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Advancing interdisciplinary science of gender is key to the success of blue carbon initiatives

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The lack of practical knowledge and effective engagement with gender in blue carbon initiatives poses a threat to their success and sustainability and risks exacerbating existing gender inequalities. Developed by an interdisciplinary team of experts, this paper proposes a research agenda, comprised of seven research areas as well as priority actions, designed to catalyze a shift towards more just, equitable and effective blue carbon initiatives. This paper is a call-to-action to increase commitment, funding, and collaborative, interdisciplinary science to close the gender gap in the conservation and restoration of blue carbon ecosystems and enhance their social-enovironmental impacts.

Blue carbon ecosystems (BCEs)—including mangroves, seagrasses, and salt marshes—are globally recognized for their capacity to capture and store carbon[1]. In their given contexts, BCEs also provide an expansive range of ecosystem services to coastal populations[2]. These ecosystems are highly productive, critical to food security and livelihoods for hundreds of millions of people across the world, and often exist in the territories of Indigenous Peoples and local communities[3,4]. Despite their significance, BCEs are some of the most endangered ecosystems on the planet. Over the past 50 years, mangroves have declined by 20–35%[5,6], seagrass ecosystems have declined by 35%[7], and salt marshes have declined by 25–50%[8] of their area. Given these ecosystems' social and ecological significance and their role in global climate change mitigation, there is increasing attention and investment in blue carbon initiatives, defined as practical, legal and political efforts to manage, conserve, and restore BCEs for the benefit of people, nature, and the climate. At the national level, countries are including BCE-focused conservation and restoration targets within their commitments to the Paris Climate Agreement, known as Nationally Determined Contributions (NDCs)[9], and within other climate and biodiversity policies (e.g., Kunming-Montreal Global Biodiversity Framework). A wide range of financing strategies exist for BCEs, including domestic and international carbon markets, as well as nonmarket

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climate finance approaches, such as payments for ecosystem services, results-based finance, and innovative insurance products[10]. Carbon markets have emerged as a popular avenue for mobilizing private sector finance to support BCE conservation and restoration activities that generate climate mitigation outcomes[11].

Often located near coastal communities, BCEs are widely accessible and routinely used by women and other community members for fishing and gleaning[12,13], which have led many BCEs to be socially identified as "women's spaces"[14]. Women are recognized as the bearers of valuable knowledge on BCE resource use and management and are critical to the successful conservation and restoration of BCEs[15]. Nonetheless, gender inequality is pervasive[16] and research shows that women are often excluded from decision-making and typically receive disproportionately low benefits from BCE management interventions (which broadly refers to placed-based programs or projects focused on conservation and restoration of BCEs)[17,18]. In fact, studies of conservation initiatives have demonstrated the potential for negative social impacts of management interventions, such as a marked decline in the wellbeing indicators of women engaged in some projects participating in the Reducing Emissions from Deforestation and Forest Degradation (REDD+) framework[19], limiting women's immediate freedoms to exercise agency[20], and increasing gender-based violence[21]. These inequities and exclusions are particularly true for women from vulnerable groups (including Indigenous women) experiencing compounding marginalizations[22].

Even with the advancement of ambitious global gender equality targets[23] and the recent increase in requirements from funding agencies to integrate gender into programs and projects, to date, relatively little progress has been made in actualizing these commitments to gender equality in the environmental conservation sector[24]. Several prominent challenges persist, such as the lack of consistent uptake and buy-in, widespread assumptions (e.g., gender equality is a women's issue)[25], and a pervasive gender data gap[26] with noted failures in transparency and availability of sex-disaggregated and gender data across national and global data systems[27]. Research on the convergence of gender (defined as a social construct, which considers the economic, social, political and cultural attributes associated with being men, women or other gender identities) and conservation practice is limited, and existing studies frequently conflate or misuse gender terminology or lack inclusion of important concepts, such as intersectionality (i.e., the compounding effects of social and gender discriminations)[28]. Furthermore, gender has been identified as a "blind spot" in ecosystem services research, even though it is a critical determinant of how people differentially benefit from ecosystem services[29].

In practice, the integration of gender and the use of commonly valued tools (e.g., gender assessments) in the execution of management interventions in the conservation sector lacks prioritization, qualified and knowledgeable practitioners, and sufficient resourcing[26]. When gender is considered, it tends to be done superficially, rather than being integrated more deeply into the design of the intervention[30,31]. For example, in one project in Papua New Guinea, communities were provided with clean cookstove technology to reduce mangrove deforestation for fuelwood. The design of the project focused on rapid, technological solutions and invested heavily in external expertise with limited understanding of social and gendered aspects. This caused confusion and uncertainty with local women who consequently halted the project[32]. As this example illustrates, BCE management interventions often fail to account for the views and experiences of diverse (and often less powerful) social groups in stakeholder engagement. As a result, many BCE management interventions are gender-blind, lack deeper analysis of social and gender power relations, and overlook issues of justice and equity across scales in environmental governance. These weaknesses have contributed to a persistent gender gap in the conservation and restoration of BCEs, which undermines the success and sustainability of those efforts, harms the wellbeing of local communities, and hinders the potential for positive impacts on gender equality.

BCEs sequester up to 10 times more carbon per unit area than terrestrial forests and provide many additional ecosystem services to coastal communities, making conserving and restoring BCEs a particularly attractive nature-based solution[33,34]. As such, investors interested in offsetting their carbon footprint via the voluntary carbon market have started to catalyze capital for blue carbon crediting projects—which refer to BCE management interventions that aim to result in mitigation benefits in the form of carbon credits that can be sold on the carbon market. While the rapid increase in demand for blue carbon crediting projects has fueled efforts to conserve and restore BCEs, it has also pushed project developers to move quickly, leaving deficiencies in the social, economic, and scientific rigor of project designs[35]. Mangrove-focused projects, in general, often fail due to science-based methods not being followed (e.g., unsuitable site selection, poor hydrological conditions or planting non-native species[36]) and/or lack of local engagement and, in some regions, they exhibit failure rates of up to 80%[35]. These challenges have led critics to raise concerns about the negative impacts of weakly-informed or top-down approaches and the potential for harmful impacts on community rights and livelihoods[37]. Against this background, effectively integrating a robust gender lens into BCE management interventions is a crucial and time-sensitive social innovation[38].

The lack of attention to gender leaves BCE management interventions at risk of exacerbating inequalities and weakening the social-environmental systems upon which long-lasting and resilient conservation outcomes are built[39]. Therefore, understanding the gender dimensions and related social-environmental relationships with and within BCEs and taking deliberate steps to incorporate them into the design and implementation of BCE management interventions is critical to their success[38]. To conserve BCEs and ensure inclusive, equitable, and just sustainable development, diverse and broad support is needed to improve how we perceive, prepare, and execute BCE management interventions. This paper is a call-to-action to increase commitment, funding, attention and collaborative, interdisciplinary science to close the gender gap in the conservation and restoration of BCEs.

A research agenda to turn the tide

This research agenda is a "guidepost" to turn the tide by strengthening gender knowledge and integration into BCE management interventions and blue carbon initiatives more broadly. It is the result of a collaborative effort of more than 20 gender, blue carbon, and BCE experts, including social scientists, economists, biophysical scientists, practitioners and private sector representatives (hereafter referred to as the authors), from a range of scientific and practitioner backgrounds and geographies including Africa, Southeast Asia, the Pacific, North and Central America, and Europe. The research topics were developed using a semi-structured, collaborative process over several months (including approximately a dozen virtual meetings, a three-day in-person workshop and online exchanges) and coalesced into seven research areas.

This research agenda reflects that practical, equitable, and sustainable ways forward require integration of perspectives and knowledge of diverse scientific disciplines[40]. Referred to as "interdisciplinary science", this embodies a collaborative approach that integrates knowledge, expertise, and methodologies from two or more scientific disciplines to address complex problems. In doing so, this research agenda builds on the recognition that incorporation of social dimensions will improve conservation, and without doing so, management inventions may fail[41]. This is particularly important in the context of blue carbon initiatives, which are otherwise framed primarily by

ecological and economic sciences. A unique feature of this research agenda is that it positions the science of gender as a science in its own right (not an add-on) to partake in this collaborative endeavor. Furthermore, this research agenda reflects the assumption that complex challenges require transdisciplinary collaboration, meaning the integration of scientific perspectives and knowledge with those of public, civil society and private actors. While this research agenda has started down this path by incorporating perspectives and knowledge from non-scientific actors, there is a need to deepen and sharpen the agenda in consultation with Indigenous Peoples and civil society groups. Last, the research agenda is directive and responsive—directing research efforts toward critical and emerging challenges and opportunities and responding to knowledge and capacity gaps identified as barriers to successfully implementing BCE management interventions.

Investigate the relationship between BCE conservation outcomes and gender impacts

BCEs are productive and accessible foodscapes and sources of livelihoods. They are also gendered spaces. Women commonly undertake fishing and resource use (i.e., fuel wood harvesting) in mangroves and other nearshore BCEs in proximity to their communities (in line with gendered norms and reflecting the need to concurrently fulfill their socially ascribed caring and household duties[42]) and hold valuable ecological knowledge critical to successfully conserving them[43]. In contrast, men often have more access to and control over resources and financing for boats and equipment and often undertake fishing in offshore areas[44]. As such, BCE management interventions are likely to have differentiated impacts on food, livelihoods and cultural assets of people of different genders and social backgrounds. Moreover, BCE management interventions may have intended and unintended impacts on underlying gender dynamics, and the perception of those impacts is likely to vary between actors, across and within different scales[45]. Unfortunately, it is often unclear whether and how women and men (and people of nonbinary genders) experience the costs or benefits of BCE management interventions. When conservation organizations integrate gender into BCE management interventions, efforts to monitor and assess gender impacts typically involve simple "box-checking" metrics, such as tracking the number of women present in meetings or activities. Overall, the use of theory of change processes and methodologies for measuring gender impacts are often poorly established and lack integration of key factors (such as intersectionality) or robust mixed method designs[28,46]. The focus of evaluative efforts tends to be on whether gender integration into BCE management interventions was applied, rather than on how it was experienced by communities and other stakeholders[31,47,48], with a few exceptions[49].

More attention is needed to improve the visibility, understanding and complexity of gender and other social impacts of BCE management interventions. Within the conservation sector, there is a dearth of tools and approaches to monitor and assess the impacts of BCE management interventions on gender dynamics at the community level. Existing evaluative tools, such as the Women's Empowerment in Fisheries Index (WEFI)[50], which measure the empowerment, agency and inclusion of women in fisheries and aquaculture, would need to be adapted for application in the context of BCE management interventions. Furthermore, when well-designed and implemented, theory of change processes can enable shared understanding across different actors, help to elucidate causal pathways, and clarify assumptions about gender and change processes, creating the foundation for effective design and measurement of gender impacts[51,52]. To advance knowledge in this area, research efforts should prioritize investigating causal linkages between gender equality, equity, and conservation processes and outcomes; understanding if and how enabling conditions (or other contextual factors) support or hinder the ability of BCE management interventions to have positive impacts on gender equality; and developing evaluation tools (or refining evaluation tools from other sectors, such as the WEFI) to better understand the impacts of BCE management interventions on gender dynamics within communities.

Advance gender equality through gender transformative approaches in BCE management interventions

Incorporation of gender approaches into conservation programming has evolved and grown in recent years. Decades of theory, practice, and growing bodies of evidence[25] have signaled the need to more accurately reflect the nuance of societies by going beyond gender as binary, engaging with diverse gender identities, and recognizing that women are not a homogeneous group (nor is any gender). This includes progressing efforts to understand how social and gender relations and structures (e.g., norms, policies) interact to compound experiences of discrimination or privilege (i.e., intersectionality). Furthermore, there are calls for conservation and development sectors to go beyond "add women and stir" or "empowerment lite" approaches[53] and to advance gender equality in more lasting ways through the smart application of gender transformative approaches--approaches that tackle the underlying causes of gender inequality by challenging and transforming societal norms, power dynamics, and structures that perpetuate these inequalities.

Historically, efforts to integrate gender have been dominated by accommodative approaches that work around or accommodate gender barriers[54] (Fig. 1). These approaches address visible inequalities and typically aim to "reach" or "benefit" women, such as by adjusting the times and locations of activities so that women can be involved despite their socially ascribed domestic responsibilities. Approaches that look to "empower" address visible inequalities by expanding strategic freedoms, usually by providing targeted access to economic, knowledge, health or other resources. Overall, effects of well-intended accommodative approaches and efforts to reach, benefit, or empower women have been critiqued as relatively limited or at risk of being short-lived[55] and/or leading to unintended consequences or backlash[17]. Examples from Mexico[56], Tanzania[57], and Solomon Islands[20] demonstrate that women engaging in BCE conservation can experience negative impacts, including increases in workload, social exclusion, and surges in gender-based violence. Impacts such as these occur when the norms underlying gender inequities (e.g., positioning women as caregivers and holding violence against women as appropriate if women disagree with or "disobey" men) are not addressed.

While "reaching" and/or "benefiting" women can have positive impacts, more lasting effects come from gender transformative approaches[58,59]. These disrupt the cycle of gender inequality by addressing it at the underlying structural level, not only in relation to visible symptoms. Core to gender transformative approaches is the focus on underlying structures that perpetuate inequalities, including gender relations, policies (e.g., constraining women's land tenure), and constraining gender norms[60,61]. Furthermore, gender transformative approaches engage men and women together in identifying and moving toward locally led, context-appropriate relations and structures that support equity and equality. To facilitate more effective and lasting gender outcomes within and beyond BCE management interventions, research efforts should prioritize understanding the key incentives, knowledge and capacity gaps needed to inform and execute gender transformative approaches that are fit for purpose in BCE social-environmental contexts.

Evaluate ways to ensure meaningful and gender equitable community ownership of, and participation in, BCE management interventions

Top-down or externally imposed BCE management interventions often fail to meaningfully engage local communities during the different phases of the intervention, especially in the initial design and agenda

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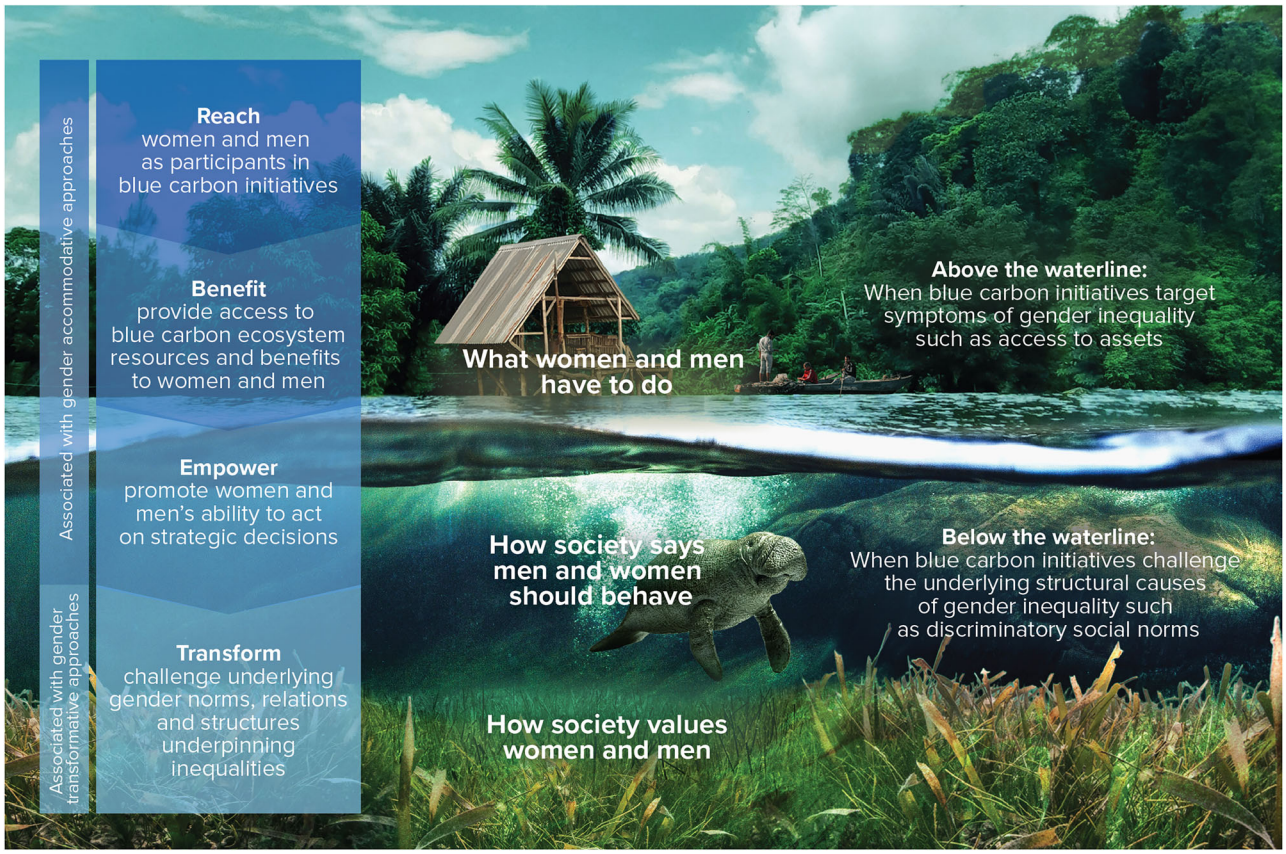

Fig. 1 | Reach, Benefit, Empower and Transform Framework for considering gender in blue carbon initiatives. The Reach, Benefit, Empower and Transform Framework is a tool that helps planners and implementers of blue carbon initiatives identify and analyze how activities contribute to improving the wellbeing of women and men. The figure has been adapted to specifically address blue carbon ecosystems and is sourced from a figure originally published under a *CC BY-NC* 4.0 *Attribution-NonCommercial* 4.0 *International license* by CARE in the publication "Gender Transformative Approaches for Advancing Gender Equality in Coral Reef Social-ecological Systems" by Jacqueline Lau and others. Background image provided by Garçon Design and figure designed by Conservation International.

setting[62]. There are increasing efforts to better center social dimensions, including community ownership and equitable participation, into ecosystem restoration interventions[63]; however, the extent to which these principles apply and are being applied in BCE management interventions is unknown.

A fundamental challenge relating to community ownership and participation in BCE management interventions relates to how fully and effectively interventions employ a bottom-up perspective to recognize and engage with local actors and institutions. At the community scale, this often includes systems of land and sea use and access rights that benefit particular groups over others or coexisting statutory and customary laws that influence BCE governance. In Timor-Leste, co-management arrangements enable communities to manage their coastal resources using a blend of *tara bandu*[64] (a customary mechanism) and local and national government involvement, plus support from external organizations. Similar examples, such as in Bangladesh[65], show that co-management of mangrove forests are often based at the local level, through village forums and groups, and connect to higher-level institutions with district and national stakeholders. Although co-management arrangements, such as these may be valuable tools that lay a bottom-up foundation for community-led coastal management, they do not ensure equitable benefit-sharing between gendered social groups. The nature of women's participation and engagement varies across the mechanisms, actors, and interacting scales of governance[66]. Even when women are intentionally included in management activities, this does not necessarily result in increased decision-making power[67] and women often experience gender inequality in participation[65]. Co-management arrangements with local institutions can be an opportunity to seek greater participation of diverse stakeholder groups in decision-making processes that can empower communities in managing their coastal resources. However, critical reflection on the power dynamics behind participatory approaches, as well as of gendered power dynamics and cultural norms and expectations in the local context, is needed to avoid doing harm.

As a way forward, the nature of research around BCEs offers an opportunity for more meaningful and equitable engagement of community actors of all genders. A bottom-up perspective—borrowing from a "humanity-centered design" approach[68] – is needed to center local actors, especially women and marginalized social groups, in the design process. Furthermore, experienced facilitation is needed so that less powerful actors are not overpowered in the multi-actor processes. Centering gender equality in the processes goes beyond who is invited or represented to equity in voice and influence. Using such an approach can reveal what empowerment means for women in a particular context and lead to more inclusive, equitable and sustainable interventions by working with and through communities holistically, in ways that strengthen the entire social-environmental system, including improving women's status and how they contribute to and benefit from the system[69]. Research efforts should seek to strengthen community ownership and equitable engagement in BCE management interventions by investigating patterns and drivers of inclusion (and exclusion) and evaluating the distribution of decision-making power, rights, benefits and burdens among diverse gender and social groups in BCE social-environmental contexts.

Interrogate how gender and power relations shape agency to access, participate, and benefit from BCE management interventions

The availability of choice, and the capability to exercise it, are essential for individuals to access, participate in, and benefit from BCE management interventions and opportunities[20]. Agency, defined as what a "person is free to do and achieve in pursuit of whatever goals or values he or she regards as important"[70], is gendered in BCE social-environmental contexts. Gendered expectations about what it is to be a woman or a man (or other gender), and relationships of power, shape an individual's capability to access and make choices. Gendered differences in agency mean that women, and other marginalized groups, tend to be less able to make or influence decisions on BCE resource use and management[20]. In this, blue carbon initiatives mirror development initiatives in other sectors by being criticized for not addressing the imbalances in power dynamics that ultimately shape the equity of initiatives[19,71]. As an illustration, a terrestrial carbon project in Nepal found that existing elite and male-centered practices were reinforced when men had more access and choice in preparation of meeting agendas and were more dominant in providing input than women or other social groups[72]. Furthermore, in cases where individual women may be elevated into leadership positions, these decision-making structures are often underpinned by constraining gender norms and unequal relationships of power, meaning such changes do not translate into women's greater voice or influence[71]. Women's marginalization from decision-making can be further compounded by women having less flexibility to attend project meetings due to the constraining gender norms related to gendered divisions of labor (i.e., caregiving responsibility and food provisioning)[20].

Whether BCE management interventions intentionally acknowledge and engage with gender or not, they can have flow-on effects on the agency of men, women, and other gender groups. For example, minimal or tokenistic engagement of women or marginalized groups (such as including women in management committees without creating the conditions that allow them to have real decision-making power) may further reinforce their limited role in decision-making, uphold inequitable community structures, and overlook the views, needs and aspirations of society's most vulnerable[59,73]. BCE management interventions are most likely to achieve sustained and equitable outcomes if they are designed and delivered based on robust understanding of how people of different genders rely on, use, and engage with BCEs. There remains considerable scope for research to investigate how BCE management interventions can best apply this knowledge in a way that challenges and shifts the underlying norms and relationships that perpetuate gender inequality. Research efforts should prioritize interrogating how intersectional gender power relations and norms influence agency of individuals in the management and use of BCEs and how the nature and strength of collective agency (including via civil society organizations, women's coalitions, etc.) shape the outcomes of BCE management interventions.

Examine issues of social equity, gender, and justice in the multiscale governance of BCEs

Effective conservation and restoration of BCEs necessitates interaction between a variety of formal and informal governance systems (agents, rules, and processes at different levels of decision-making at and across multiple scales). Gendered exclusions and inequities are embedded within these systems, manifesting as hierarchies within hierarchies. These systems reflect gender (and social) power imbalances present in the wider BCE social-environmental arena[74], which can lead to intersectional gendered exclusions and marginalizations as well as inequitable outcomes in the collaborative governance of BCE management interventions[75]. Recent scholarship highlights that social aspects of biocultural approaches to sustainability (such as BCE management interventions) have not been substantively addressed, whereby gender issues have been largely overlooked[76].

While gender equity is increasingly considered at the community level (see section above), questions of social equity, gender and justice, more broadly, across scales has received less attention. All too often, multiscale governance reflects a top-down framing and process with local communities and marginalized groups situated at "the bottom rung" on the ladder, despite being the most climate vulnerable, the least responsible for climate change, and the most directly dependent on BCEs for their livelihoods and wellbeing. A result of inter-actor, inter-scale power relations, specifically between communities and external actors, these systems reflect neocolonial "big D development" dynamics[77], which refers to intentional, large-scale and often externally driven interventions that manifest in inequitable distribution of burdens and benefits between more powerful external actors and communities. Despite their direct reliance on BCEs for food and livelihoods, innate rights, and history of management, communities (and women and other marginalized groups within communities) have the smallest sphere of influence (e.g., Fig. 2 of carbon market actors). Moreover, as funds flow from the top towards the community, they are reduced as each actor along the chain draws funds and benefits—leaving the community with a small portion of funds to generate benefit for local actors (who ironically may be termed "beneficiaries"). A review of blue carbon crediting projects across the Asia-Pacific region revealed that around 80% of the average carbon credit price goes to project developers without benefiting local communities[78].

Addressing these historical imbalances requires more holistic and critical perspectives on multiscale power relations, and procedural and distributional justice within BCE management intervention design, implementation and monitoring. When these are not sufficiently understood, considered, or addressed, there is a risk that BCE management interventions may reinforce inequities and exacerbate the exclusion of communities and marginalized groups. Ways forward may involve advancing social equity by balancing power, perspectives, and aspirations between communities and other actors along the whole chain, striving for inclusive, equitable, and collaborative decision-making. Reliable and robust evidence is needed to guide the development of practical equity-enhancing mechanisms. Research efforts should prioritize building understanding of how gender (and social) dynamics manifest across scales and in relation to different financing and management approaches and systems in different contexts. As a foundation, research is needed to uncover differing perceptions of justice among actors at different scales within the BCE social-environmental arena.

Understand the impacts of commodification of BCE resources on gender and social-environmental sustainability

In BCE management interventions, the commodification of BCE resources (i.e., fisheries, aquaculture, seaweed, etc.) is often considered to be a livelihood benefit that helps to drive sustainable economic growth[79]. Efforts to commodify or increase the economic value (e.g., value adding) of BCE resources are often pursued to improve local livelihoods. Given their close connection to BCEs, these efforts often focus on women and include enhancing women's capacity to engage in and benefit from the value chains of new and existing BCE commodities. For example, women's traditional role harvesting mud crabs has put women at the center of interventions to sustainably harvest, farm and manage mud crab fisheries in Fiji[80]. In Fiji, and in other examples, such as an octopus fishery initiative in Madagascar[81], women and men often benefit from commodification efforts, with men typically benefiting more than women.

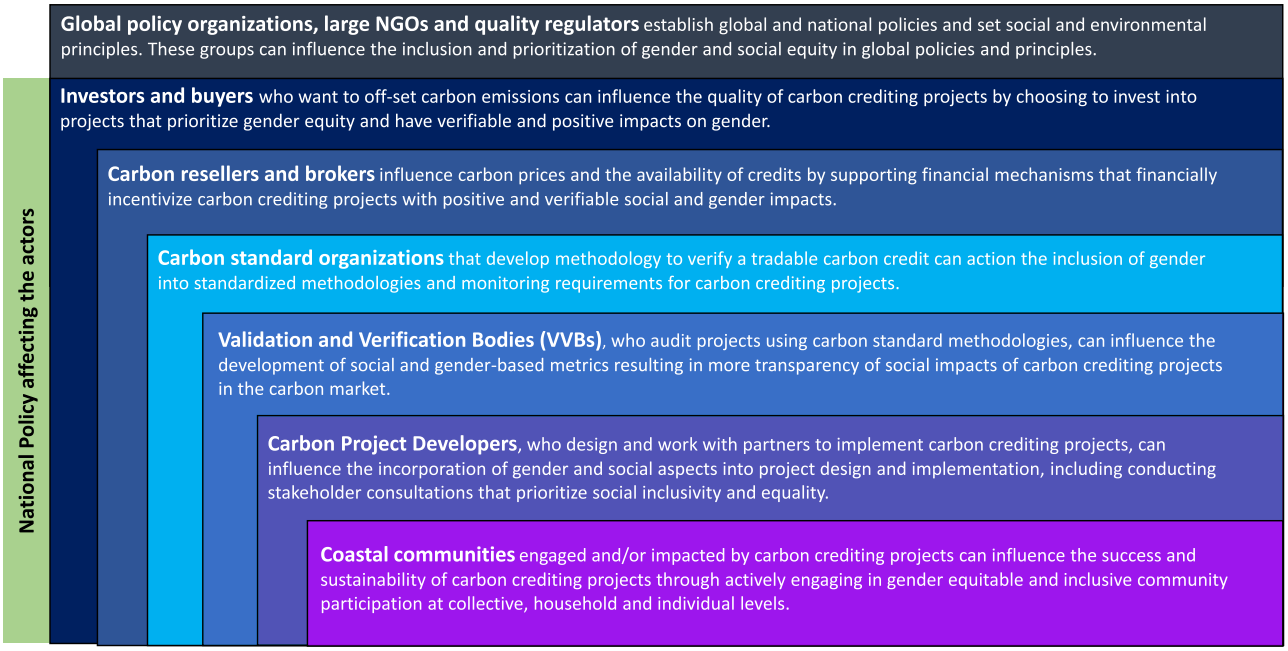

Fig. 2 | Carbon market actors and their sphere of influence. This figure depicts various carbon market actors and their spheres of influence related to gender. The location of the actors in this figure is representative of the top-down nature of carbon markets. Applying a gender transformative approach could help to challenge the uneven distribution of power in these markets. Source: authors.

Unfortunately, the implications of commodification of BCE resources are not always positive. The likelihood that commodification will derive positive social-environmental impacts depends on the presence of enabling conditions, capacities, capabilities, and resources available within communities, local institutions, and at the national level among public and private sector stakeholders[82,83]. Even when favorable conditions exist, the commodification of previously un-commodified BCE resources, or shifts in their economic value, can be detrimental, especially for women and populations with less "relative power" and living in more precarious conditions[84–87]. Often driven by private sector, governments, or non-governmental organizations and other actors, commodification or change in economic value of BCE resources can lead to unsustainable and perverse socio-cultural or economic patterns that in turn harm communities[84–87]. For example, increasing the value of a commodity can lead to new players entering the fishery, displacing women and shifting away from sustainable harvesting practices as seen in an octopus fishery in Madagascar[88] and a sea cucumber fishery in Palau[89].

To mitigate the risks of commodification, effective, equitable, and legitimate BCE governance that embrace sustainability principles is paramount. Governance mechanisms need to be rooted in locally led, transparent and long-term planning, taking into account and mitigating future risks, such as land grabs or displacement. Additionally, BCE management interventions should be designed, monitored and evaluated using a human-centered design approach with an explicit gender and social inclusion lens. Furthermore, interventions that effectively integrate commodification activities with other conservation approaches that emphasize traditional knowledge, customs, and rights have the potential to ground changes in behavior to deep-rooted social foundations and lead to positive and sustainable social-environmental impacts[84,86]. Research is needed to unravel the intersectional gendered nature of commodification of BCEs (specifically to understand how commodification of BCE resources impacts resource access, use and control between genders and social groups within communities and between communities and external actors), direct future efforts to build just, gender equitable governance mechanisms, and understand the enabling conditions that empower communities to sustainably and equitably 'benefit' from their BCE resources.

Strengthen gender integration in blue carbon crediting projects, policy, and the carbon market

The carbon market is a financial mechanism that connects actors interested in purchasing carbon offsets (in the form of credits) with projects that produce verifiable carbon credits, most of which are currently located in low-income countries. Investors and credit purchasers can influence blue carbon crediting projects by prioritizing and incentivizing investment in high-quality projects that support benefits beyond climate mitigation (Fig. 2). Unfortunately, the authors have observed that there is little awareness in the corporate sector regarding the role of gender integration in successful and sustainable blue carbon crediting projects, and research efforts are needed to explore how to build gender awareness with these actors. While there are carbon crediting standards that use accounting methodologies to transparently quantify and communicate the carbon mitigation benefits of blue carbon crediting projects, only a few include criteria to evaluate the integration of gender and other socially inclusive processes, and those that do face challenges in verifying on the ground impacts[90].

Rising awareness of these shortcomings has led to the development of optional add-on standards, such as the Climate, Community and Biodiversity Standard (CCB)[91] and the W+ Standard[92], which provide accounting methods for the incorporation of social and environmental principles and requirements into the design and implementation of crediting projects. Furthermore, new tools, such as the High-Quality Blue Carbon Principles and Guidance[93], Integrating Gender into Design, Implementation and Monitoring of Carbon Credit Projects[90], and the High-Quality Blue Carbon Practitioners Guide[94] provide principles and guidance for a range of actors to base blue carbon crediting projects in a firm understanding of national and local social contexts, applicable legal frameworks, and target level of engagement and consultation with local communities and other

stakeholders. The application of optional certifications and standards allows blue carbon projects to receive premium carbon prices and often results in increased financing; however, these new tools and standards have yet to be widely applied and evaluated. An assessment of the Verra Registry revealed that less than 15% of blue carbon crediting projects have opted to include the CCB standard. Overall, there continues to be a lack of visibility on the effective integration of gender and other social standards within blue carbon projects.

Policy and legislation tools are essential to driving the sustainable and effective financing of blue carbon initiatives. Unfortunately, gender considerations are limited within efforts to strengthen the integration of BCEs into global and national climate, biodiversity, and development policies, such as NDCs, national climate change plans, biodiversity strategies, and sustainable development plans. Strengthened incorporation of intersectional gender evidence within BCE policy discussions under the UN Framework Convention on Climate Change and the Convention on Biological Diversity could enable greater clarity on how these efforts can progress their commitments to equity[95]. At the national level, policies, such as national blue carbon strategies, REDD+ strategies, and national climate plans set standards for the implementation of high-quality blue carbon crediting projects. Including gender science (and scientists) in the development and implementation of these policies could help to move from relatively abstract commitments to gender equality to more granular and effective strategies and guidance for operationalization. This could include in relation to preventing harm, equitable carbon rights and land tenure, benefit sharing agreements, grievance and legal redress mechanisms, and safeguards, including Free, Prior and Informed Consent—all aspects that have the potential to improve positive social-environmental outcomes when developing and implementing crediting projects.

Incorporating gender considerations into the design and implementation of blue carbon crediting projects and systems can enhance the socioeconomic stability, permanence, and effectiveness necessary for generating quality blue carbon credits. Appetite within the carbon market to pay higher prices per ton of carbon when combined with "optional standards and certifications"[96,97] indicates interest in investing in gender and social assessment processes and tools to enhance the sustainability of investments and safeguard against risk inherent in poorly designed blue carbon projects that can lead to negative impacts on communities[96,97]. Research efforts should prioritize identifying gaps and opportunities to scale application of gender-integrated carbon market standards, methodologies and certifications. Efforts are also needed to build the skills and capacity of carbon crediting programs and verification bodies to effectively review, evaluate and validate socially inclusive processes and gender outcomes. Additionally, in relation to assessment, gender integration should be a required factor for considering the permanence[98] of blue carbon projects (alongside current factors, such as tenure and regulation requirements), and research is needed to identify practical and appropriate gender evaluation methodologies. Last, with timelines for blue carbon crediting projects typically between 30 and 50 years, there is opportunity for these projects to pioneer long-term purposive gender approaches—this requires not only design of gender strategies but also iterative long-term evidence building around causal factors for shifts in gender drivers and longitudinal outcomes in these social-environmental contexts.

Moving forward with priority actions

As blue carbon initiatives progress on a global scale and standards and processes of blue carbon crediting projects are strengthened, targeted interdisciplinary gender research is needed across all scales. Building on the above research areas, here we identify priority actions necessary to create the enabling environment for key actors (i.e., communities, local institutions, INGOs, intergovernmental organizations, project developers, institutions, and universities) to undertake high-quality, interdisciplinary gender research and effectively incorporate findings into knowledge and practice. Advancing the priority actions can support bridging the gender knowledge gap in this sphere and create fertile ground for blue carbon initiatives to achieve positive and sustained gender (and social) impacts and environmental outcomes.

Priority actions by and for communities and associated civil society organizations should focus on contributing to collective agency and action. Specifically, priorities may include distilling, elevating and pro-actively communicating expectations and standards for engagement in BCE management interventions, including procedural, tenure, and other rights being recognized and enacted. This may require civil society and community-led capacity strengthening (such as on negotiation) and planning prior to engaging in BCE management dialogs or planning (such as how community representation will avoid elite capture and identify local priorities and non-negotiables). Clear, strong and equitable engagement with local communities from the beginning enables communities to shape interventions around their needs; provides communities with sufficient and timely information to make decisions and negotiate effectively with project developers; and increases the likelihood of communities, including women and marginalized groups, being effective and equitable co-owners of BCE management interventions.

Within BCE management interventions, priority actions should focus on integrating gender and social equity into the BCE management intervention design, processes and outcomes consistently, effectively and ambitiously. This involves the use of existing and valued early-stage steps, such as gender analyses and gender action plans, to effectively inform the BCE management intervention design and development processes. Consistent use of quality gender analyses to inform intervention design can help to preempt barriers and leverage opportunities for different gender and social groups and ensure solutions are inclusive and equitable. Effectively integrating gender and social equity into BCE management interventions also requires recognition and prioritization of the diverse skills and capacity needed to effectively implement gender approaches. BCE management interventions sit at the nexus of academic, practitioner, civil society, public sector, and local knowledge and require interdisciplinary teams and transdisciplinary collaborations to protect BCEs and support people. Once the standards and expectations for gender integration are raised, the sector can turn to laying the foundation for more lasting and positive outcomes by engaging in gender transformative strategies.

Finally, given the number of different disciplines and actors engaged in BCEs, the importance of framing and communication cannot be understated. Action should be taken through transdisciplinary collaboration to establish shared gender language around which to build consensus and understanding among diverse actors. The framing of BCEs, whether in the context of 'conservation', 'biodiversity', 'climate change adaptation and resilience', 'blue foods', and 'fisheries management', 'economic and social development', or 'conflict prevention and peacebuilding', affects what is prioritized. Therefore, finding broadly accessible language and terminology for gender and BCE concepts is essential. This includes making gender and blue carbon language accessible to key actors, exploring how BCE benefits are framed and communicated, valuing ways community members (including those from different genders) frame and communicate their knowledge and perspectives, and adopting less hierarchical data collection methods that highlight alternative voices and perspectives (e.g., storytelling, photo-voice[99], participatory mapping[100], etc.). Ultimately, blue carbon initiatives should foster and facilitate enabling

environments for different voices and perspectives to be heard, understood, valued and incorporated.

Call to action

This paper is a call to action to increase commitment, funding, attention and collaborative, interdisciplinary science to close the gender gap in the conservation and restoration of BCEs. It is the result of an interdisciplinary and transdisciplinary collaboration between the authors with expertise and experience in social science, biophysical science, economics, conservation and BCEs. The seven research areas and priority actions were derived to direct interdisciplinary research efforts toward the most pertinent and problematic gender knowledge gaps inhibiting blue carbon initiatives from reaching their potential for just, gender equitable, and sustainable social-environmental change. Furthermore, closing the gender gap in the conservation and restoration of BCEs can also provide valuable insights into advancing gender equality in environmental conservation and development sectors more broadly through the generation of evidence-based approaches and best practices.

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Author contributions

The contributing authors (L.A., N.A., M.B., S.C., S.D., K.G., J.H., J.H., J.H., R.J., S.L., S.M., C.M., K.M., J.N., M.N., E.P., S.R., K.W., S.Y. and L.Y.) participated in multiple remote sessions and one in-person workshop in the formation of this collective work, as well as contributed draft text and provided review and input in multiple phases of manuscript development. Lead (W.Y.) and co-author (D.L.) are listed first, followed by all contributing authors in alphabetical order.

Competing interests

The authors declare no competing interests.

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