying on 'accidental protection' though proximity to other habitats of conservation focus. This requires that seagrass meadows be included as important components of marine spatial plans. Where ecological connections have broken down, remediation measures such as restoration may be required to reintegrate seagrass into a connected seascape.

LONG-TERM INVESTMENT

Marine conservation can be financially costly, the scale of the costs being dependent on the purpose (e.g. maintenance of a specific ecosystem service value) and action required as well as the local social and cultural context. Ecosystem-based management for ecosystem services (e.g. storm protection) must also consider natural variability. Data collection and reporting of evidence can be costly. Although large-scale investment is not always required, and concerned individuals setting up citizen science projects can achieve significant impact with small amounts of money, finding ways to bring larger financial resources into conservation has the potential to enhance conservation outcomes. There is increasing interest in the use of Payments for Ecosystem Services (PES) to support seagrass conservation (Hejnowicz *et al.* 2015), particularly with respect to their value for trapping and storing carbon dioxide. This type of financing offers considerable wider benefits for the economic well-being of stakeholders, but it is important to realize that our understanding of the long-term societal implications of such initiatives (particularly within the marine environment) remains in its infancy. Alternatively, investing in long-term strategies to limit seagrass destruction by directing fines levied for seagrass damage to conservation programmes can be effective.

Where funding is available, making effective use of it may require prioritizing conservation action where the greatest gains can be made or the chances of success are highest. Associated decision-making requires consideration of a wide range of factors and is based only on the 'best available' data, and we therefore need to expand our seagrass data bases, encourage data sharing and improve our seagrass knowledge base.

Concluding remarks

The world's seagrass meadows are under threat across their distribution, but strategies exist that can be used towards a reversal of their decline. Action is required to protect the ecosystem services we receive from seagrass meadows and to confer seagrass resilience in the face of rapid and global environmental change.

Of the actions outlined here, many have the potential to singularly enhance the long-term viability of seagrass meadows. Such actions, however, still require associated measures such as improved long-term investment. Importantly, for seagrass conservation to have longevity improved policy and legislation is also needed to support local and regional management as part of a connected seascape. Critically, improved seagrass education and awareness is required highlighting their importance and sensitivity. This can bolster local action to lobby for political and financial support to enable change. Multiple overlapping strategies may be required to secure a future for seagrass, but evidence demonstrates that small-scale, context-specific actions can support the protection of seagrass meadows and their vital ecosystem services now and in the future.

Data accessibility

Data have not been archived because this article does not contain data.

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Biosketch

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