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Mapping global threats to seagrass meadows reveals opportunities for conservation

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Abstract

Numerous global maps chart humanities impact on multiple levels of biodiversity, revealing a multitude of pressures across a variety of ecological systems. While useful for identifying the global scale policy changes needed to conserve the world's biodiversity, they often lack resolution at the scale needed for local management and conservation. While we can broadly speculate the key large-scale drivers that have influenced seagrass populations over the last century, no global map exists that reveals the range and scale of human pressures on seagrass meadows. Using a citizen science database (https://seagrassspotter.org) that comprises of more than 8000 georeferenced points, we use a subset of these map the prevalence of multiple, locally observed anthropogenic threats to seagrass meadows. We find that 50% of human-impacted sites were within areas with designated protection, reflecting 4.4% of the world's marine protected areas and other effective area-based conservation measures where anthropogenic activities place seagrass at risk. Using vulnerability scores for each human impact, we identify high-risk sites in Columbia, Fiji, Indonesia, Mexico, Mozambique, the Philippines, Sri Lanka, and Tanzania, where multiple pressures likely place seagrass meadows on a trajectory of decline. In doing so, we build on a growing body of research highlighting the vulnerability of coastal ecosystems to human impacts, and at the same time, highlight the role of citizen science in identifying and mapping these threats at the resolution needed for management.

1. Introduction

Numerous global maps of human pressures to the world's biodiversity exist [1–7], revealing hotspots where anthropogenic activities threaten biodiversity, and the ecosystem services it provides [8]. Such maps identify the large- and broad-scale policy changes needed to conserve biodiversity for both land and sea, but also reveal the challenges associated with mapping spatio-temporal changes in human pressures [7]. For effective local-scale management that harmonizes conservation with sustainable development, we also need to develop a better understanding of human pressures at finer resolutions to those used for large-scale mapping of anthropogenic pressures [9]. While this is true for all the world's ecosystems, coastal ecosystems are vulnerable to impacts from both land and sea [10, 11]. These impacts range in size and frequency from persistent large-scale, watershed-driven impacts to small-scale pulse events that interact in antagonistic, additive or synergistic ways. Datasets for these impacts are either fragmented or lacking at the global scale.

Identifying and recording these pressures require different strategies. The synergies of citizen science and local knowledge have benefitted our understanding of environmental change and human pressures in coastal ecosystems [12–17]. Such information and data provides much needed evidence at local or regional scales to fill knowledge gaps, but also improves our understanding of how humans interact with, and perceive nature [18]. The use of such strategies provides a different means of obtaining data on human impacts that cannot be readily observed through traditional ecological observations. Citizen science and local knowledge may often extract data that spans much larger time scales to pick up on locally specific events [19, 20], while also contributing 'relatively' real-time current data.

Seagrass meadows are a prominent feature across the world's coastlines [21]. Yet, since 1880, an estimated 19.1% of surveyed global seagrass extent has been lost across the six global seagrass bioregions [22, 23]; distinct global regions facing variable rates of decline possibly due to different threats. Globally, loss is most commonly attributed to large-scale threats like coastal development and poor water quality [23, 24], but also fishing [25], reflecting the vulnerability of seagrass to pressures from both land and sea. Other global analyses model the cumulative human pressures that place seagrass at risk [26], focusing on broad-scale variables for which datasets exists. However, where local experts have been consulted, these have identified numerous small-scale, but frequent impacts from boating, bait digging, seaweed farming and small-scale fishing activities [24, 27, 28]—variables for which global datasets do not exist, and citizen science could help to fill gaps [29, 30].

Despite multiple calls and new legal requirements to map and protect seagrass [31, 32], only a quarter of recorded seagrass meadows fall within marine protected areas (MPAs) [33]. This protection is often by chance [30], and where protection is designated for seagrass, protection is insufficient at addressing cumulative impacts [34]. However, MPAs and other effective area-based conservation measures (OECMs) can be a successful tool to help mitigate against local losses and manage coastal resources. Where conservation and management strategies have specifically focused on local (or regional scale impacts like poor water quality), reversal of declining trends for seagrass meadows have been observed [35, 36].

Understanding, and identifying local-scale human impacts to seagrass globally is a challenge [30]. The scale of this challenge becomes even greater given the unprecedented scale of global seagrass loss [23], and the risk of future loss from large-scale threats [26]. We have argued that citizen, or community, science is vital in confronting this challenge [29], yet to date, progress has been slow to embrace and incorporate such data across spheres of research, conservation or management. Here, using a large database of citizen science observations, we create a novel global map revealing the range and scale of human pressures on seagrass meadows. Using this database we (1) explore the variability in local threats to seagrass meadows across the world's seagrass bioregions [22], (2) understand their prevalence across MPAs and OECMs, and (3) identify areas of high vulnerability to anthropogenic threats.

2. Methods

2.1. Citizen science dataset

We used data gathered through the global citizen science programme SeagrassSpotter (https://seagrassspotter.org). SeagrassSpotter is a website platform and phone application that allows users (hereafter observers) to upload georeferenced photos (hereafter uploads) of seagrasses to species-level across a variety of spatial scales. The programme couples uploads with optional information on seagrass morphology, associated biodiversity, threats and recreational uses [29]; users are prompted to choose from dropdown categories for information on seagrass morphology, but other questions such as threat information require users to enter descriptive text. SeagrassSpotter is a basic citizen science programme and due to the questions asked, requires no prior training. Instead, observers are guided through species identification and motivated to report their confidence in the identification of seagrass species (not very [confident], a bit, very, definite). Uploads are verified monthly by SeagrassSpotter administrators, whom are seagrass researchers, and uploads of non-seagrass species are transferred to a separate absence database (hosted in the same programme). Uploads where locations appear to be incorrect and outside the bounds of expected seagrass distribution (e.g. open ocean), and where species identification is incorrect or not within known species distribution are flagged and fail the verification process. SeagrassSpotter data is available open access via the website and data were downloaded on 12 December 2024 for the purpose of this analysis.

2.2. Data processing and analysis

We first cleaned data by removing uploads that had been flagged by administrators resulting, in a dataset containing 8202 uploads from 109 countries and territories across all seagrass bioregions, reported from 2004 through to 2024. Given that providing information on threats is optional, not all uploads contained relevant information for the purpose of this analysis. After removing uploads with no threat information reported, we were left with a final dataset containing 3402 geo-referenced points spanning 86 countries and

Table 1. Categories used for citizen science driven threat mapping taken from Grech *et al* [24] and separated into broader origin categories.

Threat origin	Anthropogenic threat
Land-based	Coastal development Elevated nutrients Urban runoff (e.g. sediments, pollution)
Sea-based	Aquaculture (and seaweed farming) Boat and mooring damage Dredging Fishing (not including trawling) Invasive species Trawling

territories [37]. Importantly, this does not mean that the removed uploads with no threats present are reflective of pristine sites, only that these uploads did not contain any optional information.

Threats are reported within SeagrassSpotter in the form of an open-ended question that allows observers to be more specific about the impacts present. Following the list of anthropogenic threats generated by Grech *et al* [24], we analysed answers and assigned a value of 1 to each threat that was reported. Some threats listed by Grech *et al* [24] did not appear in our dataset, or had fewer than three reported observations across uploads, and were removed from our analysis (e.g. desalination plants). After this, we were left with a list of nine broad anthropogenic threats (table 1) which we categorised further based on whether they primarily originate from land-based or sea-based anthropogenic activities. Seagrass meadows are vulnerable to these anthropogenic threats in different ways [24], and relative risk is influenced by the scale and frequency of the threat, the influence of the threat to seagrass function, seagrass resistance, and recovery time [24]. Because of this, using expert knowledge, Grech *et al* [24] assigned vulnerability scores to each anthropogenic threat for each bioregion (as risks across bioregions vary). These scores identify the relative risk to seagrass meadows where 0 = no impact, and 4 = highest risk. We assigned the scores presented by Grech *et al* [24] to our dataset, specifying different scores based on which bioregion the upload was located in. Finally, we summed vulnerability for each observation to create a 'cumulative vulnerability index'; observations with more human impacts recorded had higher cumulative vulnerability index scores. In doing so, we acknowledge that this ignores any potential relationships between individual threats [34], but it is known that impacts from one threat may lessen resilience to other natural or anthropogenic pressures [38, 39].

As part of our analysis, we focused on assessing whether uploads fell within MPAs and OECMs. Protected areas are complimented by OECMs, which are defined as 'a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio–economic, and other locally relevant values' [40]. In order to do this, we downloaded a database of the world's MPAs and OCECMs [41] and used the *st_intersects* function in the *sf* package for R [42] to assign a yes/no value to each upload based on whether it fell within or outside of an MPA or OCECM. Unsurprisingly, numerous uploads were clustered in similar locations (e.g. multiple uploads per meadow across multiple years), so for the purpose of creating summary statistics we sought to find distance-based neighbours using the R package *spdep* [43]. For this, we trailed various upper distances resulting in the creation of a differing number of sites (e.g. 0.25 km^2 = 1388 sites; 10 km^2 = 599 sites). However, for the purpose of analysis, we set the upper distance bound to 0.5 km^2, resulting in 1222 semi-unique seagrass meadow sites where anthropogenic threats have been observed, that were either within or outside of MPAs and OECMs. This is a relevant size because (a) many coastal MPA's across the Indo-Pacific and Caribbean, for example, are small (<0.5 km^2) [44, 45], (b) 0.5 km^2 is a scale at which terrestrial mapping has detected human-induced change [46], and (c) it incorporates the lower bound of what is generally considered a large continuous meadow.

To identify areas of high vulnerability, we used the full suite of 3402 observations of anthropogenic threats, and the vulnerability score to each threat. For global mapping, we projected observations onto a 5° resolution (∼555 km) raster dataset, resulting in 166 human-impacted raster grid cells worldwide. For each of these grid cells, we averaged the cumulative vulnerability index scores for each upload present. We acknowledge that these grids span large distances, and therefore include multiple meadows, but believe these grids to be useful for identifying global patterns. For the purpose of regional mapping, we instead projected observations onto a 1° resolution (∼111 km) raster dataset, resulting in 403 human impacted raster grid cells. All analysis was conducted in R [47]. For local mapping, all uploads, and their assigned threats can be viewed and explored at https://seagrassspotter.org/threat-mapping.

3. Results

3.1. Human impacts widespread across protected areas

Of the 8202 uploads we retrieved from SeagrassSpotter, 3402 observations reported optional information of anthropogenic threats to the world's seagrass meadows (explorable at https://seagrassspotter.org/threat-mapping). These 3402 observations correspond to 1222 sites distributed across the world's seagrass bioregions. Nearly 60% of sites were dominated by seven countries; sites in the United Kingdom were most numerous (19.4% of sites), followed by Sweden (12.4%), Australia (6.7%), Indonesia (6.0%), the Philippines (5.2%), the United States (4.1%), and Mexico (3.2%). The remainder of sites were distributed across a further 79 countries and territories.

Across sites, the most frequent threats to seagrass meadows were elevated nutrients (77% of sites), boat damage (40%), and fishing (31%). Sites with elevated nutrients were identified by observers as having high epiphyte cover or large green fleshy algal mats. Sites with boat damage frequently had mooring, anchoring, or propellor damage, and sites with fishing-related impacts varied, including use of destructive gears, bait digging and gleaning (both harvesting and digging). Threats identified with lower frequency at the global scale were urban runoff (10%; e.g. sediments and garbage), coastal development (3.8%) and aquaculture (2.6%; e.g. fish farms and seaweed cultivation).

Averaged across bioregions (figure 1), we found that 50.6% ± 11.6% of human-impacted sites were situated within MPAs and OECMs. In sum, this reflects 4.4% of the world's MPAs and OECMs ($n = 723$), given boundaries of many protected areas overlap, particularly in Europe. At the bioregion level, we found this to be highest in the Temperate North Atlantic, where 66.5% of human-impacted sites fell within MPAs and OECMs, and lowest for the Tropical Indo-Pacific and Temperate North Pacific, where only 40.9% of human-impacted sites were within protected areas (figure 2). Summed across bioregions, land-based threats were identified at 78.6% of sites, with 41.8% of these sites located within MPAs and OECMs.

Averaged across bioregions, we found that anthropogenic threats to seagrass meadows inside of protected areas originated from both land and sea. At 30.9% ± 13.1% of protected sites, both land- and sea-based threats were observed, compared with 46.0% ± 13.5% and 23.2% ± 5.17% of protected sites where only land-based or only sea-based threats were observed, respectively. Across bioregions, we found that protected and non-protected sites had significantly different threat origins ($X^2 = 14.169$, $df = 2$, $p < 0.001$). Combined land-based and sea-based threats were significantly less common in protected areas, compared to non-protected areas, whereas only land-based or sea-based threats were more common in protected areas. Outside of protected areas, reports of land-based threats were marginally less, and 41.6% ± 10.5% of non-protected areas were exclusively impacted by nutrient inputs, urban runoff, or coastal development.

3.2. Identifying cumulative risk to global seagrass meadows

Using the full suite of 3402 observations of anthropogenic threats and their cumulative vulnerability scores, we mapped threats to seagrass meadows by identifying a series of global grid cells (∼555 km) with the highest vulnerability to anthropogenic threats (figure 3). Based on these cells, we identify locations in Sri Lanka (highest risk), Columbia, Fiji, Indonesia, Mexico, Mozambique, the Philippines, and Tanzania that are most at risk from cumulative human pressures; sites with the highest number of co-occurring anthropogenic threats reported by observers. These high-risk areas were often locations where population density was high [48], seagrass provides multiple ecosystem services [49, 50], and both biodiversity and communities are at increased risk from climate change [51, 52].

Regionally, across Europe (figures 4 and 5), we found that cumulative risk was high in sites where both boating damage and nutrient inputs were observed, but risk was highest in areas where these two threats interacted with fishing activities and urban runoff, and, for sites in the Mediterranean, where invasive species been observed (i.e. *Caulerpa taxifolia, Halophila stipulacea*). In the Tropical Atlantic, vulnerability was influenced by high nutrient inputs combined with urban runoff, coastal development and boating damage; this region had the highest prevenance of coastal development threats across sites. Southeast Asia (and the Indo-Pacific more broadly), had high numbers of anthropogenic threats relative to other sites. These sites frequently had two or more localised threats observed, including dredging, trawling, aquaculture, small-scale fishing, and boating activity, combined with the more persistent impacts of urban runoff and nutrients.

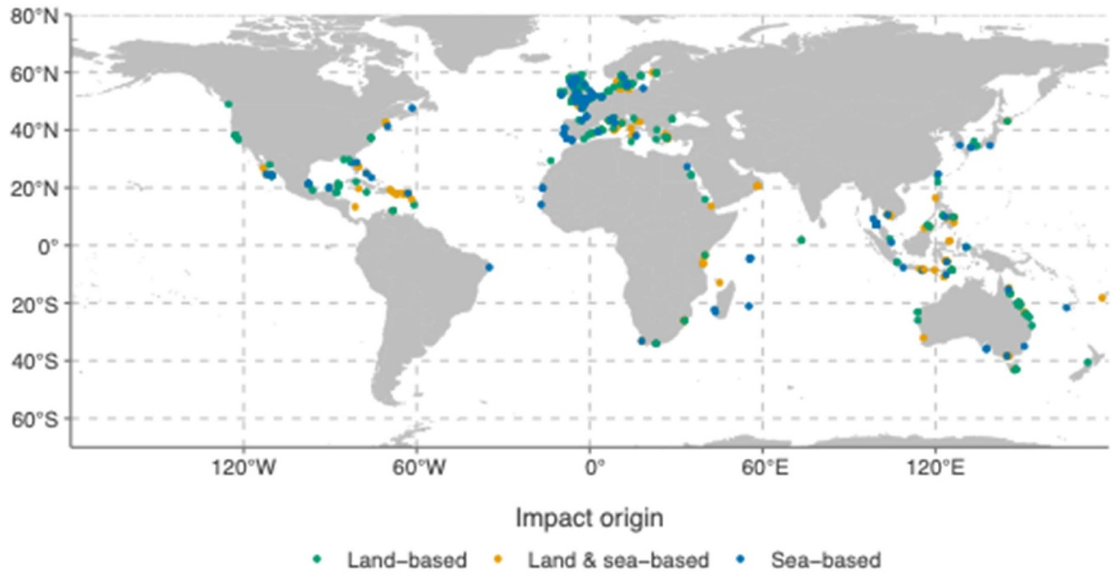

Figure 1. Prevalence of land- & sea-based anthropogenic threats to seagrass meadows across marine protected areas (MPAs) and other effective area-based conservation measures (OECMs). Points represent unique sites identified by citizen scientist where human impacts to seagrass meadows are situated within MPAs and OECMs and are coloured by whether impacts were land-based only (e.g. runoff), land- and sea-based, or sea-based only (e.g. fishing, boating).

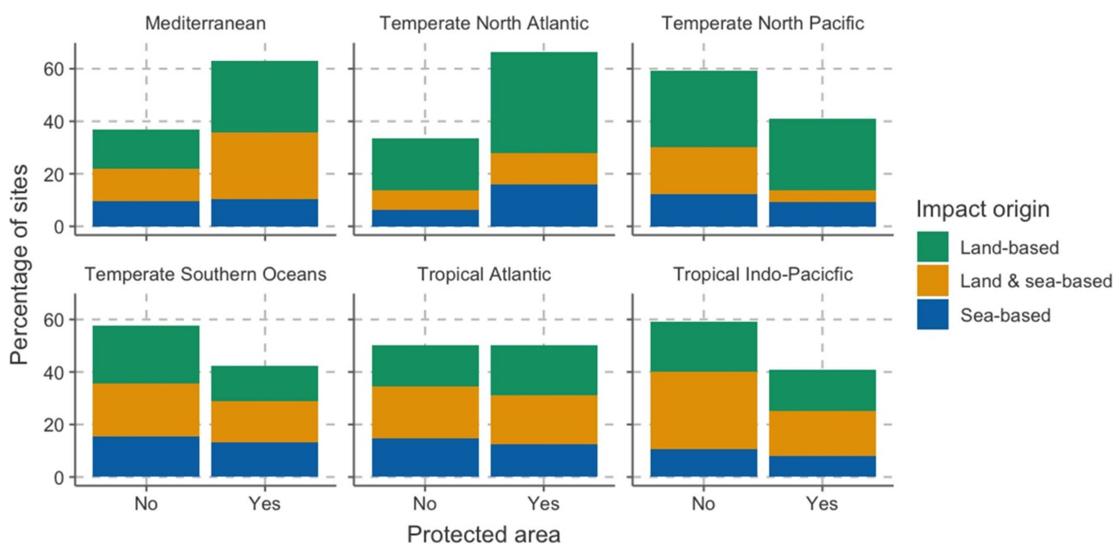

Figure 2. Percentage of unique seagrass sites with observed anthropogenic threats within and outside marine protected areas and other effective area-based conservation measures across the six seagrass bioregions. Bars are coloured by whether impacts at the site were land-based only, land and sea-based, or sea-based only.

4. Discussion

Seagrass meadows face a plethora of impacts that threaten their ability to contribute significant ecosystem services that are vital to people and planet [53]. Here, we respond to the global challenges for seagrass [30], presenting the first attempt to quantify localised anthropogenic threats to seagrass meadows on a global scale using data gathered through citizen science. In the context of legal requirements to map and protect seagrass meadows [31], and global trajectories of loss and recovery [23], global mapping reveals that over 50% of seagrass sites with anthropogenic threats were within locations with designated protection. This number represents 4.4% of the world's MPAs and OECMs where human pressures place seagrass at risk. We identify a series of high-risk sites where multiple pressures likely place seagrass meadows on a trajectory of decline and identify several others where cumulative impacts pose concerns.

Land-based threats, including nutrient enrichment, urban runoff, and coastal development, were identified at nearly 80% of sites, with 42% of these sites located within MPAs and OECMs. These findings

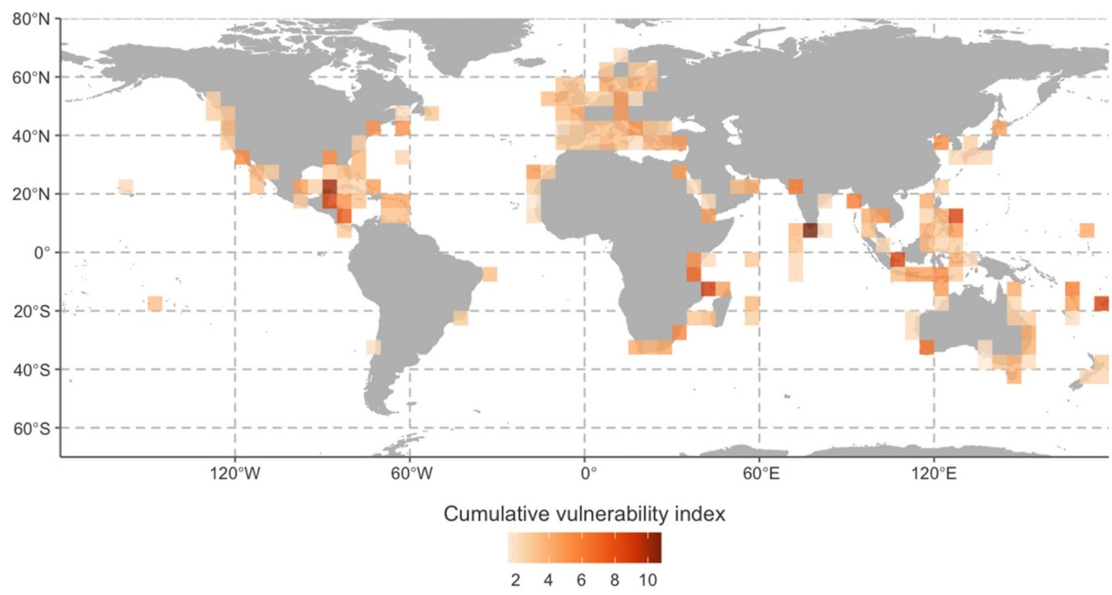

Figure 3. Cumulative vulnerability to local-scale human induced impacts for seagrass meadows across the globe. Squares represent 5° resolution (∼555 km) grid cells shaded by average cumulative vulnerability. Vulnerability is higher where multiple impacts are present.

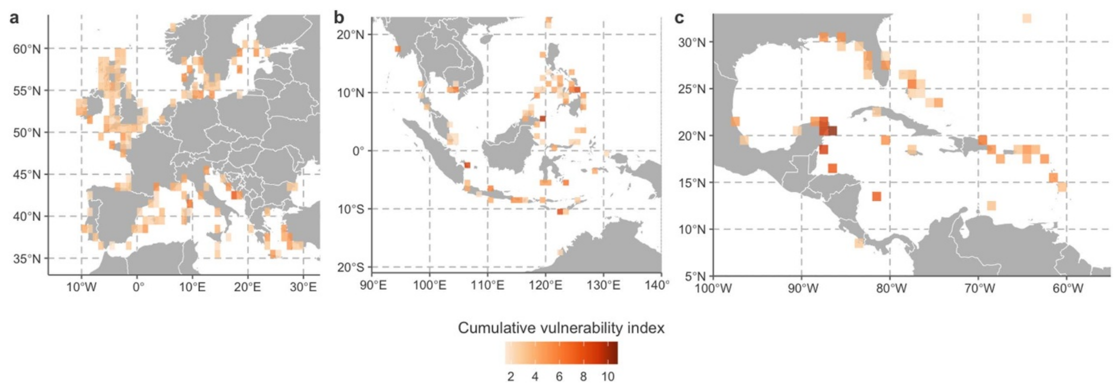

Figure 4. Seagrass hotspots of high vulnerability to localised human-induced threats across (a) Europe, (b) Southeast Asia, and (c) the Caribbean. Squares represent 1° resolution (∼111 km) grid cells shaded by average cumulative vulnerability.

echo earlier research suggesting that threats originating from land are the most significant drivers of both large-scale and small-scale seagrass loss [23, 26, 28, 54–56]. While calls to protect the world's oceans are indeed ambitious and necessary [57–60], priorities often focus on the protection of biodiversity from fishing [61–63]; a threat also observed at 31% of sites. While fully protected areas are defined as having no impact from extractive or destructive activities [58], these do not protect habitats from impacts originating from elsewhere. These findings endorse calls made by others that quality is lagging behind quantity for MPA progress [64].

We argue that the limited ability of marine protection to mitigate land-based threats necessitate a broader conservation strategy that includes terrestrial interventions [34]. Arguably, large-scale land-based threats pose a greater risk to the seagrass habitats that support fisheries [65–67], than the fisheries themselves, although fisheries exploitation and mechanical damage from certain gears remain an issue [25, 68, 69]. Restoration efforts targeting terrestrial sources of sediments and nutrients could provide far-reaching benefits for seagrass resilience [55, 70, 71]. Examples include small-scale interventions to engage smallholder farmers to restore riparian vegetation [30], and the large-scale upgrades to sewage infrastructure [72] and wider watershed changes needed to prevent nutrient inputs in coastal waters [35, 36]. Addressing these upstream challenges not only enhances the status of seagrass meadows but also bolsters the resilience of fisheries and coastal communities reliant on their services [70].

While the scale of threats to seagrass across the world's protected areas is concerning, our findings also offer some optimism. Across all sites, we found that combined land and sea-based threats were significantly

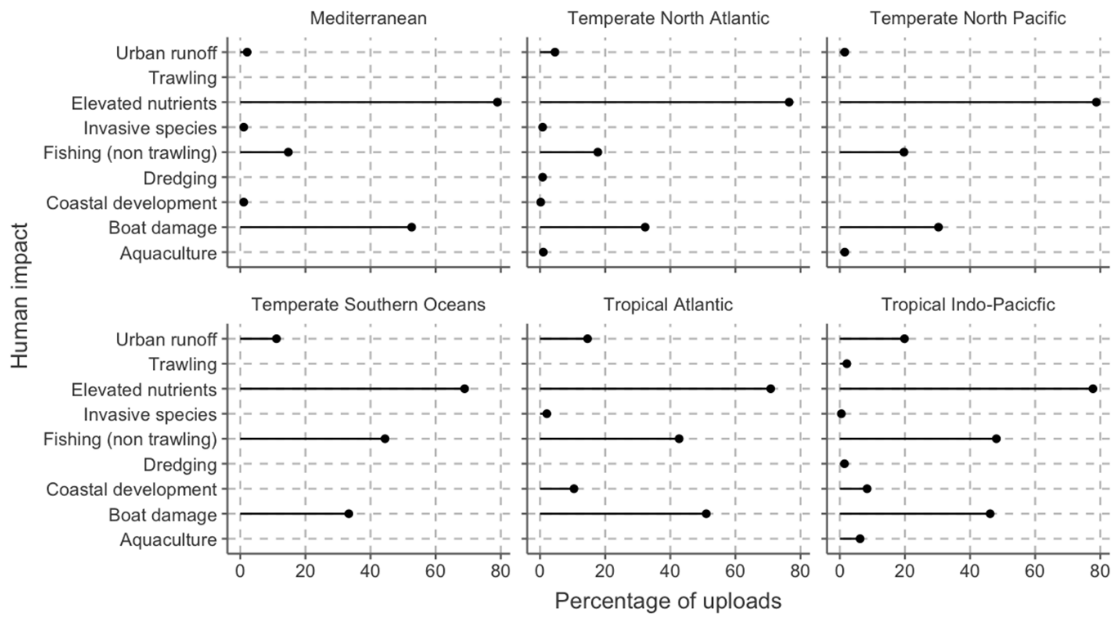

Figure 5. Percentage observations of anthropogenic threats across seagrass bioregions at ∼1222 semi-unique seagrass sites.

less prevalent within protected areas, highlighting that protection status reduced the number of combined threats, whilst also providing small reductions in either land-based or sea-based threats. We find this to be surprising given that most seagrass protection is by chance [30], and few examples exist of integrated management that explicitly references seagrass meadows or accounts for cumulative pressures [33, 34]. These findings highlight that protection for features other than seagrass may have multiple benefits, but further investigation is required.

The second most persistent threat to seagrass meadows across bioregions was boating activities, and included anchoring, mooring and propellor damage; all of which are known to cause small-scale, long-term disturbances to seagrass meadows [73–76]. Studies suggest that these activities uproot rhizomatous tissue and tear seagrass shoots [77] and contribute to a decline in seagrass extent; at least 6 ha of seagrass has been lost to moorings in the UK [78]. A review by Sagerman *et al* [79], found that the abundance of submerged aquatic vegetation halved in areas with boat traffic and mooring infrastructure, compared with control areas. Globally, our findings indicate that such threats are both frequent and widespread. While small in scale compared to land-based impacts, their persistence and cumulative effects have the potential to pose significant risks [80]. Solutions to mitigate boating impacts are well-documented and include the co-design of marine use zones [76], and use of environmentally friendly moorings [81, 82].

Threats from fishing were observed across all bioregions but were most prevalent in the Temperate North Pacific, Tropical Indo-Pacific and Temperate Southern Oceans when assessed on a site-by-site basis. The sheer scale of global seagrass fishing activity suggests that impacts are likely much more widespread [65], particularly in the context of the intensity of seagrass fishing in the tropics [25, 83–85]. That said, we do not advocate for a total cessation of seagrass-associated fishing, which is vital for livelihoods and often supports those in poverty [86]. Instead, we argue that mitigating the multitude of other impacts, while equitably managing seagrass-associated fisheries, can improve seagrass resilience to low-intensity fishing activities [34]. That said, we also endorse existing efforts to restrict usage of damaging gears within seagrass meadows [25].

A key caveat to the global maps we have presented here is that they reveal only the suite of anthropogenic threats reported by citizen scientists when providing an upload (figure 6). Given that the question on threats is optional, it is possible that this information is reported less frequently. This suggests that the ∼40% of SeagrassSpotter uploads analysed here reflect only a small portion of global sites where human pressures are present. Importantly, this also means that the ∼60% of uploads without information on impacts do not reflect sites absent of anthropogenic threats, only that any threats have not been recorded. Moreover, the full suite of pressures may also be influenced by underlying biases that may either be regional or observer based [87] and certain impacts might only be reported by particular types of observers. To counter potential biases, here, the scale of observations contribute to broad evidence-based distribution of threats, rather than relying on a small number of expertise-based observations [88], and hence builds on the 'Wisdom of Crowds' [89]; large diverse groups make more accurate predictions than smaller groups of experts. We also acknowledge

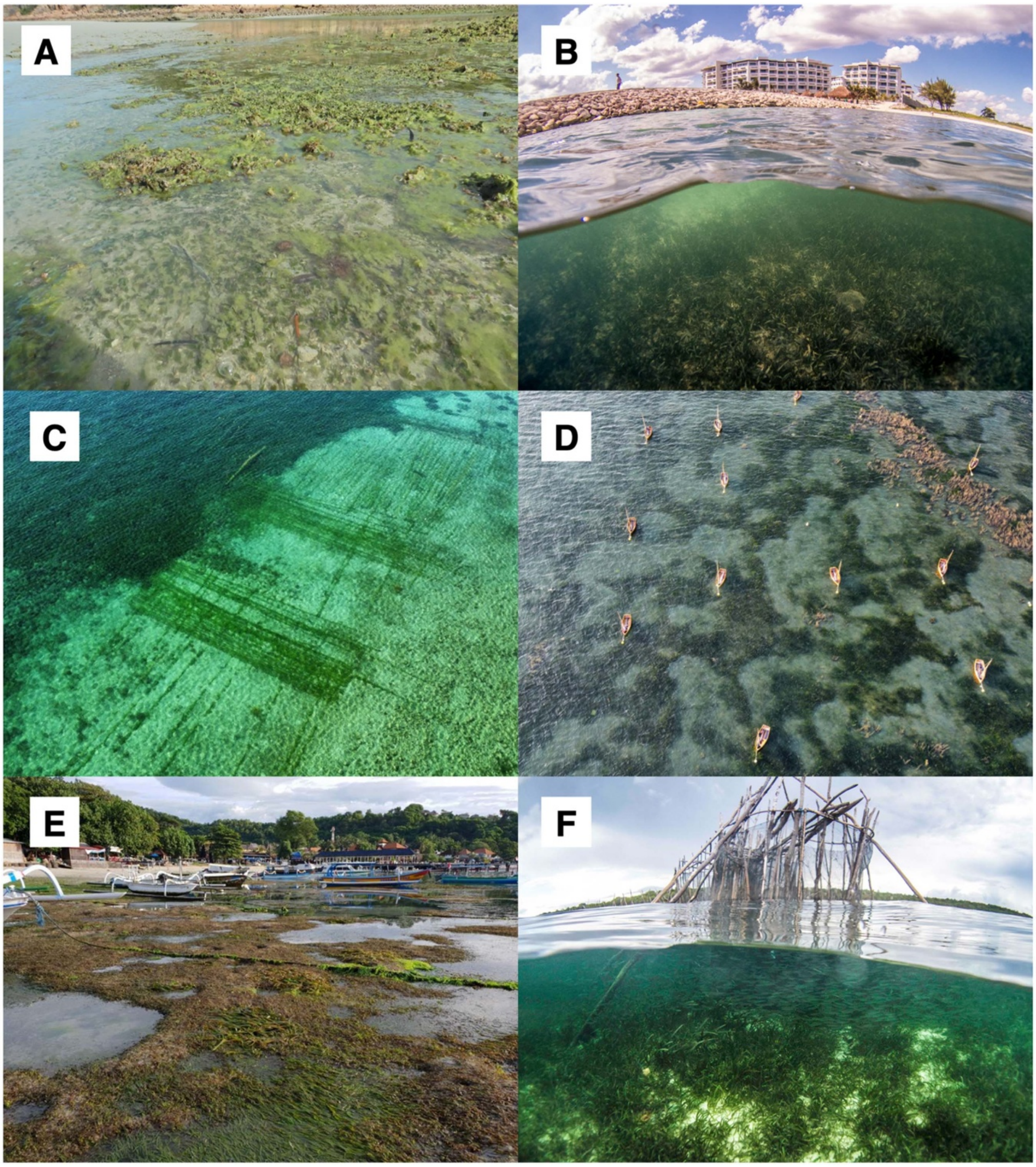

Figure 6. Uploaded images to SeagrassSpotter documenting anthropogenic threats. (A) elevated nutrients, Australia, (B) coastal development, Mexico, (C) seaweed farming, Timor-Leste, (D) boat moorings, United Kingdom, (E) boat damage, Indonesia, and (F) destructive fishing, Indonesia. Reproduced from © 2015–2024 Project Seagrass. CC0.

that numerous impacts to seagrass are not easily observed by citizen scientists (e.g. microplastics, pollution), particularly impacts from climate change such as sea level rise, ocean acidification and rising sea surface temperature.

We also note that 60% of human-impacted sites are in just seven countries, with the UK, Sweden, and Australia being the largest contributors, an issue that is prevalent across multiple citizen science projects [90, 91]. Unique additional reasons for this include the fact that SeagrassSpotter was first released in the UK, and operational for ∼18 months before expanding to allow European uploads in late 2016. Global expansion later followed in 2018, and we suggest that reports of threats are skewed towards the length of time that uploads have been possible in any given region. Uploads are also skewed towards countries where SeagrassSpotter has been incorporated into defined projects (e.g. IKI Seagrass Ecosystem Services Project), but improved participation pathways are needed to engage low- and middle-income economies [92–94].

In addition to the caveats above, we also ignore any potential relationships between individual threats [34], as well as the role of social and ecological feedbacks [95, 96]. While literature is sparse on the topic [97], impact from one pressure may lessen resilience to other natural or anthropogenic pressures [38, 39]. Across the globe, grazers are important for structuring seagrass systems [98–101], yet in the presence of multiple co-occurring human pressures and climate change, they may invertedly lessen seagrass resilience, leading to widespread decline [96, 102–104]. Sites identified as having the highest human pressure were sites where multiple threats exist, in various, possibly confounding combinations with one another, at differing levels of intensity. Underscoring the challenge of understanding how these multiple anthropogenic threats interact with each other, and with natural pressures, is that on a global scale we lack information on the global status and condition of seagrass [21, 30]; a challenge that new or current citizen science programmes can contribute to with open access data [29].

A key benefit of citizen science driven fine-scale local impact mapping, versus large-scale social and environmental variables, is their applicability to provide unique data in often data limited areas to guide conservation [13, 16]. Habitat suitability mapping is one such example, and in the context of the multiple seagrass restoration projects now being initiated across the globe, we urge scientists, practitioners and communities to consider the full suite of human impacts that may be present at sites, and work to mitigate these before attempting restoration activities [105]. The evidence presented here highlights that multiple human impacts are likely present across *most* seagrass meadows and likely remain in places where seagrass previously existed. The impacts of multiple human pressures on the success of restoration needs to be considered.

Designing strategies to conserve seagrass in the face of multiple co-occurring stressors requires collaborative thinking, combining the engagement of multiple stakeholders, local and expert knowledge and scientific data [106]. Priority threat management is an emerging decision framework for this purpose [107], designed to collaboratively identify the science-based and most cost-effective strategies for mitigating multiple co-occurring impacts to biodiversity. The impacts presented here have already been ranked by stakeholders and experts regionally and globally [24, 28], but for the first time, we now reveal their prevenance at local sites across the globe.

In conclusion, this study is the first attempt to create a global map of threats to seagrass meadows, and builds upon a growing body of research highlighting the vulnerability of coastal ecosystems to human pressures [10, 11]. While previous studies have provided high-level global assessments of human impacts to biodiversity [3, 5], this analysis bridges a critical gap by using localized citizen science data and knowledge to map anthropogenic threats to the world's seagrass meadows. The global maps of human impacts presented here provide a starting point for addressing the cumulative pressures on seagrass meadows, but further work is needed to address how these impacts interact, and what influence those interactions have. Importantly, future work should build on that of Grech *et al* [24], and focus on developing threat-based assessments to determine the response and resilience of seagrass meadows to the anthropogenic threats we have identified here. The prevalence of human threats to seagrass meadows within 4.4% of the world's MPAs highlights the need to rethink conservation strategies, and design management strategies to protect seagrass meadows at the watershed level. Finally, we call on seagrass researchers and practitioners to embrace the immense value of citizen science, and utilise SeagrassSpotter in their own work.

Data availability statement

The large citizen science dataset used in this study is publicly available from the SeagrassSpotter website (https://seagrassspotter.org/data/reports/sightings).

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.6084/m9.figshare.28123403.

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