Advancing public pro-environmental action for global seagrass conservation

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Abstract

Seagrass meadows support biodiversity, climate mitigation, and human well-being, yet remain threatened by interacting anthropogenic pressures. Public engagement is increasingly promoted in seagrass conservation, but the behaviours most relevant to reducing seagrass decline remain poorly defined. We surveyed 172 seagrass knowledge holders from 39 countries and territories, representing 1942 cumulative years of experience, to assess perceived threats and public pro-environmental behaviours. Respondents identified 868 threat instances across 18 categories, with runoff, coastal development, and recreational boating among the dominant pressures. Behavioural tractability varied strongly. Visible, direct threats, especially recreational boating, were viewed as more amenable to public action than diffuse or system-level drivers such as climate change. Using thematic analysis, we identified 21 pro-environmental behaviours relevant to seagrass conservation. Responsible boating, coastal protection advocacy, education, sustainable consumption, and reducing household watershed impacts were most common. We argue that effective seagrass conservation requires broader behaviour portfolios aligned with multi-scalar threat pathways.

Keywords: behaviour change; coastal stewardship; environmental psychology; land-sea interactions; marine governance; social-ecological systems

Introduction

Anthropogenic activities have pushed the Earth system beyond safe operating limits. Transgressions of multiple planetary boundaries (Richardson et al. 2023; Sakschewski et al. 2025), biodiversity loss, and climate instability show that human behaviour is now a primary driver of environmental change (Steffen et al. 2015; Whitmarsh et al. 2021; Merz et al. 2023). These crises are rooted in patterns of consumption, governance, and resource use (Lenzen et al. 2012; Sans and Combris 2015; Dorninger et al. 2021; Hoang et al. 2023), requiring technological and policy innovation alongside shifts in behaviour (McElwee et al. 2020; Chaigneau and Schill 2022; Read and Selinske 2024).

Pro-environmental behaviour refers to individual or collective actions that minimise harm to, or benefit, the natural environment (Kollmuss and Agyeman 2002). A range of models explain such behaviours and inform interventions to foster environmental change (Jensen 2010; Gatersleben 2018; van Valkengoed et al. 2022). Interventions are more likely to succeed when they target the psychological, social, and structural drivers of action, including perceived control, norms, habits, infrastructure, and institutional context (van Valkengoed et al. 2022). Well-designed communication campaigns, policy instruments, community initiatives, and technological innovations can shift behaviour when aligned with these determinants (Domegan 2021; Rau et al. 2022; Helferich et al. 2023). Within social-ecological systems, this requires attention to both biophysical stressors and the social structures, governance systems, and behaviours that generate them (Bodin 2017; Schill et al. 2019).

Seagrass meadows are subject to interacting anthropogenic pressures, including physical disturbance, declining water quality, and global environmental change (Grech

et al. 2012; Jones et al. 2025). Moorings, anchoring, and coastal development can damage or remove seagrass (Unsworth et al. 2017; Grech et al. 2018; Bockel et al. 2024), while nutrient enrichment and sedimentation from agricultural and urban runoff reduce light availability and impair growth (Ralph et al. 2006; Freeman et al. 2008). Many of these stressors are chronic, spatially extensive, and rooted in everyday human activities, making them resistant to single, site-based interventions (Jones et al. 2025).

Seagrass conservation has increasingly combined ecological, social, and policy-oriented approaches with varying success (Lefcheck et al. 2018; de Los Santos et al. 2019; Rifai et al. 2022). As seagrass has gained visibility as a blue carbon habitat (Duarte de Paula Costa and Macreadie 2022; Duarte et al. 2025), public-facing efforts have become strongly associated with restoration and citizen science. Restoration provides visible engagement through planting seeds, seedlings, or transplants (Ferretto et al. 2021; Unsworth et al. 2024; Evans et al. 2025), while citizen science can enhance monitoring and stewardship (Jones et al. 2018; Jones et al. 2025). Yet restoration cannot succeed or scale where underlying drivers of decline persist (Unsworth et al. 2024; Jones et al. 2025). Planting seagrass into systems still characterised by poor water quality, physical disturbance, or coastal pressure risks treating symptoms while leaving causes intact.

Despite growing recognition of seagrass as globally important blue carbon habitat (Duarte de Paula Costa and Macreadie 2022; Duarte et al. 2025), the public behaviours needed to reduce seagrass decline remain poorly defined, under-communicated, or difficult to operationalise. This creates a misalignment between promoted actions and behaviours most likely to reduce pressures on seagrass ecosystems. Here, we examine

how seagrass knowledge holders perceive threats to seagrass ecosystems and the public pro-environmental behaviours that could help reduce them. Our aim was not to produce a representative public opinion survey, but to identify an expert-informed set of behaviours that could support seagrass conservation across local, catchment, coastal, and global scales.

Methods

Sampling design

We used a purposive, network-based sampling strategy to recruit participants with direct knowledge of seagrass research, conservation, or management. Participants were recruited through professional networks, seagrass communication channels, targeted calls circulated through established seagrass networks, and a curated list of approximately 400 corresponding authors from seagrass publications. This approach captured knowledge across geographies and professional contexts rather than statistical representativeness.

The final sample comprised 172 respondents from 39 countries and territories, representing 1942 cumulative years of seagrass-related experience. Respondents self-identified as actively engaged in seagrass research, conservation, or management and represented research, conservation, management, regulatory, educational, and private-sector backgrounds. Participation required access to an online device and ability to complete the questionnaire in English.

Survey design

Data were collected using a structured online questionnaire administered through Qualtrics over 10 weeks between September and November 2025. The survey combined closed-ended questions, Likert-scale responses, and open-text responses. Respondents first selected primary threats to seagrass in their bioregion from a predefined list adapted from established frameworks (Grech et al. 2012; Jones et al. 2025). For each selected threat, they rated how effective public pro-environmental behaviours could be in counteracting that threat using a five-point Likert scale from "very ineffective" to "very effective". Respondents then listed up to five public pro-environmental behaviours that could reduce threats to seagrass or improve seagrass conservation, explained their rationale, and indicated whether each behaviour was globally applicable or regionally specific.

Analysis

Closed-ended responses were summarised using descriptive statistics. Threat responses were aggregated by category and bioregion, while Likert-scale responses were summarised to assess perceived behavioural tractability. Open-text responses were analysed using thematic analysis (Clarke and Braun 2016). Responses were independently reviewed and iteratively coded by both authors, with coding focused on the intended conservation consequence or threat pathway of each behaviour. Through discussion and refinement, 21 behaviour categories were identified and grouped into three broader domains: direct disturbance reduction, indirect land-sea and consumption-based actions, and systemic or governance-oriented actions. Percentages

describe the distribution of coded responses within this expert-informed sample and should not be interpreted as population-level prevalence.

Results

Seagrass threats are diverse, widespread, and behaviourally uneven

Drawing on 1942 cumulative years of seagrass experience from 172 knowledge holders in 39 countries and territories, respondents identified 868 threat instances across 18 categories, with individuals selecting a median of five threats each. Seagrass decline was therefore perceived as a multi-threat challenge shaped by interacting local, catchment, coastal, and global drivers (Fig. 1).

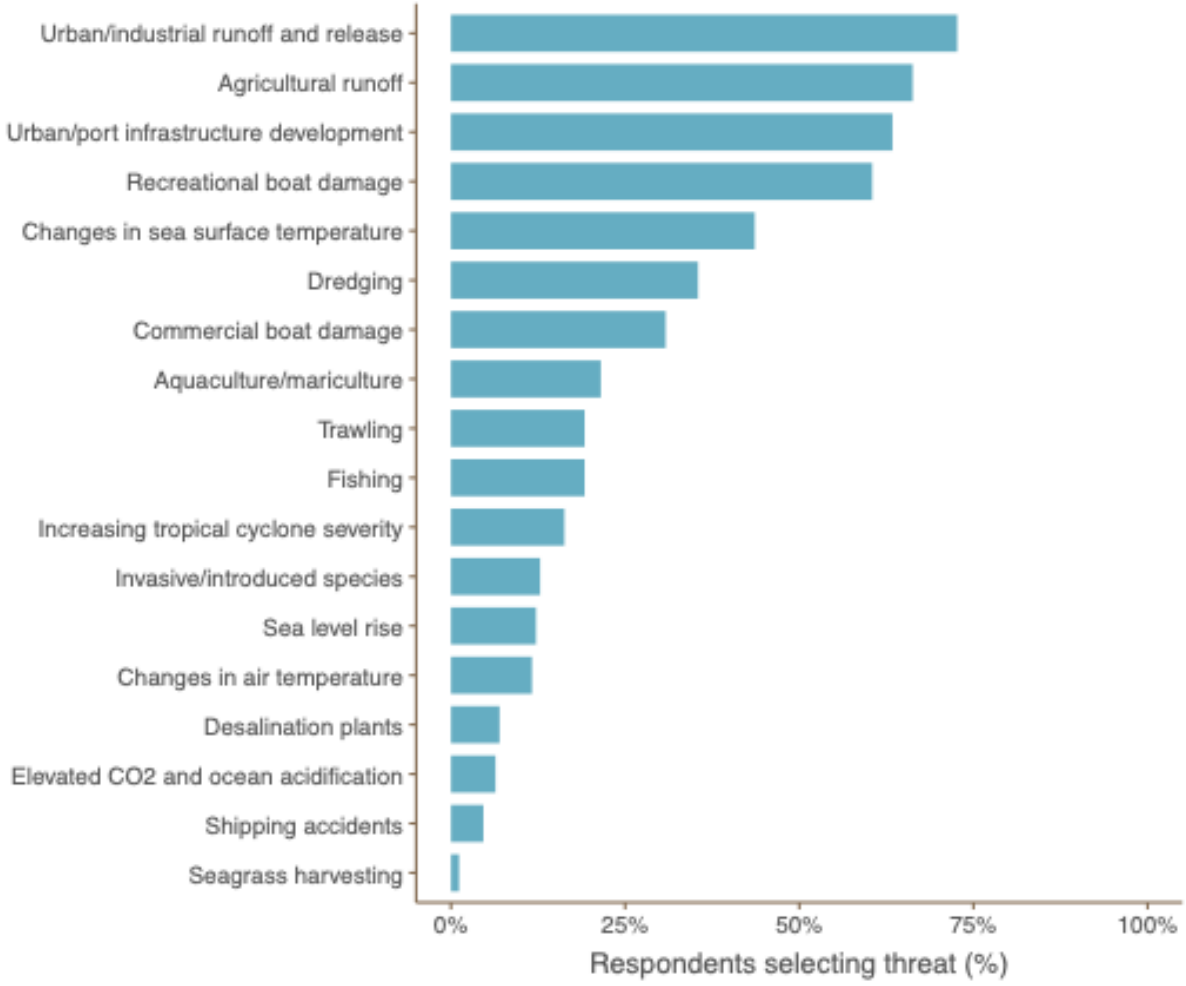

Fig. 1. Perceived threats to seagrass ecosystems globally. Percentage of seagrass knowledge holders selecting each threat category as a primary factor affecting seagrass ecosystems in the bioregion where they work. Respondents could select multiple threats; percentages therefore indicate the proportion of respondents selecting each threat rather than mutually exclusive categories.

The most frequently identified threats were urban runoff (72.7% of respondents), agricultural runoff (66.3%), coastal development (63.4%), and recreational boat damage (60.5%). These were followed by changes in sea surface temperature (43.6%), dredging (35.5%), and commercial boat damage (30.8%). Threat complexity varied across bioregions. Respondents in the Tropical Indo-Pacific identified all 18 threat categories and had the highest mean number of threats per respondent (6.1), followed by the Mediterranean (16 categories; mean = 5.3), Temperate Southern Oceans (15; mean = 5.1), Temperate North Atlantic (17; mean = 4.5), Tropical Atlantic (13; mean = 4.2), and Temperate North Pacific (9; mean = 3.3).

Behavioural tractability is highest for visible, direct pressures

Respondents perceived some threats as substantially more amenable to public pro-environmental behaviour than others (Fig. 2). Recreational boat damage was viewed as the most behaviourally tractable threat, with 87.8% of respondents who selected this threat rating public pro-environmental behaviour as somewhat or very effective in mitigating it. Other threats with relatively high tractability included fishing (62.5%), agricultural runoff (62.2%), aquaculture and mariculture (61.8%), coastal development (61.5%), and urban runoff (60.3%).

Climate-related and large-scale environmental drivers were viewed as less amenable to public behavioural intervention. Only 23.3% of respondents rated public pro-environmental behaviour as somewhat or very effective for changes in sea surface temperature, 22.2% for changes in air temperature, 22.2% for sea-level rise, and 0% for

increasing tropical cyclone severity. Thus, many dominant threats were rooted in human behaviour, but not all were perceived as equally open to public action.

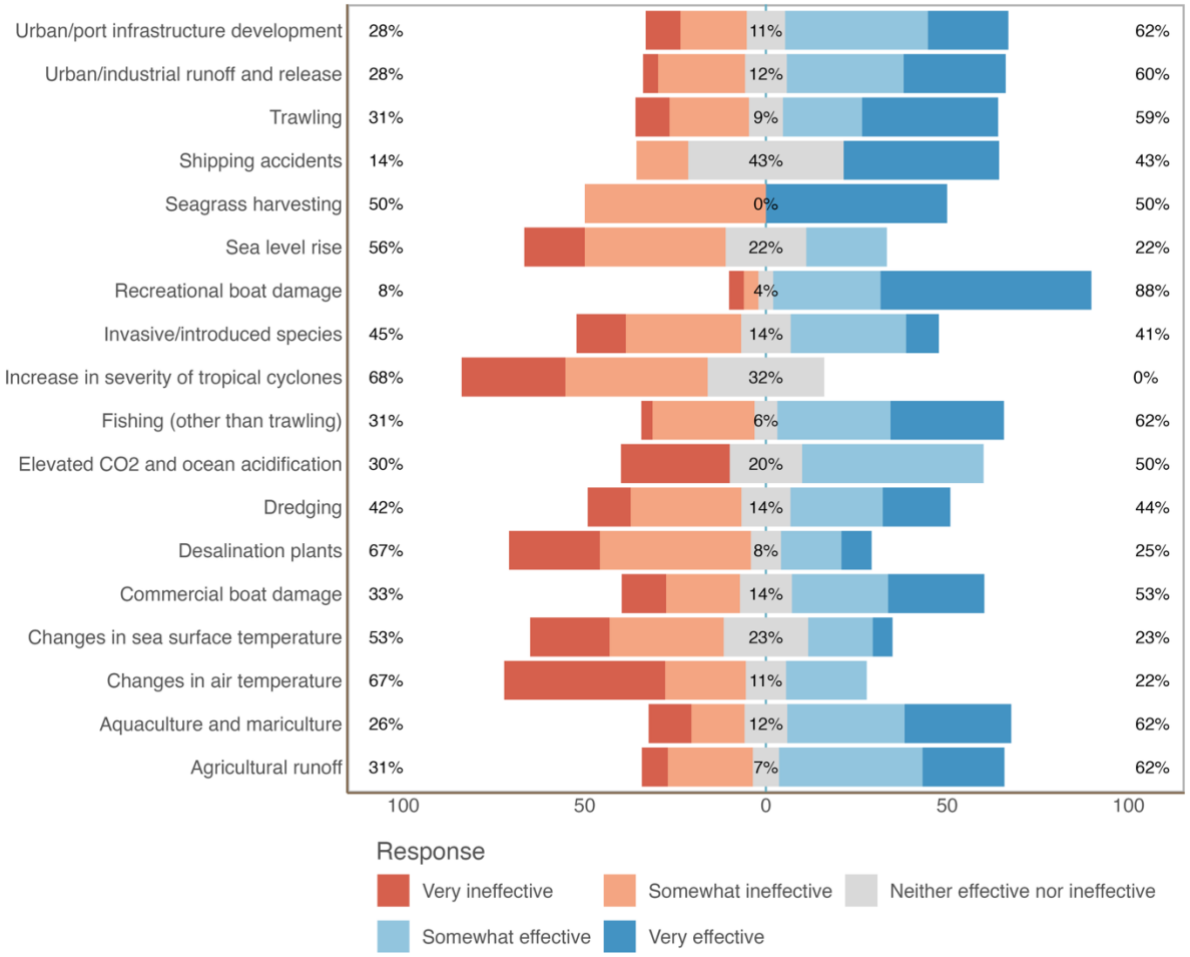

Fig. 2. Perceived behavioural tractability of seagrass threats. Likert-scale responses showing how effective respondents perceived public pro-environmental behaviours to be for counteracting each selected seagrass threat. Responses are centred on the neutral category, distinguishing threats viewed as more amenable to public action from those perceived as less behaviourally tractable.

Public behaviours cluster around a small set of pathways

Open-text responses generated 266 coded behaviour statements from 139 respondents, representing 1,625 cumulative years of experience. These were categorised into 21 behaviours spanning direct disturbance reduction, indirect land-sea and consumption-based actions, and systemic or governance-oriented action (Table 1). Most behaviours

were perceived as transferable: 231 coded statements were described as globally applicable, compared with 26 regionally specific and five uncertain.

The most frequently identified behaviour was practising and advocating for responsible boating and recreation, accounting for nearly one fifth of coded responses (Fig. 3). This was followed by campaigning for stronger coastal protection (12.8%), education and knowledge sharing (12.0%), sustainable food and consumption choices (10.9%), and reducing household impacts on watersheds (7.9%). Together, these five categories accounted for nearly two thirds of coded behaviours.

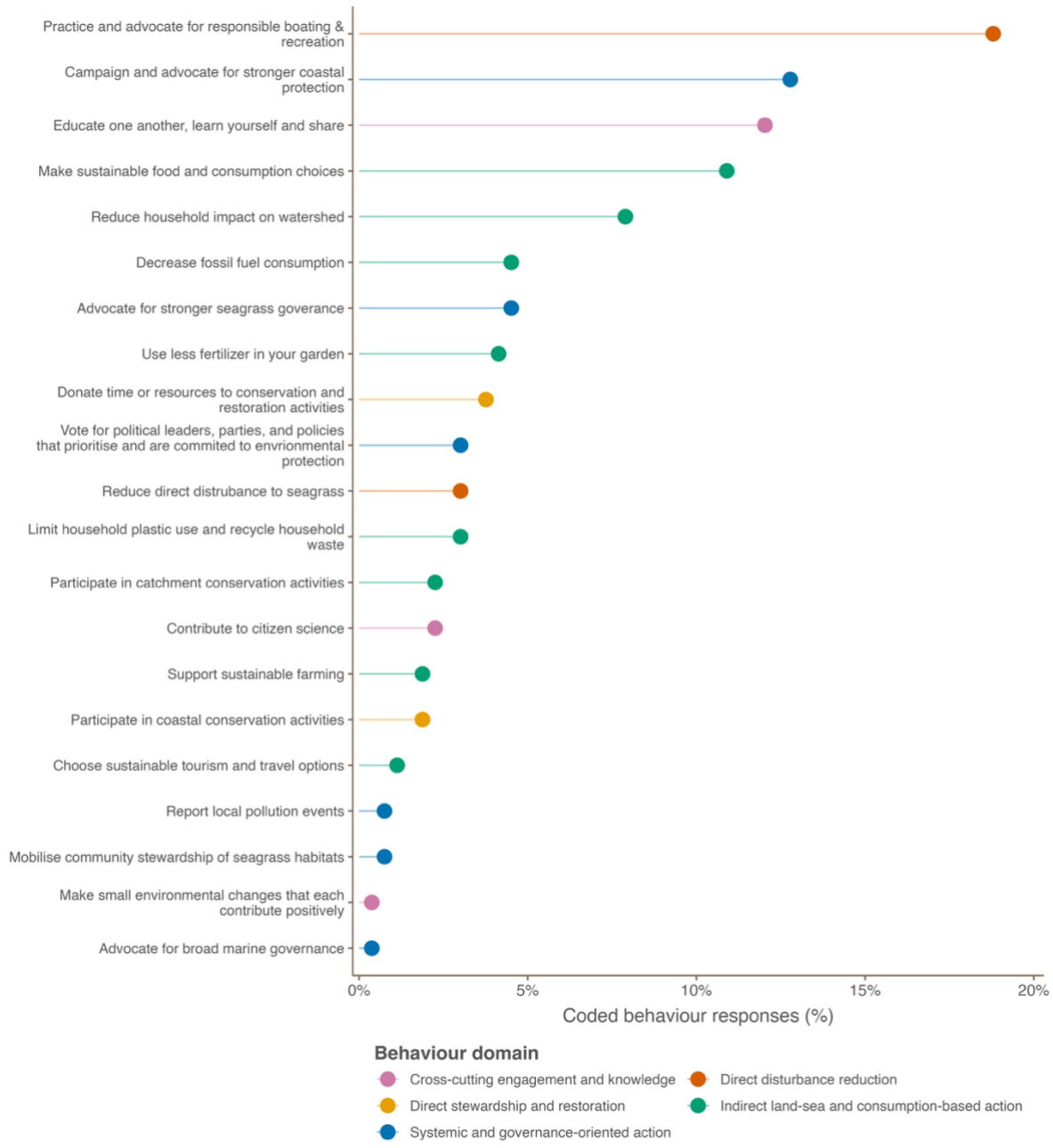

Fig 3. Public pro-environmental behaviours identified by seagrass knowledge holders. Percentage of coded open-text responses assigned to each behaviour theme. Themes represent public behaviours proposed by respondents as actions that could reduce threats to seagrass or support seagrass conservation. Colours indicate broader functional domains of action.

Direct disturbance reduction was especially prominent. Responsible boating and recreation included avoiding anchoring in seagrass, reducing vessel speed, using advanced mooring systems, and advocating for reduced boat-based impacts. Related

behaviours, such as reducing direct disturbance to seagrass (3.0%) and participating in coastal conservation activities (1.9%), were less frequent.

When grouped by domain, the largest proportion of behaviours targeted indirect drivers, particularly land-sea interactions and consumption (Fig. 4). These included reducing household watershed impacts, decreasing fossil fuel consumption, reducing fertiliser use, limiting plastic waste, supporting sustainable farming, and making sustainable food and consumption choices. However, participation in catchment conservation activities remained low (2.3%), suggesting that upstream and catchment-scale action was less commonly identified than household or consumption-based behaviours.

Fig. 4. Functional domains of public pro-environmental behaviours for seagrass conservation. Proportion of coded behaviour responses grouped into broader functional domains, including direct disturbance reduction, direct stewardship and restoration, indirect land-sea and consumption-based action, systemic and governance-oriented action, and cross-cutting engagement and knowledge. Percentages describe the distribution of coded responses within the expert-informed sample.

Systemic and collective actions were present but in low frequency. Advocating for stronger seagrass governance accounted for 4.5% of coded responses, voting for environmental protection for 3.0%, supporting sustainable farming for 1.9%, advocating for broad marine governance for 0.4%, and reporting pollution events for 0.8%. Mobilising community stewardship accounted for 0.8%, while contributing to citizen science accounted for 2.3%. Education and knowledge sharing accounted for 12.0%, suggesting that respondents viewed education as an enabling behaviour that may support uptake of direct, indirect, and civic actions.

Discussion

Drawing on nearly 2000 years of cumulative seagrass knowledge, we show that seagrass conservation faces a behavioural alignment problem. Respondents identified a broad suite of threats, but proposed behaviours were not evenly distributed across this threat landscape. Instead, public pro-environmental behaviours clustered around visible, spatially explicit actions, especially those reducing direct physical disturbance. Because seagrass decline is shaped by interacting local, catchment, coastal, and global drivers (Dunic et al. 2021; Turschwell et al. 2021; Jones et al. 2025), behavioural responses must extend beyond the meadow itself.

Respondents identified threats operating from local to global scales, consistent with existing syntheses of seagrass pressures (Grech et al. 2012; Jones et al. 2025). Coastal development, water-quality degradation, boating impacts, and climate-related pressures were recognised across bioregions. Many of these pressures originate beyond the meadow, meaning effective conservation requires responses that connect

household practices, catchment management, coastal planning, consumption, governance, recreation, and climate action.

The cross-scalar nature of threats reinforces central challenges for seagrass conservation (Unsworth et al. 2019). Seagrass meadows often occur in discrete locations, but many of the pressures acting on them originate elsewhere (Jones et al. 2025). Nutrient enrichment, sedimentation, infrastructure development, boating damage, and climate impacts operate through different pathways, at different scales, and through different actors. Effective conservation therefore requires more than local protection alone and requires behavioural and governance responses that connect household practices, catchment management, coastal planning, recreation, consumption, and climate action.

Despite this complexity, only a subset of threats were perceived as strongly amenable to public pro-environmental behaviours. Direct, localised pressures were viewed as more behaviourally tractable than diffuse or system-level threats. This dissimilarity is critical because it suggests that the public may be more readily mobilised around actions where the causal pathway is visible, immediate, and personally controllable, while threats embedded in broader social, economic, and governance systems may appear less actionable.

Direct disturbance reduction was the clearest behavioural pathway. Responsible boating, avoiding anchoring, reducing vessel speed, and supporting seagrass-safe moorings were commonly identified because their links to ecological outcomes are direct: anchors scar meadows (Bockel et al. 2024), propellers damage plants (Barry et al. 2020), and poorly designed moorings fragment habitat (Unsworth et al. 2017). Evidence

from mooring interventions suggests that reducing physical disturbance can promote recovery when paired with regulation and compliance (Solandt et al. 2024). Such actions are powerful for communication because they translate ecological risk into practical action.

This visibility also creates risk. Boating and anchoring impacts may become disproportionately prominent because they are visible, communicable, and behaviourally tractable. Other drivers, including coastal development, runoff, sewage discharge, land-use change, and catchment degradation, can profoundly affect seagrass while remaining less legible as public behavioural pathways. This pattern aligns with pro-environmental behaviour research: people are more likely to recognise and engage with actions that are concrete, visible, and perceived as individually controllable, while interventions are more effective when they target determinants such as perceived control, norms, habits, infrastructure, and institutional context (van Valkengoed et al. 2022).

Indirect behaviours linked seagrass conservation to land, food, and consumption. Respondents identified reducing meat consumption, reducing fish consumption, household waste, household pollution, and fertiliser use as relevant behaviours. These actions are less spatially explicit than boating behaviours, but are critical for addressing diffuse pressures that undermine seagrass resilience and align with broader pro-environmental behaviours associated with climate mitigation (Whitmarsh et al. 2021). Nutrient enrichment, sedimentation, and chemical pollution often originate from agriculture, urban runoff, wastewater, and household activities. Dietary shifts, including reducing meat and dairy consumption, may reduce demand for intensive livestock

production and associated nutrient runoff, sediment mobilisation, and land-use change. Similarly, reducing demand for unsustainably sourced fish may reduce pressure from fishing practices that damage seagrass habitats, alter coastal food webs, or contribute to cumulative marine degradation; demersal fishing pressure is a key driver of seagrass decline globally (Turschwell et al. 2021). These land-sea connections are harder to communicate, yet align with broader evidence linking consumption, trade, food systems, and resource use to biodiversity loss and environmental degradation (Lenzen et al. 2012; Dorninger et al. 2021; Hoang et al. 2023). Public messaging should therefore make these pathways explicit.

Systemic and governance-oriented behaviours were less frequently identified, despite many seagrass threats being shaped by institutions, markets, infrastructure, regulation, and political choices. Public behaviour therefore matters not only through lifestyle change, but through civic action, collective pressure, and support for governance reform (Bodin 2017). This aligns with social-ecological systems thinking, which emphasises that environmental outcomes emerge from interactions among ecosystems, actors, institutions, and feedbacks (Schill et al. 2019). The limited reporting of systemic behaviours may reflect reduced perceived agency at larger scales, where diffuse or institutionally embedded problems can diminish self-efficacy and collective efficacy (Thaker et al. 2016; Hamann et al. 2024). Conservation organisations should therefore communicate civic and collective actions, such as consultation responses, pollution reporting, voting, and stewardship, as legitimate pro-environmental behaviours.

Education and knowledge sharing were prominent, reflecting the low public visibility of seagrass relative to other coastal ecosystems, such as coral reefs and mangroves.

Awareness can shape norms, build stewardship, and increase support for regulation. However, education alone is unlikely to be sufficient (Rau et al. 2022). Research has repeatedly challenged the assumption that information deficits are the primary barrier to environmental action (Owens and Driffill 2008; Fisher et al. 2025). Behaviour change also depends on perceived control, situational costs, habits, norms, infrastructure, and structural barriers (Kollmuss and Agyeman 2002; Diekmann and Preisendörfer 2003; Liu et al. 2020; Kaiser and Brüggemann 2025). For seagrass conservation, education should therefore be treated as an enabling condition, and not the outcome.

This distinction is important for ongoing and future public engagement within and across seagrass conservation. Campaigns that only ask people to "learn about seagrass" risk stopping at awareness, whereas campaigns that link knowledge to specific behaviours, such as avoiding anchoring, reducing fertiliser use, supporting water-quality regulation, reporting pollution, or participating in local decision-making, may be more likely to produce meaningful long-term conservation outcomes.

Our results suggest that seagrass conservation needs a behavioural portfolio rather than a single public action (Brick et al. 2024). Restoration and citizen science have clear value, given they build connection, generate data, and create visible routes for participation, but they cannot substitute for actions that reduce the pressures causing seagrass decline in the first place. We argue that a more effective behavioural agenda would combine direct, indirect, and systemic actions. Direct actions reduce immediate physical damage. Indirect actions address land-sea pollution pathways, consumption, and household impacts. Systemic actions influence policy, governance, regulation, and social norms. Combined, these behaviours better match the multi-scalar nature of seagrass pressures.

Broadly, our findings point to three practical and actionable implications for seagrass conservation. Firstly, both scientists and conservation organisations should promote both awareness-raising and threat-matched behaviour change. Public engagement should specify which pressures a behaviour addresses, where that behaviour is relevant, and what ecological pathway it is intended to influence. Messages such as “protect seagrass” are unlikely to be sufficient unless they are translated into concrete actions.

Secondly, conservation organisations should communicate a broader behavioural portfolio. Restoration, volunteering, and citizen science remain important, but they should not be presented as the primary or only public routes to engage with seagrass conservation. Public-facing campaigns should include behaviours that address diffuse and systemic pressures, including household pollution, catchment health, sustainable consumption, water-quality regulation, coastal development, and climate action.

Finally, scientists and practitioners should begin to evaluate behaviour-change interventions against threat pathways, not only engagement metrics. Campaign success should not be measured solely through participation, awareness, or number of people reached, but through whether promoted behaviours plausibly reduce the pressures limiting seagrass persistence and recovery. This requires closer integration between ecological monitoring, social science, communication, and governance research.

These recommendations shift seagrass engagement from a general call to care towards a more strategic framework of public action. The central question that should be asked is not simply whether people are willing to help seagrass, but whether they are being asked to take actions that match the local, national and global drivers of seagrass decline.

This framework may also help move public- and donor-facing seagrass conservation messaging beyond restoration as the default action. Planting seagrass into degraded systems without reducing poor water quality, physical disturbance, or coastal development pressure risks treating symptoms while leaving causes intact. Behaviour change should therefore be positioned not as an add-on to ecological conservation, but as a core mechanism through which seagrass conservation is achieved. Effective seagrass conservation will depend on making the full range of relevant behaviours visible, feasible, and socially meaningful. The task is not only to inspire people to care about seagrass, but to align public action with the drivers of seagrass decline.

Data availability

All anonymised data will be made available on reasonable request.

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List of tables

Table 1. Public pro-environmental behaviours for seagrass conservation. Behaviour themes, definitions, and example actions derived from open-text responses provided by seagrass knowledge holders. Themes were developed through iterative thematic coding and grouped according to their intended conservation consequence or threat pathway.

Theme	Definition / examples
Advocate for broad marine governance	Support wider marine conservation measures, including protection of marine predators, ecosystem-based management, and broader marine protected area effectiveness.
Advocate for stronger seagrass governance	Support measures that directly strengthen seagrass protection, including marine protected areas, local marine management areas, restrictions on damaging fishing practices, and stronger seagrass-specific regulation.
Campaign for stronger coastal protection	Advocate for policies and initiatives that protect seagrass and coastal ecosystems, including improved water quality, stricter sediment-control rules, opposition to damaging coastal development, petitions, letters to elected representatives, and participation in public consultations.
Choose sustainable tourism and travel options	Choose tour operators, hotels, and coastal businesses with strong environmental practices, and avoid tourism activities or purchases that contribute to habitat damage or unsustainable wildlife trade.
Contribute to citizen science	Participate in seagrass monitoring, mapping, or data collection, and encourage friends, family, schools, or community groups to engage in citizen science projects.
Decrease fossil fuel consumption	Reduce high-emission personal activities, switch to renewable energy where possible, use public or active transport, and adopt lower-carbon lifestyle choices.
Donate time or resources to conservation and restoration	Volunteer with conservation organisations, support seagrass restoration, or donate time, funds, or resources to activities that protect or restore seagrass ecosystems.
Learn and share seagrass knowledge	Learn about seagrass meadows, share information with family and community members, and communicate local coastal rules, regulations, and conservation messages.
Limit plastic use and household waste	Reduce single-use plastic consumption, dispose of waste responsibly, recycle where facilities exist, use designated waste bins, and avoid littering.
Make sustainable food and consumption choices	Reduce consumption of high-impact foods, including meat and dairy where appropriate, choose sustainable seafood, and support lower-impact or sustainably produced goods.

Make small positive environmental changes	Adopt small, cumulative actions that reduce environmental harm and reinforce the idea that individual actions can contribute to broader collective impact.
Mobilise community stewardship of seagrass habitats	Form or support local groups to monitor, protect, or steward seagrass habitats, including groups with legal, organisational, or community support.
Participate in catchment conservation activities	Support or participate in upstream conservation actions that improve catchment health, including riverbank planting, wetland restoration, riparian restoration, and local watershed conservation groups.
Participate in coastal conservation activities	Take part in beach cleans, coastal clean-ups, local conservation activities, environmental NGOs, or broader efforts to leave coastal environments cleaner and less disturbed.
Practice and advocate for responsible boating and recreation	Avoid anchoring in seagrass, reduce idle speed in seagrass areas, use or support advanced mooring systems, follow boating guidance, and advocate for rules that reduce boat-based impacts, including sewage discharge.
Reduce direct disturbance to seagrass	Avoid walking, driving, trampling, or otherwise disturbing seagrass, support boardwalks or designated access routes, manage tourism access, follow local environmental rules, and support community stewardship.
Reduce household impacts on watersheds	Reduce chemical, nutrient, and plastic pollution from homes, limit cleaning products and garden chemicals, and manage greywater and septic systems responsibly.
Report local pollution events	Report coastal runoff, pollution, domestic waste, industrial discharge, or other water-based and land-based pollution events to relevant authorities.
Support sustainable farming	Advocate for reduced agricultural chemical use, including fertilisers and pesticides, and support farming practices that reduce nutrient enrichment, sediment runoff, and wider catchment impacts.
Use less fertiliser in gardens	Reduce fertiliser use on lawns, gardens, and other private land to limit nutrient runoff into waterways and coastal systems.
Vote for environmental protection	Use voting and civic participation to support leaders, parties, and policies that prioritise coastal protection, ocean health, water quality, and seagrass conservation.