Opportunities and Challenges for Community-Based Seagrass Conservation

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Seagrass © *Grid-Arendal*

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A school of damselfish dominating seagrasses. *© Photo by Grid-Arendal*

Scuba divers enjoying a sea turtle on a healthy seagrass meadow. *© Photo by Ewout Knoester.*

A degraded seagrass meadow due to predation by sea urchins. *© Photo by Ewout Knoester*

Abandoned fishing gear entangled on a seagrass patch. *© Photo by Grid-Arendal.*

Boat anchor lodged into a seagrass bed. *© Photo by Grid-Arendal.*

Exposed rhizomes and matte of Posidonia meadows. *© Photo by Grid-Arendal*

A school of cow bream (Salema porgy) swimming on a seagrass bed. *© Photo by Grid-Arendal*

Illustration of the processes of carbon sequestration and storage in a seagrass meadow.
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Glossary of terms

Additionality	The concept that a project taking place is in addition to the baseline – i.e. what would have taken place in the absence of the intervention. In the context of carbon-based PES, ensuring additionality means that there are net CO_2 emissions reductions
Allochthonous carbon	Carbon that has entered a location from other source(s) (e.g. organic carbon transported via rivers into coastal habitats) and stored in the soil.
Autochthonous carbon	Carbon that was produced locally by the vegetation and stored in the soil.
Blue carbon	The organic carbon captured and stored by marine habitats, most notably in mangroves, saltmarsh and seagrass meadows.
Carbon credit	A unit available for purchase representing carbon sequestered
Carbon density	The amount of carbon per unit area for a given ecosystem
Carbon sequestration	A process by which carbon is removed from the atmosphere and stored (naturally or artificially) over an indefinite period of time
Carbon sink	A natural reservoir which stores carbon-containing organic compounds accumulated over an indefinite period of time
Carbon standard	A set of specifications required for certification under a particular certifying body for a project to trade carbon offsets
Community-based ecosystem management	A bottom-up approach to ecosystem management that involves local stakeholders in planning, development, research and ongoing management
Ecosystem services	The benefits that humans gain from ecosystems and the natural environment
Leakage	The displacement of carbon emissions outside the boundaries of a project, that resulted from intervention(s) associated with the project, resulting in no net avoidance of emissions
Nature-based solutions	Actions that sustainably manage, protect and/or restore ecosystems in ways that address socio-environmental challenges and deliver societal, biodiversity and/or climate benefits
Nursery habitat	A habitat that contributes disproportionately to the number, growth and/or survival of juvenile forms of marine species
Payments for ecosystem services	Payments made to land managers to enhance or facilitate ecosystem service delivery, conditional on delivery of services
Remineralisation	The breakdown of organic matter into its constituent inorganic forms
Seagrass	Rooted, flowering plants (angiosperms) which grow in coastal (intertidal and subtidal) habitats. These belong to four families (Posidoniaceae, Zosteraceae, Hydrocharitaceae and Cymodoceae) in the order Alismatales.

List of abbreviations

C	Carbon
BAP	Biodiversity Action Plan
$CaCO_3$	Calcium carbonate
CBM	Community-based management
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EU	European Union
ha	Hectare
km^2	Square kilometres
LMIC	Low and Medium Income Country
LMMA	Locally Managed Marine Areas
NDC	Nationally Determined Contributions
MLG	Multi-level governance
PES	Payments for ecosystem services
tC	Tonnes of carbon
tCO_2e	Tonnes of carbon dioxide equivalent
Tg	Teragram (equal to 10^{12} (one trillion) grams, or 10^9 (one billion) kilograms)
UK	United Kingdom

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Executive summary

Payments for Ecosystem Services (PES)-based community seagrass conservation: Strengths, Weaknesses, Opportunities and Threats

STRENGTHS	WEAKNESSES
❑ Existing stocks of carbon buried beneath seagrass meadows are large, with a global average of ~140 tonnes C ha^{-1} (similar to soil carbon in some terrestrial forests); globally, seagrass buries 48-112 Tg (million tonnes) C yr^{-1} ❑ Seagrass delivers numerous and diverse ecosystem services to coastal communities including coastal protection, habitat for fish and opportunities for tourism ❑ Globally, community-based conservation is increasingly favoured by national policies	❑ The carbon stock in seagrass meadows is generally lower than in mangroves and some terrestrial forests ❑ The monitoring of seagrass carbon stocks is expensive and requires scientific and technical expertise and equipment ❑ Significant scientific uncertainties remain over the source of carbon stored in, and fate of seagrass carbon exported from, seagrass meadows
OPPORTUNITIES	**THREATS**
❑ Community-based seagrass conservation presents an opportunity for fishing communities to manage the natural resource upon which they rely, taking ownership of natural resource management ❑ The carbon sequestration potential of seagrass meadows means that their inclusion in NDCs would help nations to meet their commitments under the Paris Agreement ❑ There is scope for development of new standards that allow 'avoided emissions' trading for seagrass carbon	❑ The political environment for PES (in particular carbon sequestration) is susceptible to change as national and international policies and agreements evolve ❑ The carbon market, highly dependent on both the political environment and public opinion, is vulnerable to fluctuation, putting PES-funded projects at risk of declining financial income ❑ A focus on ensuring technical certainty and minimising risks in carbon markets may make costs of monitoring and compliance disproportionate

Seagrass meadows are important marine ecosystems, providing a range of services including carbon sequestration, nursery habitats for fish and coastal protection. They are suffering rapid global decline in the face of eutrophication and other pollution, damage caused by fishing activities, tourism and coastal development. Degradation and loss of seagrass meadows negatively impacts their ability to provide ecosystem services, which are often of vital importance to resource-poor communities such as local fishers who depend on seagrass ecosystems for sustenance and income. Community-based management (CBM) presents an opportunity for effective, efficient and socially just conservation of seagrass. Payments for Ecosystem Services (PES) has been used in other ecosystems as a model to support community-based conservation but its application to seagrass meadows is in a very early stage. Community-based PES involving seagrass meadows would involve parties (buyers) making payments to communities or their representatives in exchange for management measures (implementation, restriction or adaptation of certain activities) that can be shown to enhance or ensure the delivery of seagrass ecosystem services. Here, the opportunities and challenges associated with community-based seagrass conservation, particularly PES-based, are discussed; we draw on experience in community-based PES projects in similar settings, but with different ecosystems, such as mangroves, and use carbon as the exemplar service (since a global market exists for carbon trading). Recommendations are made on how community-based seagrass conservation is best facilitated through policy mechanisms and tools.

The scientific and technical challenges facing a community-based PES seagrass conservation project include those involved in assessing and monitoring seagrass meadows and their ecosystem services, which may incur high costs and require expertise not commonly available to community groups. Uncertainties in the political climate of PES, particularly carbon trading, may undermine the longevity and security of a project. Uncertain rights to tenureship and management of intertidal and subtidal areas may cause further challenges depending on the location of a project, as the legal right to manage seagrass meadows is vital. Skills in marketing and administration are required in selling the ecosystem service; these are particularly important if the aim is to access global markets such as for carbon. Finally, the social challenges arising from governance of a common-pool resource, upon which stakeholders often depend for income and sustenance, require careful consideration and meaningful engagement with and involvement of diverse stakeholder groups.

Despite these challenges, community-based seagrass conservation is well-aligned with the global movement towards stronger community involvement in natural resource management. National policies of many countries are therefore increasingly favourable towards community-based management, creating opportunities for communities to govern the ecosystems upon which they depend. Fishing communities, often the primary user group of seagrass meadows, are presented with an opportunity to govern seagrass ecosystems and benefit, directly and indirectly, from their sustainable management.

With consideration to these challenges and opportunities, it is recommended that:

(a) Seagrasses are incorporated into countries' Nationally Determined Contributions (NDCs) under the Paris Agreement where appropriate and relevant;

(b) Carbon standards (and other relevant PES frameworks) allow for seagrass to be incorporated under a flexible 'additional benefits' or 'carbon plus' approach;

(c) When considering seagrass under PES or other conservation strategies, holistic consideration is given to their ecosystem services beyond carbon sequestration;

(d) Carbon standards should not impose deductions on the carbon benefits claimed to account for calcium carbonate presence unless robust evidence shows that there are considerable CO_2 emissions resulting from calcium carbonate formation;

(e) Clarity is sought on the extent to which allochthonous carbon is prevalent in seagrass ecosystems, and a consensus is reached on whether this has implications for additionality under carbon standards;

(f) Clarity is sought on carbon dynamics following seagrass disturbance or destruction and whether this has implications for additionality under carbon standards. For example, following disturbance soil carbon is generally lost from seagrass meadows. However how much is re-mineralised into the atmosphere and how much is transported to another marine ecosystem and re-buried is generally unknown;

(g) Nationally-administered accelerator programs and funds are provided to improve the feasibility of initiating community-based seagrass conservation projects;

(h) Consideration is given to enabling access to markets and other funding by community groups, for example by relevant NGOs (in some cases supported by governments) acting as intermediary organisations;

(i) The financial sustainability of community-based seagrass conservation projects is improved through advances in satellite-based carbon stock assessment and allowances under carbon standards as outlined in (b) above.

1. Introduction to seagrass, including summary of conservation importance and status

Figure 1. A school of damselfish dominating seagrasses. © Photo by Grid-Arendal.

Seagrasses are flowering plants (angiosperms) that form 'meadows' in intertidal to shallow subtidal coastal waters around the world. Their global extent is conservatively estimated at 300,000 km² although challenges in assessment of seagrass cover, and the resulting absence of a global, regularly updated database of seagrass meadows, mean that this figure is acknowledged to be approximate and their actual extent may be 600,000 km² or more (Green and Short, 2003; Mcleod *et al.*, 2011). They deliver a range of ecosystem services including carbon sequestration, nursery habitats for fish and shellfish (including commercially exploited species) and coastal protection through hydrodynamic damping (Nordlund *et al.*, 2017). They provide a food source for numerous species, including charismatic fauna such as sea turtles, manatees and dugongs, which in turn attract marine tourism. Seagrasses are closely ecologically linked with other coastal habitats such as mangroves and coral reefs in the tropics, and tidal marshes and kelp forests in temperate areas (Huxham, *et al.*, 2018).

Seagrass meadows are disappearing rapidly (Waycott *et al.*, 2009). Eutrophication, increased sedimentation from land erosion, coastal development, climate change and impacts from boats, anchors and fishing gear are all important drivers of loss (Cabaco *et al.*, 2008; Short *et al.*, 2016; Fernandes *et al.*, 2017). Accurate estimation

Figure 2. Scuba divers enjoying a sea turtle on a healthy seagrass meadow. © Photo by Ewout Knoester.

Figure 3. A degraded seagrass meadow due to predation by sea urchins. © *Photo by Ewout Knoester*

of the global rate of loss of seagrass meadows is challenging due to a lack of a global database. Their annual rate of decline has been estimated to be as high as 7% (Waycott *et al.*, 2009), based on a global data set which draws heavily from developed countries. An estimate of 6.9% loss per annum was made for the Mediterranean (Marbà *et al.*, 2014) and more recently 1.59% in Kenya (Harcourt *et al.*, 2018). Hence it is clear that seagrasses globally are suffering rapid declines but that the rates of loss vary widely. Whilst their rate of loss and ecological importance matches or exceeds other ecosystems such as mangroves, coral reefs and terrestrial tropical forests, seagrasses are relatively marginalised due the low public awareness of their value; this is arguably the greatest threat to their conservation (Nordlund et al, 2018).

Although seagrass meadows are protected under a wide range of national and international legislation (e.g. seagrass meadows are a UK Biodiversity Action Plan (BAP) Priority Habitat and have protected status in Kenya) implementation is often inadequate or absent (Griffiths *et al.*, 2020). Low public awareness of seagrass and its importance means that there is little public pressure on the relevant authorities to enforce breaches of legislation. Seagrass meadows are rarely considered in marine planning and management strategies (Nordlund *et al.*, 2016) and where management strategies do exist, enforcement is often lacking. Due to their shallow coastal location, seagrass meadows often overlap with direct human use such as seine netting, anchoring of boats and marine recreational activities, as well as with areas of

Figure 4. Abandoned fishing gear entangled on a seagrass patch. © Photo by Grid-Arendal.

coastal development, raising conflicts between conservation interests and commercial and/or sustenance users of the coastal area (Cullen-Unsworth et al 2014). In addition, indirect impacts from activities originating on land, including sedimentation, eutrophication and run-off of chemicals such as herbicides further threaten seagrass health and survival.

Ecosystem services are defined here as the benefits that people gain from the natural environment. Costanza *et al.* (2014) estimate the total monetary value of the world's seagrass and algal beds to be US$6.4 trillion (out of a total for all ecosystem services of US$125 trillion). Hence in this analysis seagrass and related habitat (algae) is responsible for > 5% of the total value of nature. Whilst monetizing values in this way may help to communicate the importance of nature in some policy settings it is important to remember that it also fails to capture total value and is inherently biased against people with little money. For example, in mangroves, whilst the market value of fuelwood might be very low, thousands of poor households rely on collecting it to cook their daily meals (Huxham *et al.*, 2015).

Figure 5. Boat anchor lodged into a seagrass bed. *© Photo by Grid-Arendal.*

2. Social principles of community conservation

Protecting, restoring and managing seagrass ecosystems can be challenging tasks. The general lack of public awareness, scientific uncertainties and problems with extrapolating from well-known to less-known sites, combined with a shortage of resources and political will at national levels to enforce legislation, are significant barriers to traditional command-and-control, top-down approaches to management. In common with other ecosystems, particularly in developing countries, these limitations present strong practical arguments for devolving rights and responsibilities to a local level. Indeed evidence from forestry suggests that devolved, community-based management (CBM) can bring better conservation outcomes (Porter-Bolland *et al.*, 2012). Because community-based conservation should involve different perspectives on and approaches to management decisions, allowing for flexible and iterative processes, it may also permit adaptive management in the face of environmental and social change (Allen & Garmestani, 2015). In addition to these practical concerns there are strong ethical arguments for decentralisation (movement from nationally implemented management to more local decision-making) and democratic control ('top down' to 'bottom up' decision-making) and for recognising the rights of local people (although decentralisation does not always lead to greater equity; Larson & Soto, 2008).

The term 'community' can disguise heterogeneity in culture, religion, social norms and geographic boundaries between and within project areas. Here, we use this term with recognition that its definition will be context-specific and in application should be determined in a participatory manner by the participants and beneficiaries of any given project.

CBM is increasingly adopted as an environmental management and conservation strategy, centred around the people who depend on the resources and often including explicit social and development targets. When conducted well, it can facilitate management that supports both the conservation of the environment and the communities who depend on its resource, thereby facilitating more sustainable management. In the absence of traditional 'top-down' management, effective CBM relies on social principles among community stakeholders to govern an open-access resource and avoid a 'tragedy of the commons' scenario, where long-term sustainability is compromised in favour of short-term self-interest. Eight social principles required for successful governance of common-pool resources are outlined by Ostrom (1990) and can be summarised as:

- ❑ Clear definition of the resource: in the case of seagrass meadows, demarcation of the protected area would be needed so that all stakeholders are aware of what is being protected.
- ❑ Locally appropriate governance: the governing rules should be adapted to local conditions and requirements. For example, the involvement of traditional authorities and respect for tribal tenureships should be embedded in the project design, and management strategies should be sympathetic to local resource availability.
- ❑ Allowing the participation of all stakeholders in decision-making processes: in seagrass ecosystems, these may include individuals or groups involved in gleaning, fishing, recreational boating, tourism and coastal development.
- ❑ Effective monitoring by either the stakeholders or by a monitor who is accountable to the stakeholders.
- ❑ Appropriate and graduated sanctions for breaching of the common-pool resource and application of these sanctions in the case of a breach of community rules.
- ❑ Cost-effective mechanisms of conflict resolution: again, locally and culturally appropriate practices should be incorporated and practices should be transparent.

- Recognition by higher authorities of the self-determination of the community group as an entity responsible for and capable of management: this will be needed in many cases to secure legal recognition of the group's management authority and allow legally enforceable management strategies.

- Nested multiple layers of organisation; Ostrom notes that these should be present in cases of larger common-pool resources, however section 6 describes how this structure can be utilised to facilitate PES-based management where skills or resources are missing.

Poteete et al (2010) added further social principles needed for effective common-pool resource governance, including:

- Trust between stakeholders: in many cases, these stakeholders may bridge social and geographic boundaries.

- Effective communication; and

- Reciprocity: parties within an agreement will cooperate on the assumption of, and in anticipation of, reciprocal cooperation from other parties within the agreement. If reciprocal cooperation is not realised, there is a weaker incentive for parties to cooperate.

Respecting and facilitating these principles takes care and patience and can be particularly challenging where there are differing spatial and temporal scales in both natural and social systems. In addition, increasing the scale of projects (both in terms of scale of the natural resource and the societal scope) poses further challenges. A community-based seagrass conservation project should give early and sustained consideration to these principles to facilitate socially just and sustainable conservation.

3. Payments for ecosystem services as a source of funds for conservation

Payments for Ecosystem Services (PES) involves conditional payments by "buyers" to land managers or "stewards" of ecosystems to facilitate the delivery of ecosystem services, either through the protection of existing natural resources or the restoration or creation of habitats. It reflects the economic, social and health benefits that people gain from the environment. PES provides market-based mechanisms to facilitate the conservation of natural resources, providing an incentive in the absence of sufficient regulation or financing of environmental protection. Since PES involves conditional transfers of funds, it targets resources in a way designed to directly incentivise and reward people for their stewardship of a service (Wunder, 2005). Critically, PES provides protection or enhancement of ecosystems over and above what would have been provided in the absence of payment.

Interest in PES has grown over recent decades (Salzman *et al.*, 2018). In the terrestrial environment, PES approaches are most often used to maintain biodiversity, water quality and carbon sequestration. Salzman et al (2018) report that the watershed service market is the largest of the three examples in value, followed by the forest carbon market and lastly biodiversity payments. The former two markets both continue to grow, while the latter is decreasing overall, despite well-developed compliance mechanisms for habitat restoration. Carbon sequestration is commonly utilised as a policy instrument to mitigate climate change, most prominently in the implementation of the Paris Agreement.

Buying carbon credits in order to offset emissions provides income for a range of PES projects that focus on carbon sequestration as the main service (although small projects typically include co-benefits, such as enhanced biodiversity, as well). Carbon-based PES is used here as an example mechanism for facilitating a seagrass-based PES project, although many of the principles discussed will apply equally to other putative services. A carbon offset typically represents one tonne of carbon dioxide equivalent (CO_2e) in avoided emissions or in additional sequestration, through interventions such as the planting or protection of relevant ecosystems or investment in low-carbon technology.

3.1 Payments for carbon offsetting may operate through the *compliance* or *voluntary* markets.

Compliance (also called mandatory or regulatory) markets are those that exist in order to meet certain laws or regulations — such as caps on the amount of greenhouse gas that a company can emit within the European Union Emissions Trading Scheme. They have typically dealt with major emitters and have not involved nature-based solutions such as forest protection (neither terrestrial nor blue carbon). New developments in international policy, particularly the adoption of approaches designed to protect forests called Reduced Emissions from Deforestation and Forest Degradation (REDD+), already incorporate mangroves and may open opportunities for seagrass conservation under the compliance markets. At present however most opportunities for community focused nature-based projects occur in the voluntary market.

Voluntary markets involve individuals, organisations or businesses buying offsets for their own reasons, which may be to reduce their personal carbon footprints, to help achieve corporate goals or to improve their business brand. The land-based voluntary market is much smaller than the compliance carbon market, with less than 1% of the transactions (Hejnowicz,*et al.* 2015) However, it is flexible and can allow innovation and a better fit to local contexts. It also typically commands higher carbon prices than those in very large compliance market projects. This is partly because of the emphasis on co-benefits, such as improved livelihoods and biodiversity conservation that are demanded in most of the accreditation schemes. Nature-based solutions are popular, and numerous reforestation and afforestation projects exist (including for mangroves). The largest standard is the Verified Carbon Standard (VCS), administered by Verra, which accounts for around 55% of the market share; other important ones are Gold Standard, Climate Action Reserve (CAR), American Climate Registry (ACR) and Plan Vivo. These third-party organisations are facilitating institutions that accredit projects and endorse their scientific, technical and social credibility. They develop their own technical methodologies. VCS now supports a Greenhouse Gas Accounting Methods for Tidal Wetlands and Seagrass Restoration methodology (VM0033), with Plan Vivo exploring their own approach.

The value of PES depends largely on the size and condition of the ecosystem, the principles of the PES scheme and the willingness of the beneficiaries to pay. Salzman et al (2018) estimated the global market for PES to be between US$36-42 billion annually, with over 550 programs at local, regional and national scales in both developed and developing countries. The voluntary forest and land-use carbon market (one of the most likely sources of funding for seagrass PES) is estimated to have grown from US$46 million in 2009 to US$74.2 million in 2016. Values for carbon credits have fluctuated throughout the ~20-year existence of the market but they have been strengthening as of 2018. Hamrick and Gallant (2017) found that the price of carbon on the voluntary market ranged from US$0.5/t$CO_2$e to US$50/tCO_2e.

The operation of PES schemes generally (and ideally) involves governance by an accrediting body that monitors interventions, evaluates evidence of outputs and ensures that the scheme addresses key issues such as additionality and leakage. This body should have the authority to approve or deny PES transactions based on the integrity of the scheme.

Under PES, payments may be made by direct or indirect buyers. An example of a direct payment scheme is the Ohio River Basin Trading Project which allows emitters of phosphorous and nitrogen (primarily farmers) to gain funds to make nutrient reductions from the monies provided by the buyers. By enhancing nature-based regulating services, the requirement for more expensive water quality treatment is avoided and a more cost-effective means of meeting discharge requirements is implemented. An example of an indirect payment scheme is when beneficiaries of PES include individuals offsetting the carbon footprint of aviation travel, thereby mitigating climate change.

PES schemes are well-developed in terrestrial forests and watersheds but are less frequent in marine and coastal ecosystems. For example, despite sequestering three to four times as much carbon per hectare as terrestrial forests (Mcleod et al, 2011), PES schemes conserving mangrove forests were implemented much later than terrestrial forests due to scientific, technical and policy barriers and complexities. Barriers to the inclusion of marine and coastal ecosystems in PES schemes include relatively less understanding of natural processes, relatively under-developed standards for design and implementation, greater cost and expertise required for implementing and monitoring marine and coastal ecosystems and complexities or uncertainties in the policy context of coastal ecosystem governance.

4. Seagrass ecosystem services

4.1 Ecosystem services provided by seagrass

Seagrass meadows provide a range of ecosystem services that vary between species and geographical location. These include provisioning services (including compost fertiliser and pharmaceuticals), regulating services (including carbon sequestration, coastal protection and water purification, also making the system less acidic), cultural (including education and tourism) and supporting services (including habitat for commercial species) (Nordlund et al, 2016). These services benefit people directly or indirectly; the degree to which each service lends itself to PES varies depending on the feasibility of quantification or valuation, the potential economic value and the existence of markets. Here we outline three ecosystem services as most suitable for a PES program: carbon sequestration, habitat for commercially fished species, and coastal protection.

4.1.1 Carbon sequestration

Seagrass captures carbon, in above-ground biomass (plant leaf and stem tissues), below-ground biomass (root tissues) and, most significantly, in the underlying sediment. This soil carbon may be autochthonous (originally captured by the plant) or allochthonous (generated elsewhere and captured by seagrass ecosystems, for example carbon delivered by river or estuarine flow trapped by the seagrass meadow). The above and belowground biomass in seagrass is normally negligible in comparison to soil carbon and is very variable, often changing between seasons and years. This is in strong contrast to mangrove carbon stocks where the biomass of the trees themselves may provide a significant carbon store. Carbon trading standards typically demand evidence that carbon claimed as credits can be stored on a 100+ year timescale; this is not presently possible for seagrass biomass (and possibly not for upper layers of soil, as discussed in section 5). For this reason, we anticipate that a seagrass carbon-based PES scheme would be based on soil carbon only and not include seagrass biomass.

While terrestrial forests have traditionally been the focus of global ecosystem carbon budgets and sequestration schemes, wetlands and marine ecosystems are increasingly recognised as valuable carbon sinks, in many cases storing

Figure 6. Exposed rhizomes and matte of Posidonia meadows. © *Photo by Grid-Arendal*

several times as much carbon per unit area as terrestrial forests. Seagrass is one of three 'blue carbon' ecosystems (seagrass meadows, mangroves and saltmarsh) so called for their capacity to sequester atmospheric CO_2 in their soil on centennial to millennial timescales. This carbon accumulation is due to a combination of high autochthonous productivity (the ability to convert CO_2 into plant biomass), the trapping of allochthonous carbon (Geraldi et al, 2019) and low rates of decomposition of buried carbon. Accumulating carbon becomes stored in part due to the anoxic conditions of underlying soils, where microorganisms that would ordinarily degrade organic carbon in aerated soils, releasing it as CO_2, are not abundant in marine sediments. Synthesised data on the average carbon burial rates of the three ecosystems are reported (Mcleod *et al.* 2011; Duarte *et al.*, 2013). Seagrass demonstrates the lowest carbon burial rate of the three (an average of 138 ±38 g C m2 yr^{-1}, in comparison to 218 ±24 for saltmarsh and 226 ±39 for mangroves). However, the larger total area of seagrass means that globally they present a greater carbon burial potential, of between 48 and 112 Tg C yr^{-1}, in comparison to 4.8 – 87.2 Tg C yr^{-1} in saltmarsh and 22.5-24.9 Tg C yr^{-1} in mangroves. In addition to burial rates of new carbon, seagrass meadows contain large stocks of stored carbon (on average, 140 t C ha^{-1} to 1m soil depth including biomass), although stocks may reach more than three times this at some seagrass meadows (Fourqurean *et al.*, 2012). Most notably, *Posidonia oceanica*, endemic to the Mediterranean, has carbon sequestration and storage capacity that exceeds other seagrass species due to its size, dense biomass, slow decomposition and dense canopies acting as an effective trap for suspended organic matter (e.g. Duarte *et al.*, 2005; Fourqurean *et al.* 2012).

There is considerable variation in carbon sequestration, burial rates and stocks between species and geographical location in seagrass. It must therefore be noted that the averages for species or habitat type given here and widely in the literature may be very unrepresentative for any individual site and species (Mazarrasa *et al.*, 2018). Turbidity, wave height, temperature, hydrodynamic energy, seagrass canopy complexity and physiological traits all contribute to the variation in C sequestration and storage. Some seagrass species may be better suited to a carbon PES project than others. These uncertainties are further discussed in section 5.

4.1.2 Nursery habitat

The high rates of primary production and diverse canopy structure of seagrass meadows make them important food and habitat for a range of marine fish and shellfish species, many of which are commercially exploited (Jackson *et al.*, 2001). The complex structure of seagrass meadows provides shelter for fish and shellfish, particularly for less mobile species, and seagrass biomass and associated algae provide a readily available source of food for higher trophic levels. This characteristic means that association with seagrass, particularly at a juvenile stage, increases the abundance, size and survival of many fish and shellfish species. 'Gleaning' fisheries, involving hand-gathering of invertebrates including crustaceans, polychaete worms and molluscs at low tide, are often heavily concentrated around exposed intertidal seagrass meadows due to the strong association of these species with seagrass. These fisheries provide an important source of protein for many communities in developing countries worldwide (Unsworth *et al.* 2019). While few studies have attempted to quantify the contribution of seagrass habitat to commercial stocks, Blandon and Zu Ermgassen (2014) assessed this in southern Australia, using fish surveys of seagrass habitats in comparison with control sites (no seagrass cover) and modelling of fish growth and mortality, and Unsworth *et al.*, (2014) show that commercial fisheries in the Western Pacific Ocean are considerably enhanced by the services provided by seagrass meadows. Unsworth *et al.* (2019) present a global synthesis demonstrating that ~21.5% of the world's 25 largest fisheries (by global landings) use seagrass as a nursery habitat and that seagrass meadows support both small-scale and intertidal gleaning fisheries. The financial contribution of seagrass meadows to local fisheries has been quantified across geographic locations; for example at 866 EUR (approx. USD 953) ha^{-1} in Gran Canaria (Tuya *et al.*, 2014), between EUR 284 and 514 (approx. USD 313 and 566) ha^{-1} $year^{-1}$ in the Mediterranean (Campagne *et al.*, 2015) and USD 38 ha^{-1} in Indonesia (Unsworth *et al.*, 2010). The methods used by these assessments may be implemented and developed in order to assess the contribution

Figure 7. A school of cow bream (Salema porgy) swimming on a seagrass bed. © Photo by Grid-Arendal

of seagrass meadows to local fisheries in line with the requirements of a PES program.

Assessing and identifying 'nursery' habitats is the focus of scientific debate, and no single accepted method exists. Dahlgren et al (2006) argued that the total contribution of a habitat (regardless of contribution per unit area) should be used a measure of a habitat's capacity as a nursery; this would allow for habitats that may support a low concentration of individuals but cover a wide spatial area. However, in the context of PES, a per-unit-area measurement may be required in order to assess and evaluate ecosystem service provision on a spatial scale.

A recent meta-analysis of studies assessing coastal habitats' capacity to increase density, growth and survival of juvenile fishes found that both mangroves and seagrass meadows contributed to all three metrics, while structured habitats almost all increased juvenile density (Lefcheck *et al.*, 2019). The analysis also observed a significant increase in the importance of seagrass as a nursery habitat with higher latitudes. This observation is thought to be due to the greater availability of alternative nursery habitats in tropical regions in comparison to temperate seas. The contribution of the habitat to adult populations also depended on the taxa; invertebrates were found to be more dependent on nursery habitats than vertebrate species. This is perhaps due to mobility; as less mobile species, invertebrates may be more reliant on structure to hide from predators and access food. Although Lefcheck *et al.* (2019) did not report any factors affecting the contribution of a habitat as a nursery beyond latitude and phyla, other studies on mangroves have reported the influence of the influx of freshwater and nutrients and of total mangrove area (Hutchison *et al.*, 2015), complexity of seagrass beds, salinity, larval supply and landscape-level variation in habitats and geographical features both within and adjacent to the nursey habitat itself (Beck *et al.*, 2001).

It is important to note that conserving nursery habitats alone is not sufficient to benefit adult populations; the life cycle of many commercial species requires a 'mosaic' (Nagelkerken *et al.*, 2013) and connectivity between juvenile and adult habitats must be maintained (Gillanders *et al.*, 2003).

4.1.3 Coastal protection

Seagrass meadows provide coastal protection through the dissipation and reflection of wave energy. While this service can be delivered even with a low canopy height (Christianen et al, 2013; Potouroglou *et al.*, 2017, Maike 2018), the extent to which it is provided varies with environmental and biological conditions including wave energy and three-dimensional structure of the seagrass, and coastal protection cannot be assumed in all locations. It can be evaluated using both experimental studies (in-site and laboratory-based) and numerical modelling (Ondievela et al, 2014). To date, coastal protection has not been included in any PES programmes. Assessment of the value of seagrass for coastal protection would raise challenges; however, application of risk calculation methodologies used by the insurance industry may aid in the quantification of coastal protection as an ecosystem service (Lau, 2013). Alternative novel methods have been applied by Hochard et al (2019); using night-time luminosity as a proxy for coastal economic activity, the authors assessed the economic damage caused by cyclones on coastal settlements and inferred protection provided by mangroves according to relative economic damage in areas with varying mangrove forest extent.

There is ongoing, but scarce, research into the economic value of seagrass meadows for coastal protection (Drakou *et al.*, 2017, Milon & Alvarez 2019). The comparative contribution of seagrass, mangroves and coral reefs has been assessed by mathematical modelling (e.g. Guannel *et al.*, 2016), expert opinion (e.g. Liquete *et al.*, 2013) and syntheses of existing studies (e.g. Barbier *et al.*, 2011).

Liquete *et al.* (2013) ranked seabed and emerged coastal habitats in Europe according to their protective capacity and ranked seagrass as having comparatively lower protective capacity than hard substrata or biogenic reefs, coarse or mixed sediments or shallow sands, but more effective than shallow muds.

The extent to which a seagrass meadow protects the shoreline depends on incident energy flux and seagrass density, biomass and stiffness; the greatest protection is likely to be provided by large, long-living and slow-growing species (Ondiviela *et al.*, 2014). Whilst seagrass meadows have been shown to provide coastal protection (e.g. Christianen *et al.*, 2013, Silva *et al.*, 2019), the protective effect is likely to be less than habitats such as mangroves and coral reefs which have a larger biomass, and denser and stiffer substrates. However, this general assumption may be case-specific; in certain cases, such as *Posidonia*, the protective capacity of seagrass may exceed that of other marine ecosystems.

Guannel *et al.* (2016) highlight the cumulative effects of mangroves, seagrasses and coral reefs in coastal protection, noting that the combined effect of two or three of these ecosystems is greater than each alone. Although the authors note that mangroves provide the greatest coastal protection benefits, seagrass and coral reefs reduce the risk of shoreline erosion, increase the stability of the shoreline offshore of mangroves and reduce nearshore currents, thereby increasing the resilience of the mangrove forest and facilitating mangrove recruitment, maintaining a viable forest (Huxham *et al.*, 2018). In addition, seagrass meadows can protect other coastal ecosystems such as coral reefs by attenuation of wave action, including under scenarios of sea level rise, (Guannel *et al.*, 2016) and filtration of pollutants that are damaging to corals (Lamb *et al.*, 2017). Hence conserving one marine habitat in isolation may not facilitate the delivery of coastal protection; structurally heterogeneous components of the seascape may cumulatively moderate hydrodynamic processes and therefore management practices should take into consideration multiple habitats and ecosystems.

Assessment of each ecosystem service inherently involves a degree of uncertainty. This can be accounted for by conservative assumptions (for example, the exclusion of carbon stored in the top 5 cm layer of soil to conservatively assume that the carbon stored here does not exhibit permanence) and the application of risk buffers in project design (for example, deduction of ~10-15% of total carbon benefit to provide a buffer against leakage, carbon loss due to natural events, or other factors that may negatively impact net carbon benefit of the management actions).

5. Challenges of community-based seagrass conservation, framed within the perspective of a PES-based system

Community-based management (CBM) has been recognised as a means of achieving conservation targets whilst delivering socio-economic benefits to local people (Campbell and Mattila, 2003) and facilitating decentralisation, cultural autonomy (the meaningful recognition and incorporation of indigenous knowledge and rights) and meaningful participation (Agrawal and Gibson, 2001). CBM is governance of biodiversity and natural resources that is rooted in the communities that live among and benefit from such resources. Here, we discuss CBM that may also encompass multiple levels of governance to achieve its aims and objectives, while maintaining strong roots in community involvement. CBM is often conducted in, but not limited to, developing nations as a means of conserving biodiversity where traditional, government-led conservation has failed.

CBM has been shown to achieve better conservation outcomes than traditional top-down management across a range of tropical forests (Porter-Bolland *et al.*, 2012). However improved outcomes are not guaranteed and CBM often fails to achieve the high expectations held by its proponents. Complexities in human behaviour (Nilsson *et al.*, 2016), overreliance on technical support from overseas (Leach *et al.*, 1999) and insufficient decentralisation of power from government to community hands (Goldman, 2003) can all undermine success. Here we discuss the challenges facing potential practitioners of community seagrass conservation, framed within the context of carbon-based PES programs.

5.1 Scientific and technical challenges

A carbon-based PES program incorporating seagrass would require the quantification of the carbon in the seagrass soil and the monitoring of seagrass cover, soil carbon and other variables. Participants would need the appropriate skills and capacity to conduct sampling and analysis exercises, which may require swimming, snorkelling and/or diving, access to a boat and knowledge of sample analysis techniques including use of an oven, muffle furnace, weighing scales and associated technical measurement techniques. The equipment required to conduct analyses can be expensive and access to such equipment, particularly in rural areas and in developing countries, can be limited. Further technical challenges are raised by the capacity of projects to monitor and enforce management measures at sea, where land-based observations may not be enough to monitor compliance and demarcation of protected areas is challenging. At larger scales, at which projects are likely to become more financially viable (see section 5.5 Economic challenges), additional challenges are raised by higher diversity of species, and therefore variable carbon sequestration rates. This variability may be further compounded by seasonal variation in growth or other periodic event (e.g. El Niño) that affect biomass accumulation and/or carbon burial rates.

The complexity and sophistication of project implementation, management and monitoring, and hence the costs and financial viability of a proposed project, will depend in part on how regulating bodies and standards choose to deal with uncertainties and incomplete knowledge. Whilst this is true of all PES projects, there are several areas of scientific uncertainty and ignorance that are particularly relevant for seagrass carbon sequestration and storage. Key scientific and technical challenges may include:

(a) Project additionality

Most PES projects must demonstrate additionality – that the benefit (e.g. avoided CO_2 emissions or enhanced CO_2 sequestration) attributed to project interventions would not have been realised in the absence of those interventions. If a project involves avoided destruction/degradation, then information is needed on trends and a realistic business-as-usual scenario must be constructed; this can be particularly challenging for seagrass since the historical data (e.g. from satellite imagery) are often missing.

(b) Provenance additionality

It has been estimated that, on average 50% of the carbon captured in seagrass meadows is allochthonous, generated outside of, but trapped by, the seagrass meadow (Kennedy *et al.*, 2010). With the loss of the seagrass meadow, some or all of this allochthonous carbon may be captured elsewhere (for example, in deep sea sediments) as opposed to being remineralised and released as CO_2. Hence allochthonous carbon may have to be deducted from the soil carbon value. For example the Verified Carbon Standard (VCS) currently requires allochthonous carbon to be deducted from the total sediment carbon (a 'zero deduction' exception to this is allowed, however this requires field data collected over a multi-year period using technical and scientific methods that may be challenging and inaccessible to community groups). However, if a default value of 50% is not applied, methods to determine the provenance of allochthonous carbon can include published values (provided they have been collected in or can reasonably be assumed to be extrapolatable to the project area) modelling or field-collected data. The latter would include methods and measurements including bulk isotopes, compound-specific isotopes, biomarkers, molecular properties, and environmental DNA (eDNA), requiring skills, experience and resources beyond those reasonably expected of a community-based project (Geraldi *et al.*, 2019). Modelling, particularly as empirical data on allochthonous carbon from any seagrass systems are scarce and models are not yet well developed or publicly available, may also be outside of the capabilities of a community group.

(c) Seagrass carbon vulnerability

A related but even greater challenge exists in determining the fate of seagrass carbon in the case of ecosystem degradation or loss. Although it has been demonstrated that carbon may be rapidly lost from the sediment when seagrass is lost (e.g. Marbà et al, 2015; Githaiga, Frouws, Kairo, & Huxham, 2019), the ultimate fate of this lost carbon – for example whether it is oxidised and returned to the atmosphere, or moved by currents to deep sea sinks - has not been experimentally determined and the generality of this vulnerability in different sites is not well understood.

(d) Calcification and inorganic carbon

Debate also exists on whether the carbon sequestered by seagrass is offset by the release of CO_2 during the calcification process by calcifying organisms including epiphytes, crabs, molluscs and other organisms inhabiting the seagrass meadow. The calcification process, despite forming inorganic carbon in the form of calcium carbonate ($CaCO_3$), generates CO_2 in the water column potentially leading to CO_2 emissions. However, recent research by Saderne *et al.* (2019) suggests that the burial of inorganic carbon (C_{inorg}), constituting 12% of $CaCO_3$ mass, is mainly derived from inputs from adjacent ecosystems rather than by calcification within the seagrass ecosystem and so does not offset locally sequestered CO_2. In addition, allochthonous C_{inorg} burial contributes to seabed elevation within the seagrass meadow, enhancing its ecosystem service of coastal protection.

(e) Permanence and re-mineralisation

International protocols dictate that carbon must be expected to be sequestered on a >100 years' timescale in order to count as 'permanent' and be traded as emissions reductions. Due to biological and hydrological mixing of the surface layer of seagrass sediment, carbon in the upper layer may be at risk of re-suspension and therefore potential remineralisation (Arias-Ortiz *et al.*, 2018). The 'remineralisation depth' is the depth at which it can be reasonably assumed that this risk is minimised, and critics argue that only sediment carbon below the remineralisation layer should be quantified and traded (Johannessen and Macdonald, 2016). Identifying this depth in individual projects would be costly, time consuming and in many cases impractical for a community group to determine, yet variation within and between species and sites means that attempts to establish a standard depth at which remineralisation is assumed not to occur will involve multiple exceptions.

5.2 Political challenges

The carbon market was heralded in its early days as a 'capital accumulation strategy', or means of raising income, for nature (Bumpus and Liverman, 2008) although carbon markets built around the EU Emissions Trading Scheme fluctuated in performance in subsequent years. In 2018, carbon markets rose sharply and have remained

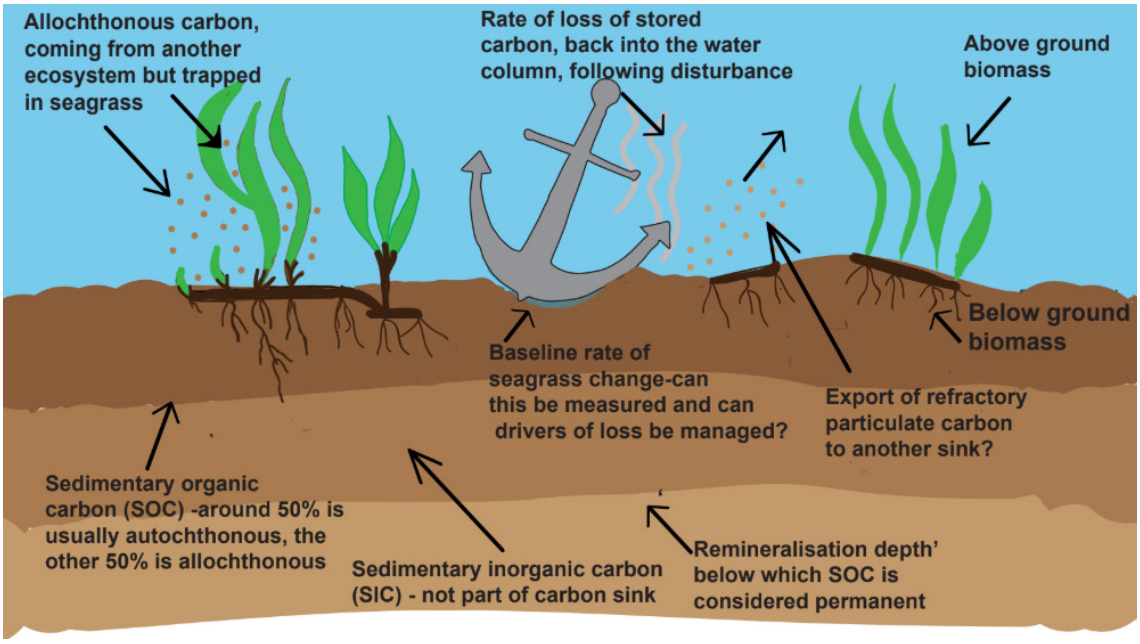

Figure 8. Illustration of the processes of carbon sequestration and storage in a seagrass meadow.
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high, reaching a peak of EUR 29.03 on the EU Emissions Trading Scheme on 22nd July 2019, up from a low of EUR 2.97 on April 22nd 2013. The market remains vulnerable to fluctuation, driven by changing perspectives on the value of carbon offsetting by the public and industry as well as the role of the carbon market within and alongside international agreements, most notably the Paris Agreement.

Given the technical, policy and operational challenges in implementing a seagrass PES program, it is anticipated that, at least initially, such a project would need to be operating at a relatively small scale and selling to the voluntary, rather than the compliance markets. With less regulation than the compliance market, the voluntary market allows smaller, disaggregated projects which may not be feasible under compliance schemes (Kollmuss et al, 2008). This means, however, that voluntary carbon programs rely heavily on the willingness of buyers to pay and this is influenced by individual ethical attitudes, calculations of corporate advantage for branding and the broader political context in which carbon offsetting operates. The question of 'additionality' is most commonly raised in relation to such projects: whether, in the absence of funding from carbon offsets, the project would have been implemented anyway; if so, the project in effect has no net climate benefit. Critics (most notably through popular media, for example Monbiot, 2006) have also called into question whether carbon offsetting projects lead to benefits for local communities. These criticisms are justified in some cases; good and bad examples of carbon offsetting programs exist (just as there are good and bad products in most markets). Each criticism, however, can be addressed by individual projects to ensure that they are ethically robust and defensible. Given that currently seagrass policy is weak to non-existent in national carbon mitigation strategies, especially for developing countries, there is a low risk of individual seagrass carbon projects raising additionality concerns at a national scale, however this could be reviewed as national-level seagrass conservation strategies improve. A systemic concern, about the idea of offsetting rather than the operation of any particular project, is that offsetting simply delays serious action on climate change by allowing unsustainable lifestyles to perpetuate while shifting the burden of responsibility to developing nations, where most offsetting programs are implemented. Because of this, it is incumbent on projects to work with buyers as part of a broader strategy of carbon reduction; offsetting is one small part of the response necessary to the climate change crisis. For example, the mangrove conservation project Mikoko Pamoja is committed to communicating 'the three Ps' to buyers and stakeholders; action on climate change requires, in order of priority:

1) Political change towards a zero-carbon economy.

2) Personal action to reduce carbon footprints.

3) Paying for carbon offsets to responsible projects.

5.3 Tenureship of intertidal regions

Successful implementation of community-led management interventions is underpinned by government-recognised land ownership or tenureship of the managed area. While provisions for this exist largely in terrestrial ecosystems, intertidal tenureship agreements in developing countries are in many cases unclear due to their positioning between land and sea. Further ambiguity can arise, particularly in vegetated ecosystems such as seagrass, mangroves and saltmarsh, as the boundaries between these ecosystems, and with terrestrial ecosystems, are not always clear (Rog and Cook, 2017). For example, Costanza *et al.* (2014) classify mangrove forests alongside tidal wetlands, although de Groot *et al.* (2012) divide mangrove forests into tropical forests, coastal systems and coastal wetlands (Mukherhjee, 2014). There is also disparity between nations as to whether mangroves are classified as forest or not, which has been a key reason for the delay in their inclusion in climate policies such as offsetting programmes. The legislating framework of tenureship of the intertidal zone would need to be examined on a region-by-region basis to determine the feasibility of community-based management of seagrass ecosystems.

5.4 Carbon trading challenges

A carbon trading project is, ideally and in most cases, conducted to one of several international standards and is accredited by a third-party organisation. This ensures robust methodologies and carbon calculations and, in most cases, that the project results in socio-economic benefits for participants. Certain voluntary standards, such as the Plan Vivo Standard and the Verified Carbon Standard (VCS), are tailored towards projects that will engage and empower local communities. These allow projects that would be otherwise unfeasible under more technically onerous compliance standards to be implemented. Despite this allowance, all standards require considerable scientific and technical abilities that community groups, if they do not contain scientifically trained members, would need to source elsewhere.

Additional skills are required in marketing and trading of carbon credits, requiring the seller to have a sound understanding of the carbon market and how it can be accessed. Issues discussed above regarding ethical challenges of carbon offsetting must be well-understood in order to generate and market ethical credits that are robust against such criticisms. With buyers of credits being located internationally, and predominantly in developed countries, whilst most projects operate in developing countries, community groups must have the technical, language and social capacity to interact across national boundaries with this market.

5.5 Economic challenges

A seagrass-based PES project is likely to involve considerable establishment and operational costs. These need to be examined in comparison to income that would be expected. It is likely, in the absence of considerable existing funds, that capital will be needed, in addition to PES payments, to ensure that the project is financially viable. The start-up costs of such a project should not be underestimated (see Table 1). These may be secured through grant funding or philanthropic donations, which in themselves require existing skills and capacity to secure and administer. While this financial challenge is true of any PES project, the high input costs of surveying and monitoring in an intertidal and marine habitat, as well as the lower density of carbon in seagrass meadows in comparison to other blue carbon ecosystems, further increase the challenge of running a financially viable seagrass PES project.

An illustrative estimation of costs and income associated with a seagrass-based PES project that markets additional carbon sequestration is outlined in Table 1 below. These will vary by project and with the carbon market, so Table 1 should be read as indicative only; its purpose is to highlight some of the relevant calculations that project designers may need to make. Costs have been estimated on a 5-year timescale, assuming this aligns with processes for independent validation and verification. Assessment has been conducted for an arbitrary 50-hectare site, assuming 1.38 tC/ha year^{1} burial based on the synthesis by McLeod *et al.* (2011); this will vary by species and location. The value of credits sold is estimated under scenario 1 (conservatively using a value of US$7/tonne) and under scenario 2 (using an optimistic value of US13/tonne), and assuming that all credits are sold each year. The calculations assume costs are incurred in a low-middle income country (LMIC), where the majority of PES projects are conducted; costs will be considerably higher in a high-income country.

Table 1. An illustration of the estimated costs and income of a seagrass carbon PES project, assuming a 50 hectare site. Avoided carbon losses assume 1.38t ha^{-1} year^{-1} additional sequestration and avoided emissions of 3.16 t ha^{-1} yr^{-1}, extrapolated over 20 years in total assuming 1.68% losses yr^{-1} under business as usual scenario (data on emissions and losses taken from Githaiga *et al.* (2019); figures will vary depending on project design)

								Scenario 1 (US$7/tonne income)		Scenario 2 (US$13/tonne income)		
		Staff, contractor and labour costs (salary) (US$)	Equipment (US$)	Marketing and communications (US$)	Independent validation assessment (US$)	Independent verification assessment (US$)	Total cost (US$)	Total income from carbon credits (US$)	Surplus/shortfall (US$)	Total income from carbon credits (US$)	Surplus/shortfall (US$)	Avoided C loss (t)
50 hectare (small) site scenario	Year 0 (project planning, start up costs)	20,000	3,000	3,000	5,000	0	31,000.00	0	-31,000	0	-31,000	0
	Year 1 (project initiated)	15,000	1,000	1,000	0.00	0	17,000	668.5	-16,332	1241.5	-15,759	95.5
	Year 2	15,000	1,000	1,000	0.00	0	17,000	668.5	-16,332	1241.5	-15,759	95.5
	Year 3	15,000	1,000	1,000	0.00	0	17,000	668.5	-16,332	1241.5	-15,759	95.5
	Year 4	15,000	1,000	1,000	0.00	0	17,000	668.5	-16,332	1241.5	-15,759	95.5
	Year 5	15,000	1,000	1,000	0.00	5,000	22,000	668.5	-21,332	1241.5	-20,759	95.5
	TOTAL						121,000	2,415	-118,585	4,485	-85,546	121,000

It is evident that under either income scenario, ensuring financial viability of a seagrass-based carbon PES project is likely to be challenging. If the area was scaled up to 1000 ha (a 20-fold income) then, assuming costs only increase marginally and not proportionally, the project may bring profit provided the higher carbon price could be commanded and that start-up and verification costs were met separately. Profit margins can be improved by securing in-kind support through partnerships and voluntary support, and seagrass may be embedded in existing blue carbon projects thereby lowering staff and equipment costs. Additional support in the form of grants, philanthropy, commercial funding or other forms of income is likely to be required under both conservative and optimistic income scenarios. The scenario in Table 1 addresses additional sequestration in an existing seagrass meadow along with avoided emissions. Where project operations include seagrass restoration then projected income will be higher (although so usually will be costs).

5.6 Social challenges

In contrast to their terrestrial counterparts, marine ecosystems and resources are considered by most governments to be common-pool and therefore open to all users, often with few restrictions (Dhanjal-Adams *et al.*, 2016). This has led in many cases to a 'tragedy of the commons' scenario, resulting in resource over-exploitation. 'Top down' governance structures, where management strategies are designed and implemented at a state level, are often ineffective, particularly in resource-poor countries that lack enforcement capacity. The separation between the regulators and the users of a system often fosters mistrust and a lack of buy-in from resource users, and results in a lack of adherence to rules. This has led to a growing interest in 'bottom-up' resource management, with community groups having greater involvement, self-regulating the management of the resource. The increased interest in bottom-up management has been driven by the failings of top-down approaches, but challenges including bottom-up management systems becoming time and resource-intensive must be addressed (Fraser et al, 2006).

In order to be successful and sustainable, community-based management requires social challenges to be addressed, particularly so when a common-pool resource such as many marine habitats and species are the focus of the management. Feeny et al (1990) identify two common characteristics of common-pool resource regimes: that exclusion of non-participating actors is difficult ('the exclusion problem') and that all participants can subtract from the welfare of other participants ('the subtraction problem'). The exclusion problem can in theory be addressed by state-recognised community governance structures, clear demarcation of the resource and effective communication within and between communities, although trends including growing populations and migration pose an additional challenge here in increasing pressure on the resource. If users of a resource are guaranteed that they alone have access to future harvests of that resource, they have an economic incentive to self-regulate and conserve the resource (Berkes, 2006). The subtraction problem can be addressed by ensuring clear and equitable rules of self-governance, effective monitoring and appropriate and enforced sanctions.

6. Strengths and opportunities of community PES-based seagrass conservation

6.1 Global political movement towards community-based management

Despite the challenges of implementing a seagrass-based PES project described above, there remain many opportunities and strengths. These are primarily social and environmental in nature and demonstrate how conservation can work for both people and the natural environment. In other ecosystems, it has been demonstrated that integrating stakeholder opinions increases the effectiveness of management strategies by ensuring that they are appropriate to the local society and natural environment (e.g. Wondolleck and Yaffee, 2000) and incorporating more comprehensive information (Reed, 2008). In seagrass meadows, stakeholder perceptions can be helpful in understanding how governance can be achieved (Ruiz-Frau et al 2019).

There is a global movement towards 'bottom up' community-based management (CBM). Governance structures are often categorised as 'top-down' (traditional, hierarchical governance led by state-level actors) and 'bottom-up' (community-led 'grassroots' governance), as well as finance-driven mechanisms of management. In practice, hybrids of these governance structures exist as multilevel governance (MLG) structures, most commonly (but not restricted to) co-management regimes between community groups and governmental organisations. PES can be incorporated as a financial driver of community-based management by providing direct financial incentives to conserve ecosystems. Here we include these MLG structures if community groups are deemed to have a genuine influence on the planning and implementation of management strategies, and benefits sharing structures reward the communities involved in the management.

Multilevel governance (MLG) structures allow community-based conservation projects to engage state and non-state participants, strengthening the management of ecosystems and resources by engaging skills, expertise and resources that may not exist within the community group alone. MLG also facilitates the dissemination and extension of the management strategies from local and regional to national and international levels (Sattler et al, 2016) and allows the alignment of management with national and international policies and conventions. This cooperation between community groups, governmental and non-governmental participants, when there is effective and meaningful input by all partners, can assist in overcoming the previously discussed challenges. Engagement with governmental organisations may provide formalised tenureship agreements and enforcement capacity, while both governmental and non-governmental organisations can provide support for economic, scientific and technical challenges.

Crucially, CBM aims to balance the needs of ecosystems with those of communities who often rely on them for sustenance and income. This may mean compromising between the ideals of traditional management, aiming for greatest environmental protection, and the cultural and economic requirements of the community. Stakeholder-driven or informed indicators for monitoring of management strategies help to ensure that the drivers of conservation are locally appropriate and that communities as stakeholders benefit from resource management practices.

Communities are empowered to take ownership of natural resources in a way that top-down management does not typically facilitate. Community involvement in projects adds value in more comprehensive information inputs, including those of indigenous knowledge, and fosters an understanding of the aims and the philosophy of the project (Dyer et al, 2014). It facilitates social learning among and beyond project participants, allowing opportunities for wider community education regarding environmental conservation.

6.2 Fishing communities as owners and beneficiaries of community-based management

The primary community beneficiaries of a seagrass conservation project are likely to be fishers who will benefit from enhanced fish stocks (Unsworth et al, 2019). Fishing activities are also most likely to be directly impacted by management measures, particularly in less-developed regions where nearshore fishing is prevalent. Where fishing activities overlap with seagrass meadows, the fishing community will likely play a prominent role in the management strategy.

Direct and meaningful involvement of stakeholders in the planning and implementation of management strategies helps to ensure their success and sustainability by minimising conflict between management measures and the needs of those who secure an income and/or food security through use of the natural resource. A sense of ownership of a project encourages buy-in from stakeholders, improving the likelihood that management measures will be adhered to. A seagrass conservation project led by the fishing community would therefore benefit from an enhanced likelihood of success and provide fishers with the direct benefit of stock enhancement.

The general principles of community-based fisheries management are illustrated by numerous examples, which have demonstrated that direct involvement of fishing communities in the planning and monitoring of management interventions has resulted in greater cooperation and an increase in fish stocks (e.g. Cudney-Bueno and Basurto, 2009; Lobe and Berkes, 2004), particularly in the Pacific Islands (e.g. Johannes, 2002). No published examples to date have illustrated seagrass-based fisheries management. Socio-economic factors including subjective norms (the belief that a behaviour will be accepted by a particular, important person or group), disposition to cooperative behaviour and nested institutions influence the participation of community members (Gurney et al, 2016) and so management strategies must be locally appropriate to minimise conflicts or disruption arising from these principles.

6.3 Contributions to national and international policy commitments

Conserving and restoring carbon-rich ecosystems, including seagrass meadows, is an essential part of achieving the goals of the Paris Agreement. To date, there has been very limited incorporation of Blue Carbon ecosystems, particularly seagrass meadows, into Nationally Determined Contributions (NDCs – the commitments that nations must make towards the Paris goals), despite their potential to contribute to both mitigation and adaptation strategies (although see Martin *et al.* (2016) for existing examples). This is in part due to initial lack of guidance on accounting methodologies for carbon in seagrass meadows in particular, and wetlands and coastal habitats in general. The Intergovernmental Panel on Climate Change (IPCC) issued the Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for Wetlands (Wetlands Supplement) in 2013 to provide guidance on accounting methodologies. Additional guidance has been produced, including the Guiding principles for delivering coastal wetland projects (UNEP and CIFOR, 2014). Both examples give only limited guidance for seagrass meadows. Further challenges are faced in the administrative burden of meeting the standards of mechanisms such as the Clean Development Mechanism (CDM), for which small Blue Carbon projects would not, in most cases, qualify. For this reason, Blue Carbon projects are generally more compatible with voluntary markets, using methodologies such as the VCS or Plan Vivo (Ruiz-Frau et al 2017), but at present it is uncertain if and how small projects operating under these standards may complement national and international approaches, for example in the planning and monitoring of Nationally Determined Contributions (NDCs). Development of Article 6 (cooperation and market mechanisms) of the Paris Agreement may contribute to the accessibility of mechanisms such as CDM to smaller Blue Carbon projects through the provision of mechanisms for international cooperation and cost-effective and globally recognised centralised crediting, providing opportunities for countries that have lacked the capacity to develop their own crediting systems.

6.4 Ecosystem services and benefits delivered to coastal communities

While PES projects may focus on only one or a limited number of ecosystem services, the broader benefits of seagrass conservation to coastal communities will be more diverse. These services include: food provision (by acting as a nursery habitat and supporting invertebrate and small vertebrate species harvested by gleaning); coastal protection; tourism; cultural value, water purification; educational and research opportunities; and raw materials (e.g. as fertiliser). These services are of particular importance to resource-poor communities who may be dependent on them for sustenance or income, for example on fisheries for food security or on tourism for income. Whilst it is often difficult to translate these services into economic terms, their collective value to coastal communities should not be underestimated when evaluating seagrass-based PES projects. Project developers may be able to include them as 'carbon plus' benefits that increase the attraction of a project to donors and buyers, even if they are not costed using formal economic analyses.

7. Case studies for potential PES-based seagrass conservation.

7.1 Community-based monitoring of seagrasses in Ataúro Island, Timor-Leste (facilitated by Blue Ventures)

A seagrass monitoring programme on Ataúro Island in Timor-Leste, managed by international NGO Blue Ventures, involves the local community in mapping and monitoring of the seagrass meadows. The aims of this project are:

(i) to collect seagrass data in a data-poor region and

(ii) strengthen community ownership of marine resources and foster conservation principles among the community.

Background

Seagrass, and associated dugongs, are a key component of marine-based tourism in Timor-Leste and many local people rely on fish and shellfish (Mills *et al.*, 2017) associated with the seagrass as a source of nutrition. Women and children primarily engage in gleaning fisheries (gathering seafood in shallow coastal waters) and men utilise deeper-water fisheries as well as fishing in the seagrass meadows themselves. Adolescent malnutrition is high in Timor-Leste and so seagrass meadows are recognised as an important source of food, although conservation principles are not widely understood. Despite locally-conducted studies having been completed at Ataúro Island, little scientific literature from the region has been published and so relevant data are scarce.

Project summary

There are 13 Locally Managed Marine Areas (LMMAs) around Ataúro Island. The current seagrass monitoring takes place in a buffer zone of the Haru Ina LMMA, although it is hoped that the project will be extended into additional sites in an LMMA (Akrema), a high-impact area (Biqueli) and within an area of seaweed farming (Beloi).

Blue Ventures engage community members from Beloi and Biqueli in mapping and monitoring of the seagrass meadows, providing training on survey methods and data recording. Extensive training is provided to ensure that participants have the skills to conduct surveys and perform necessary mathematical processes to record data. Seagrass surveys are conducted according to the standardised protocol from Seagrass-Watch, ensuring that data are scientifically robust. Data are shared with the government with the objective of improving local and national-level seagrass conservation policy.

Micro-loans were also provided to 8 households in Beloi to establish homestays for tourists, strengthening the local marine tourism industry and demonstrating the value of seagrass meadows to tourism. There is overlap between the recipients of these microloans and participants in the seagrass monitoring. This scheme helped to build a trusting relationship between Blue Ventures and the community.

Motivation to take part

Motivation to take part has been reported by participants to include the opportunity to learn new skills and take part in a novel activity, beyond household and sustenance activities that much of their time is otherwise devoted to. The opportunity to socialise, both with Timorese and non-Timorese people (primarily Blue Ventures volunteers), is also a strong driver of participation.

Although the participants were initially 50% male and 50% female, many of the men dropped out due to prioritising income-generating activities. In Timorese society, women typically have access to fewer opportunities than men and so this project presents an opportunity for women to engage in a novel activity. Additional training in necessary skills, such as swimming, ensures that women are able to participate.

Participants in the programme report an increased understanding of seagrass value and recognition of the importance of locally-driven natural resource management. Several participants have advocated for conservation of seagrass to the wider community, communicating the value of the ecosystem and the importance of its protection.

Challenges
The project has encountered technical, logistical, social and cultural challenges associated with community-based monitoring. Limited literacy and numeracy among participants has led to extensive training being conducted to ensure that participants meet the required standard. Many of the participants are not confident swimmers, limiting the tidal period during which surveys can be conducted; original plans involved swimmers conducting surveys, but this has been adapted to involve only surveys conducted in up to chest-deep water. Menstruating women prefer to take on roles that do not require them to enter the water, and so surveys have been adapted to include these individuals as shore-based data recorders.

Project sustainability
Blue Ventures operate the project, supporting with logistics and other technical capacity, on behalf of, and in conjunction with, members of the local community. Blue Ventures intend to continue operating the project as project managers. The standardised Seagrass-Watch protocol ensures that the project will continue to collect robust and consistent data under changing management.

7.2 Marine Conservation Agreements in Fiji

In Fiji, coastal tourism operators participate in a program to protect marine ecosystems. This is not conducted under a formal PES structure but meets many of the criteria of a PES program outlined by Wunder (2005). The focus of the program is on coral reefs, but the area encompassed within the program does include seagrass meadows.

Background
Fijian culture has a strong cultural connection to the marine environment, and this is reflected in the social and customary tenure system under which traditional leaders and communities, alongside the tourism sector, can manage the environment under Marine Conservation Agreements (MCAs). Marine tourism makes a significant contribution to Fiji's economy.

Summary
Tourism operators, communities and an NGO participate in MCAs, all involving forms of Marine Protected Areas (MPAs). Under the MCAs, economic incentives provided by tourism operators are made in exchange for natural resource users to take certain actions, refrain from certain actions, or transfer certain rights or responsibilities, with the aim of achieving marine conservation goals. These economic incentives are not limited to direct financial payments and include community income-generating opportunities, funds for community development projects, and in-kind benefits and ecosystem improvements. These activities directly involve communities, including in restoration and monitoring activities.

Sustainability
The long-term involvement of the Wildlife Conservation Society (WCS) and Seacology has provided the technical expertise and assistance in fundraising that facilitated the establishment and ongoing maintenance of MCAs, including monitoring,

MCAs contribute to Fiji's national marine conservation goals and contribute to the conservation of vulnerable megafauna and sensitive ecosystems, and it has been recommended by Sykes, Mangubhai and Manley (2018) that the MPAs established under the MCAs are included in Fiji's national and international reporting on conservation targets.

7.3 Incorporating seagrass into a mangrove PES project in Gazi Bay, Kenya

Mikoko Pamoja is a community-based mangrove conservation project funded by the sale of carbon credits (Wylie et al 2016). It has been running since 2013 and protects and restores a total of 117ha of mangrove forest in Gazi Bay on the southern coast of Kenya. It is certified under the Plan Vivo Standard, under a co-management agreement between the Mikoko Pamoja Community Organisation and the Kenya Forest Service, a government agency.

In 2019, a stakeholder consultation was launched to explore the potential to incorporate the conservation of areas of the bay's seagrass meadows. The management measures will be designed in collaboration with the fishing community as the primary user group of the seagrass meadows, which are at risk of damage by fishing activities including seine netting and anchoring. Economic incentives to participate in the project will be delivered through a PES-based program facilitated by the Mikoko Pamoja Community Organisation in the form of financial support for community development activities.

Options for incorporating seagrass conservation into the existing PES project are being explored, although it is anticipated that its inclusion will not involve formal, accredited accounting of carbon for the sale of offsets. There are several reasons for this at present: first, the high expense of implementing and monitoring the seagrass meadows to the standard required by Plan Vivo (or any offsetting certification) would outweigh the financial benefits of the project; seagrass contains considerably less carbon per hectare than mangroves (around 80% less) and requires more expensive and technically challenging monitoring techniques including the use of furnaces to measure soil carbon. Secondly, there remains debate in the scientific literature about several assumptions that a seagrass carbon offsetting project would need to make (see the challenges discussed in section 5.4) on which the project coordinators believe clarity is needed to ensure a scientifically robust project.

The project coordinators, therefore, anticipate adding seagrass conservation as an added benefit to the formal mangrove carbon offsetting project. This would mean that a simplified monitoring protocol, such as Seagrass Watch, would be used to gather information on percentage cover of seagrass and algae and species composition by the community organisation, to gather scientifically robust data using a methodology that is accessible to and understood by community members. Buyers of mangrove carbon credits would be given the option to make an additional donation to conserve seagrass, and the additional funds generated by this would be allocated to community development projects designed to primarily benefit the fishing community.

The project coordinators anticipate that carbon sequestration would not be the primary ecosystem service upon which the project would be based. The contribution of the seagrass meadows to fisheries enhancement would be highlighted as the primary ecosystem service to be enhanced as the service most practically relevant to the fishing community as primary stakeholders, and carbon sequestration and coastal protection are likely to be included as secondary ecosystem services.

8. Recommendations for PES-based community seagrass conservation

8.1 Policy

(a) **Seagrass Blue Carbon in NDCs:** National governments should include seagrass meadows, as a Blue Carbon ecosystem, under mitigation and adaptation strategies in their Nationally Determined Contributions (NDCs) in contribution to their commitments under the Paris Agreement. Nature-based solutions are increasingly recognised as vital to reaching the targets, and seagrass meadows, which capture and sequester carbon over centuries to millennia, present an opportunity to contribute significantly to nature-based carbon sequestration. The Blue Carbon inclusions in NDCs (including a limited number of nations which explicitly include seagrass in their NDCs), published by Martin *et al.* (2016), give early examples of how the inclusion of seagrass, and other Blue Carbon ecosystems, in NDCs can be achieved.

(b) **Seagrass in PES programs under an 'added benefits' approach:** Although seagrass ecosystems have been demonstrated to deliver numerous and diverse ecosystem services to coastal communities, challenges remain in implementing seagrass-based PES projects due to scientific, technical and financial barriers. These barriers may prevent the uptake of seagrass PES projects under current standards, despite the benefits that they have the potential to deliver. Carbon standards should include provisions to allow for seagrass meadows to be included in PES projects in conjunction with adjacent marine ecosystems (such as mangroves), allowing for seagrass conservation to be facilitated under a multi-ecosystem approach while alleviating the challenges of a project relying solely on seagrass-based PES. If carbon sequestration was included in the ecosystem service, a key barrier will be if allochthonous carbon must be eliminated from inclusion as being non-additional. If there is no relevant published data such an onerous demand is likely to make seagrass carbon PES infeasible. It is recommended that seagrass management be considered by carbon standards as an added benefit to formal PES-based ecosystem protection and restoration.

(c) **Consideration of multiple ecosystem services:** PES programs are most commonly based on carbon sequestration as a relatively quantifiable process and one that aligns with the current policy environment. However, this approach may underestimate or disregard broader, less easily quantifiable, services and benefits delivered to coastal communities. Under PES and other outcome-based conservation strategies, a holistic approach to ecosystem service evaluation should be taken and strategies should not only consider carbon sequestration but wider ecosystem services and benefits that are of value and importance to adjacent communities.

(d) **Calcium carbonate and its implication for carbon stock assessment:** As well as trapping and sequestering organic carbon, seagrass meadows are sites for deposition of inorganic carbon (mostly in the form of calcium carbonate). Understanding the impacts of this inorganic carbon (C_{inorg}) on total carbon storage is complicated and subject to scientific controversy. Although some research suggests accounting for calcification may imply significant reductions in seagrass sequestration capacity, recent research by Saderne *et al.* (2019) demonstrated that seagrass meadows that have previously been classified as carbon sources due to the burial of calcium carbonates were in fact carbon sinks when allochthonous C_{inorg} and the balance between calcification and dissolution in the meadows was accounted for. We recommended that C_{inorg} should not be deducted from total carbon in seagrass meadows unless a full assessment, as conducted by Saderne et al, has demonstrated the impacts of C_{inorg}. Given the considerable scientific challenges of assessing allochthonous and autochthonous

C_{inorg}, particularly for community groups, and the contribution of C_{inorg} to both sediment accretion (and therefore coastal protection) and gleaning fisheries (as some of the C_{inorg} is in the form of edible shellfish) it is recommended that the default position of carbon standards is to assume no net effect of inorganic carbon on total sequestration potential.

8.2 Scientific

(e) **Carbon source and additionality:** The challenges of measuring and separating allochthonous and autochthonous carbon, and the implications of this within carbon standards, presents a barrier to establishing seagrass-based PES projects. Establishing the allochthonous to autochthonous carbon ratio for any given project is time consuming, resource-expensive and requires specialist skills and equipment unlikely to be available to community groups. In the absence of empirical data on this ratio, it would disadvantage projects to deduct an estimated allochthonous carbon value from the total carbon valuations, when this deduction is not required for other marine or terrestrial ecosystems under current carbon standards. If this deduction is to be made, it should be based on more geographically diverse data, which does not yet exist in the literature. However, given that this requirement is not imposed on, for example, mangrove carbon projects, consideration should be given as to whether or not this deduction is appropriate and necessary.

(f) **Carbon dynamics in disturbance and destruction scenarios:** Similarly to (a) above, the fate of carbon in the event of disturbance and destruction (i.e. whether it remains in the sediment, is re-mineralised into the atmosphere or is transported by currents and stored elsewhere in the marine environment) requires scientific clarification. Determining whether carbon remains in the sediment following disturbance or destruction can and has been demonstrated empirically by analysis of sediment cores and disturbance experiments. However, tracking this carbon once it has left the ecosystem is very challenging. Whilst modelling of carbon dynamics in disturbance scenarios may improve the understanding of the net carbon benefit of seagrass conservation over time we are at an early stage of scientific understanding of these issues. Requiring projects to demonstrate that carbon lost from seagrass sediments following disturbance is all oxidised, rather than transported and re-buried, would prevent avoided disturbance/destruction based carbon PES in seagrasses for the immediate future.

8.3 Financial

(g) **Start-up costs of a community seagrass conservation project:** As demonstrated in section 5.5, a considerable proportion of the finances required to run a community seagrass conservation project occur during the process of planning and initiating the project; a bottleneck that is likely to prevent many projects from being established. Under current funding frameworks this money is most likely to be sourced through grant funding, requiring time and skills input from the community and potential overlap between projects where resources could be pooled and strategies aligned. Following on from the recommendations on Blue Carbon in NDCs in 8.1 (a), a nationally-funded accelerator program and fund for seagrass meadows and other Blue Carbon ecosystems would not only make projects more financially viable, but also improve skills and experience sharing thereby improving the efficiency, across and between countries, of Blue Carbon projects.

(h) **Ongoing financing of community seagrass conservation projects:** Section 5.5 has outlined the likely lack of financial viability of a community seagrass conservation project to be funded by PES. This challenge may also extend beyond PES projects due to high time and resource requirements of monitoring an intertidal ecosystem, regardless of formal reporting to and auditing by carbon standards. Investment in community-based monitoring such as that by Blue Ventures in Timor Leste, may reduce costs and increase community engagement and support, although the project will be reliant on ongoing largely voluntary commitments. While advances are being made in mapping seagrass using satellite monitoring, improvements in the ability to extrapolate this to carbon stocks, few applications of which currently exist, would assist large-scale carbon stock assessment and mitigate the requirement for extensive empirical data gathering. Within PES projects, allowances for seagrass meadows as an added benefit, as recommended in 8.1 (b) above, would mitigate stringent monitoring and auditing requirements and their associated costs.

9. Conclusion

The conservation of seagrass ecosystems is vital to maintain the delivery of ecosystem services that they provide to coastal communities. Seagrass meadows face multiple anthropogenic pressures including pollution and sedimentation, physical damage and direct removal and climate change yet have been the focus of comparatively few conservation efforts. As a result, seagrass ecosystems are declining globally. Community-based conservation of seagrass meadows presents an opportunity for environmental conservation, community empowerment and to assist countries in achieving their commitments under international agreements. PES-based tools (most notably carbon-based PES) for community seagrass conservation may provide means to facilitate projects under a structured, transparent and accountable mechanism. However, challenges (most notably financial, scientific and technical) facing community-based conservation are currently preventing the development of such projects. Here, it is recommended that carbon standards (and associated PES mechanisms) also initially allow for the inclusion of seagrass under an 'added benefits' approach with adjacent ecosystems such as mangroves, under which the protection and restoration of seagrass meadows could be facilitated under the PES structure (and with the associated quality assurances) for mangroves but minimising the financial, scientific and technical burden of a seagrass-only project. The scientists who study seagrass ecosystems and the locals who rely on them agreed about their importance; our challenge is to find ways of supporting and financing seagrass conservation for the benefit of people and nature.

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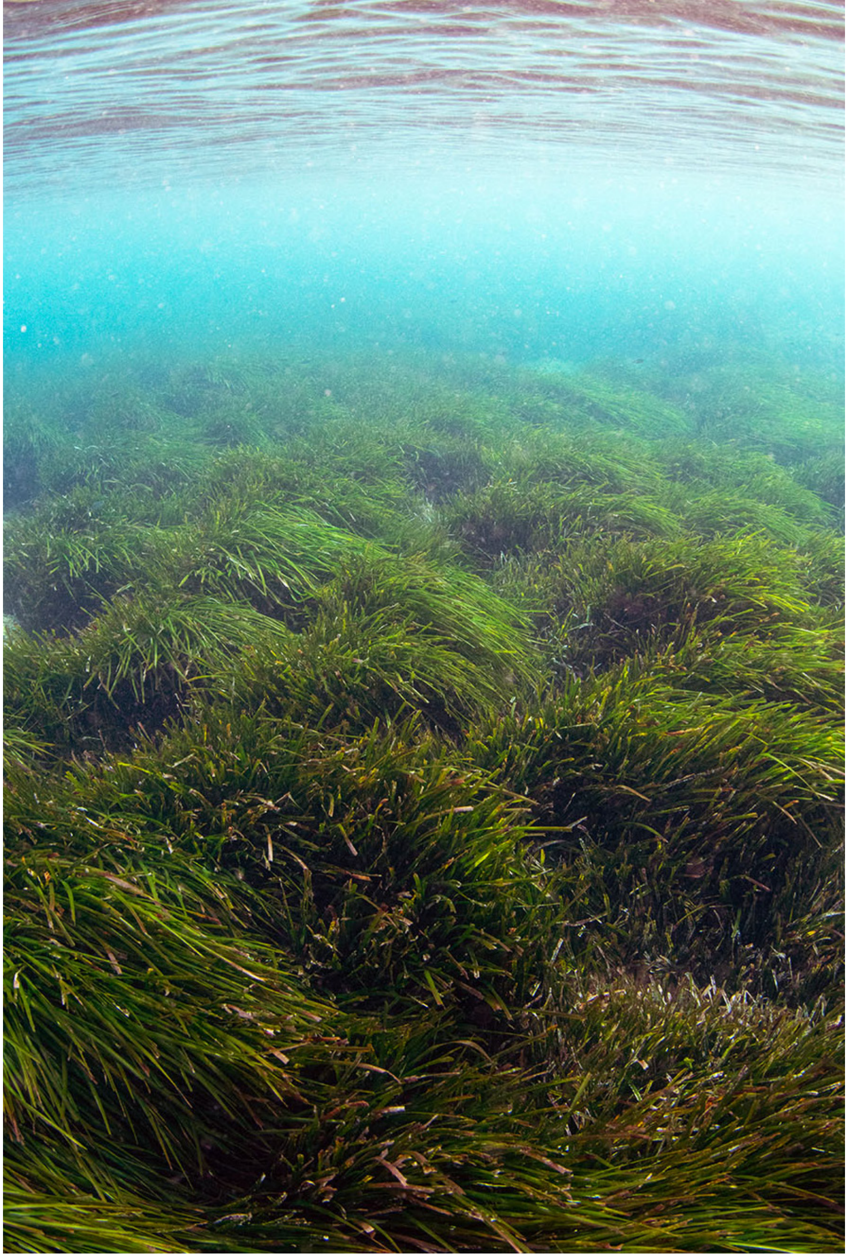

Support for communities interested in seagrass conservation

The UK-based NGO ACES (The Association for Coastal Ecosystem Services), who support community-based coastal conservation, welcome interest from community groups interested in conserving seagrass meadows.

If you would like more information or to discuss this, please see the ACES contact details below along with those of our partners.

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