PLOS CLIMATE

REVIEW

Capitalizing on the global financial interest in blue carbon

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Abstract

Natural climate solutions are crucial interventions to help countries and companies achieve their net-zero carbon emissions ambitions. Blue carbon ecosystems such as mangroves, seagrasses, and tidal marshes have attracted particular attention for their ability to sequester and store carbon at densities that can far exceed other ecosystems. The science of blue carbon is now clear, and there is substantial interest from companies and individuals who wish to offset greenhouse gas emissions that they cannot otherwise reduce. We characterise the rapid recent rise in interest in blue carbon ecosystems from the corporate sector and highlight the huge scale of demand (potentially $10 billion or more) from companies and investors. We discuss why, despite this interest and demand, the supply of blue carbon credits remains small. Several market-related challenges currently limit the implementation of blue carbon projects and the sale of resulting credits, including the cost and burden of verification of blue carbon compared to verifying carbon credits in other ecosystems, the general small scale of current blue carbon projects, and double counting of credits between commercial and national institutions. To overcome these challenges, we discuss other supplementary financial instruments beyond carbon credit trading that may also be viable to fund the conservation and restoration of coastal habitats, such as bonds and ecosystem service insurance. Ultimately, a portfolio of financial instruments will be needed in order to generate funding streams that are substantial and reliable enough to realise the potential of blue carbon ecosystems as a natural climate solution.

1. Introduction

Keeping global temperature increases within 1.5-2˚C above pre-industrial levels will require the rapid decarbonization of the global economy, alongside technological and other solutions that draw down greenhouse gas emissions from the atmosphere. Natural climate solutions refer to a range of management actions that increase carbon sequestration by vegetation, and are an essential supplement to decarbonisation efforts for countries and corporations with net-zero ambitions. Natural climate solutions can potentially sequester 23.8 petagrams of CO_2e per year, which represents 37% of the cost-effective CO_2 mitigation required by 2030 for a >66% change of keeping temperature increases below 2˚C [1].

The protection and restoration of coastal ecosystems such as mangrove forests, seagrasses, and tidal marshes has been highlighted as a key set of natural climate solution pathways [1]. These ecosystems are collectively known as 'blue carbon' ecosystems (BCEs) due to their high rates of carbon sequestration and high densities of permanent carbon storage relative to their small extent [2]. This translates to a negative sustained global warming potential compared to most terrestrial and freshwater ecosystems [3]. A large proportion of this carbon is stored in waterlogged soils, where decomposition processes are slower and soil carbon accumulates over millennia instead of being released back to the atmosphere. As a result, BCEs store >30 Pg of carbon globally across approximately 185 million ha [4]. Over the past decade, global wetland experts have established the climate mitigation potential of these ecosystems and the science is clear [5]. Academic, government, non-governmental and corporate actors are now beginning to build the essential tools to integrate blue carbon into climate policy, financing, and management. As such, blue carbon is now being considered a key contributor to the broader Blue Economy [6].

Blue carbon has received specific attention from commercial stakeholders wishing to offset emissions that cannot be eliminated through decarbonization and production efficiencies. Natural climate solutions (predominantly terrestrial carbon) currently receive only a few percent of global climate finance, despite their potential to facilitate substantial climate draw down by 2030 [1]. However, financing is expected to increase rapidly; corporate stakeholders are increasingly committing to net-zero emissions goals as part of their post-COVID 'green recovery' [7], and blue carbon has gained particular interest in this context because it is regarded as a natural climate solution that can provide key additional benefits that align with corporate social responsibility.

Yet, despite the interest from the corporate sector, thousands of scientific studies on BCEs, and the continued loss of these ecosystems worldwide, only a handful of blue carbon projects are currently producing and selling carbon credits. As a result, we have not yet capitalized on the huge demand for blue carbon credits from the corporate sector. Blue carbon remains a niche offsetting approach, though like many markets it is expected to become mainstream once specific constraints are overcome [8]. In this qualitative review we evaluate the current landscape and potential for blue carbon finance, discuss why this potential has not yet been realised, and suggest a finance portfolio approach to overcome current barriers to implementation.

2. Current and future interest in blue carbon

2.1 The potential for blue carbon as a natural climate solution

BCEs have attracted substantial interest as a natural climate solution because of their high rates of carbon sequestration and storage [2]. BCEs are also a strong candidate for conservation finance because they have experienced extensive historical loss, and continue to be threatened around the world [9–11]. Habitat loss represents an important source of carbon emissions both historically and into the future. For example, it has been estimated that continued rates of mangrove loss will result in almost 3400 Tg CO_2e released and lost due to foregone soil carbon sequestration by 2100 [12]. As such, many blue carbon landscapes satisfy the additionality criteria required for carbon credit generation. There is also scope for BCEs to draw down emissions further through restoration. While net carbon sequestration is dependent on restoration age [13], restored BCEs are able to rapidly sequester carbon [14] as well as reduce methane emissions through the reintroduction of tidal exchange [15]. The scope of resulting carbon gains could be large, because at least 800,000 ha are biophysically suitable for mangrove restoration around the world [16], and large areas are expected to be suitable for the restoration of other BCEs [4]. When avoided emissions and restoration are combined, the scope of carbon additionality is large. Globally, the conservation of all BCEs could avoid the emissions of 141–466 Tg CO_2e per year, and their large scale restoration would draw down a further 621–1064 Tg CO_2e per year; the combined carbon benefits are equivalent to ~3% of global carbon emissions [1, 4]. The full blue carbon wealth generated by blue carbon sequestration has been valued at >US$190 billion per year [17].

Conserved and restored BCEs are further attractive as a natural climate solution because they provide a range of other ecosystem services that are monetizable or otherwise support local livelihoods [18]. This includes provisioning services such as fish, construction materials and fuel [19], regulating services such as coastal protection [20] and pollutant trapping [21], and myriad cultural services including ecotourism [22] and spiritual values [23]. These additional ecosystem services are important because they are often more directly relevant to local coastal communities than global climate change mitigation through carbon sequestration, and in some cases can provide further financial incentive (alongside carbon finance) for coastal conservation and restoration.

2.2 The potential for investment in blue carbon

Global corporate interest in natural climate solutions has blossomed in the context of the COVID-19 pandemic. There is a clear push from G20 countries for a green economic recovery that prioritises a net-zero transition, with investment in natural capital a clear priority [24]. Experience from previous economic crises suggests that a green recovery can have a higher return on investment than returning to business as usual, and will be even more effective if fossil fuel subsidies are reallocated to net-zero strategies such as natural climate solutions [25].

The financial sector certainly sees natural climate solutions as an important contributor to corporate net-zero ambitions, with the voluntary carbon market worth potentially as much as $50 billion by 2030 [26]. Natural climate solutions, particularly avoided deforestation and forest restoration projects accounted for 22% of CO_2 volume transacted globally on the voluntary carbon market between 2008 and 2018 [27], increasing to 52% of CO_2 volume in the first half of 2021 [28]. This is expected to increase further in the near future, as increasing quality standards cause the retirement of some other carbon credit types (such as those produced prior to 2015), coupled with a stronger desire from buyers for credits that have higher environmental integrity and co-benefits, which avoided deforestation and restoration carbon projects are assumed to provide.

Blue carbon is currently a small slice of the carbon market pie, but the potential for blue carbon finance within the voluntary carbon market is large. For example, ~20% of the world's mangrove extent (~2.6 million ha) could potentially qualify for avoided deforestation carbon credits, generating 1.1 billion USD per year [29]. The higher rates of habitat loss for ecosystems such as seagrasses [11] suggests even greater potential for other BCEs. A recent market survey showed that 51% of asset managers saw opportunities for investment in blue carbon [30], motivated by regulatory requirements and corporate social responsibility [8]. Major banks have highlighted a US$11.1 billion investment requirement for carbon sequestration through global mangrove restoration [31], and this scope has attracted the interest of accounting firms [32] and asset managers [33].

The commercial interest in blue carbon is now strong enough that investors are pushing ahead to identify and fund blue carbon opportunities. A major bank recently announced the launch of two natural capital funds that are expected to raise a combined investment capital of up to US$3 billion, with BCEs a key focus [34]. A financial services company is developing a

Table 1. Summary of recent finance initiatives to facilitate the development of blue carbon projects.

Initiative	Sector	Potential funding availability	Ref
Natural Capital Fund	Banking	US$3 billion (unspecified proportion to support blue carbon)	[34]
Public-private Partnership for Blue Carbon Projects	Banking	Unspecified	[35]
Blue Carbon Facility	Fund manager	US$50 million (unspecified proportion to support blue carbon)	[36]
Blue Natural Capital Financing Facility	Intergovernmental	Unspecified	[37]
Blue Carbon Accelerator Fund	Intergovernmental	Unspecified	[38]
Blue Carbon Challenge	Multiple	Unspecified	[33]
Blue Carbon Buyers Alliance	Business	Unspecified	[40]
Global Blue Carbon Coalition	Governments, banking, insurance, intergovernmental, NGOs	Unspecified	[39]

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public-private partnership financing model to facilitate blue carbon project development [35]. Carbon project developers are partnering with investors and other stakeholders to establish structures to facilitate blue carbon project development (Table 1), such as the Blue Carbon Facility [36]. Similarly, the Blue Natural Capital Financing Facility and Blue Carbon Accelerator Fund were established to facilitate cooperation between stakeholders such as financiers, technology providers, and academia [37, 38]. The World Economic Forum has established the Blue Carbon Challenge, which will identify and support potential blue carbon projects through financing, training and education [33]. In February 2022 at the global One Ocean Summit, the French President Emmanuel Macron announced the formation of the Global Blue Carbon Coalition, bringing together governments, intergovernmental organisations, international NGOs and banking and insurance partners to scale blue carbon projects [39]. These examples show that multiple structures and partnerships are now being put in place to facilitate the development of blue carbon projects, and the commercial sector is increasingly primed for blue carbon opportunities.

3. The current state of blue carbon projects

Blue carbon projects are recent compared to credits from management activities in other forest types, so are based on verification methodologies created for terrestrial carbon projects. Certified carbon credits for the voluntary carbon market were first produced by community-based terrestrial forestry activities in Mexico by Plan Vivo in 1997 [41], with a focus on poverty alleviation through community-based action, and a commitment to send at least 60% of income to host countries. A suite of market-based verification standards have also been created by Verra. Their Verified Carbon Standard (VCS) is the world's most widely used voluntary greenhouse gas emissions offset program, with ~1800 projects that have collectively removed >865 million tonnes of greenhouse gas emissions from the atmosphere [42].

Two projects have been instrumental in showing the viability of blue carbon projects, using both verification processes. Mikoko Pamoja in Kenya [43] was the world's first mangrove avoided deforestation and restoration project of 117 ha, validated under Plan Vivo and issuing credits in 2014. The project was a collaboration between the local community, an international university and a Kenyan Government Research Institute. Mikoko Pamoja is not reliant on profits, and locally rooted and owned (and therefore built upon trust and long-term relationships). These features explain its success and longevity, and suggest some of the challenges in scaling the approach to larger areas. A critical early challenge was in finding buyers for voluntary credits, though demand for credits now usually exceeds supply. Key challenges now are overcoming the initiation costs for expanding existing and establishing new projects, and in avoiding the moral hazard and greenwashing involved in selling credits to organisations without credible plans for emissions reductions. This is a political risk that could undermine public support for blue carbon more generally [44].

A second key blue carbon project has been at Cispatá Bay in Colombia. Local communities, regional authorities, research institutes, local and international NGOs are working to protect and restore 11,000 hectares of mangroves, aiming to sequester ~1 million tons of CO_2 over 30 years, in addition to a range of biodiversity, hydrological, social, and cultural benefits. Upfront financing supported mangrove conservation in collaboration with local communities, and the development of blue carbon credits certified under the new coastal conservation and restoration modules of the VM0007 VCS. Carbon credits were issued in May 2021 by Verra and certified under the VCS and the Climate, Community and Biodiversity Standards. These are the first VCS-certified blue carbon credits under the new modules. Within eight months of credit issuance, the Cispatá Project sold all available credits at above-market prices. Generated finances are managed by a board of local stakeholders, community representatives and technical advisors. Credit sales are not sufficient to cover all program costs, but 92% of funding goes back into the project, covering ~70% of the funding required to implement mangrove conservation and restoration activities. The remaining funding gap is currently covered by government funding, international cooperation, and biodiversity loss compensation. The project will expand to include mangroves in two additional locations (La Caimanera and Guacamaya), and the national government has pledged to replicate Cispatá's success in at least six further locations, turning a local project into a national program.

In total there are currently 8 validated mangrove blue carbon projects and 1 validated seagrass blue carbon project, with the majority established since 2019. However, the number of validated blue carbon projects is expected to more than double in the near future (Fig 1, Table 2). Several projects are planned in Indonesia, Tanzania, Mexico, Honduras and Japan.

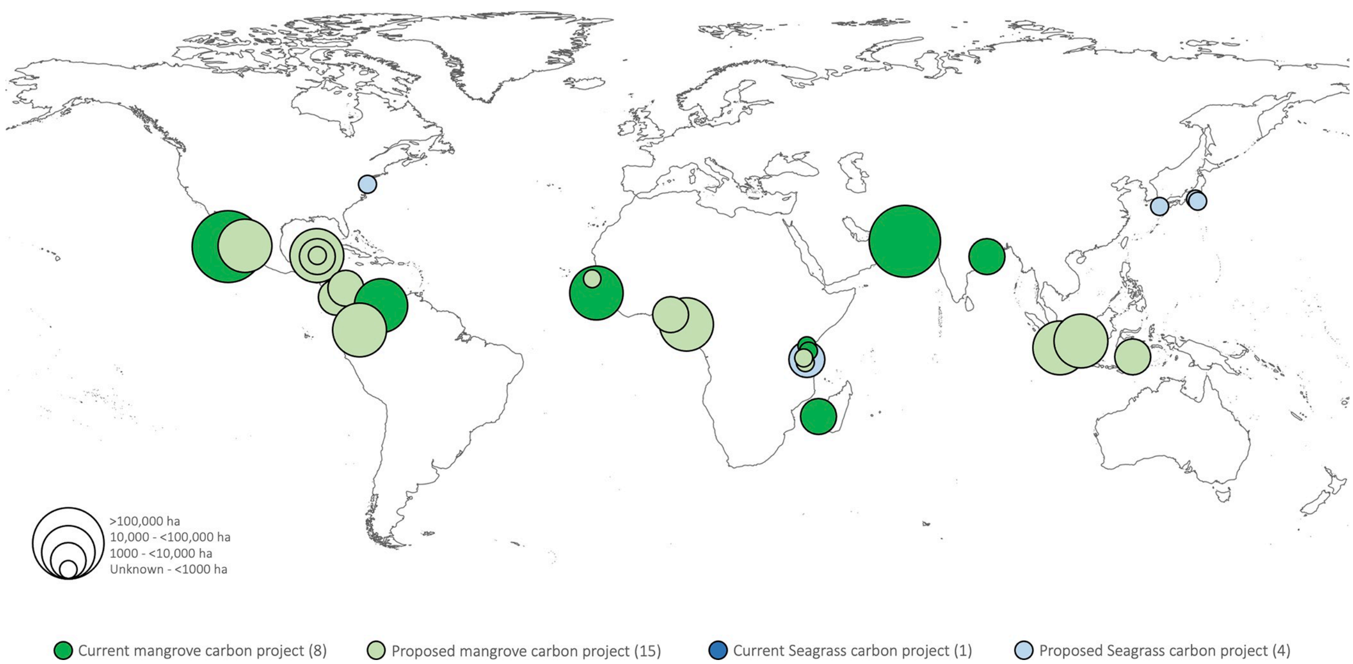

Fig 1. Global distribution of current and proposed blue carbon projects. Base map provided by Natural Earth, available from https://www.naturalearthdata.com/downloads/110m-physical-vectors/110m-coastline/.

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Table 2. Current and potential future blue carbon projects. Only projects that have derived or will derive income specifically from carbon benefits (as sales on the VCM or through private financing) are included.

Project	Country	Date	Activity	Project size (ha)	Standard	Lead Organisation	Ref
Mikoko Pamoja	Kenya	2013	Mangrove avoided deforestation, restoration	117	Plan Vivo	ACES	[43]
India Sundarbans Mangrove Restoration	India	2015	Mangrove restoration	4675	VCS	Livelihoods Fund, Danone	[47]
Tahiry Honko	Madagascar	2018	Mangrove avoided deforestation, restoration	1,200	Plan Vivo	Blue Ventures	[48]
Vanga Blue Forest	Kenya	2019	Mangrove avoided deforestation, restoration	450	Plan Vivo	ACES	[44]
Cispatá Bay	Colombia	2021	Mangrove avoided deforestation	11,000	VCS	Conservation International	[49]
Community Based Avoided Deforestation Project in Guinea-Bissau	Guinea-Bissau	2021	Mangrove avoided deforestation	35,927	VCS	BioGuinea Foundation	[50]
Magdalena Bay	Mexico	2022	Mangrove avoided deforestation, restoration	222,000	VCS	Marvivo	[51]
Delta Blue Carbon	Pakistan	2022	Mangrove avoided deforestation, restoration	~325,000	VCS	Indus Delta Capital	[46]
Vanga Blue Forest	Kenya	2022	Seagrass conservation	300	Plan Vivo	ACES	[43]
Mikoko Ujamaa	Tanzania	Project Idea Note approved 2020	Mangrove avoided deforestation, restoration	1426	Plan Vivo	Women Against Poverty	[52]
Taab Ché	Mexico	Project Idea Note approved 2021	Mangrove avoided deforestation, restoration	10,080	Plan Vivo	Resiliencia Azul	[53]
Restoration of Abandoned or Under-Utilised Shrimp Farms to Mangroves on Village Owned Land in South East Sulawesi	Indonesia	Project Idea Note approved 2021	Mangrove restoration	4487	Plan Vivo	Yayasan Bunga Bakau	[54]
Restoration and Protection of Mangroves and Blue Carbon Ecosystems in North Yucatan	Mexico	Project Idea Note approved 2021	Mangrove restoration	700	Plan Vivo	CINVESTAV, Sociedad Cooperativa Tulum Sostenible	[55]
Restoration of Mangroves Removed for Shrimp Farms and Firewood in the Gulf of Fonseca	Honduras	Project Idea Note approved 2022	Mangrove restoration	1400	Plan Vivo	Instituto de Conservación Forestal Servimos por Naturaleza, CODDEFFAGOLF	[56]
Oki REDD+ Project	Indonesia	Under validation	Mangrove avoided deforestation, afforestation	23,500 (unclear what % mangrove)	VCS	Japan Asia Group Ltd	[57]
Riscales REDD+ Project	Colombia	Under validation	Mangrove avoided deforestation	25,545 (unclear what % mangrove)	VCS	Consejo Comunitario General Los Riscales	[58]
Yokohama Blue Carbon Project	Japan	Not yet validated	Seagrass and macroalgae conservation	Unknown	Unknown	Yokohama City	[59]
Hakata Bay Project	Japan	Not yet validated	Seagrass and macroalgae conservation	Unknown	Unknown	Fukuoka City	[59]

(*Continued*)

Table 2. (Continued)

Project	Country	Date	Activity	Project size (ha)	Standard	Lead Organisation	Ref
Senegal and West Africa Mangrove Programme (SWAMP)	Senegal	Under development	Mangrove avoided deforestation	42	VCS	ALLCOT AG	[60]
Carbon sequestration in mangroves of the south–central coastal zone of the state of Sinaloa, México	Mexico	Under development	Mangrove avoided deforestation, restoration	49,387	VCS	ALLCOT AG	[61]
Bonos del Jaguar Azul	Mexico	Under development	Mangrove restoration	5060	VCS	Ban.CO2 de Carbono Mestizo	[62]
Muskitia	Honduras	Under development	Mangrove avoided deforestation	5000	VCS	South Pole	[63]
East Shore/Virginia Coast Reserve	USA	Proposed	Seagrass restoration	Unknown	Unknown	The Nature Conservancy, Virginia Institute of Marine Science, University of Virginia	[64]
Hak Pengusahaan Hutan Concession	Indonesia	Proposed	Mangrove avoided deforestation	>15,000	Unknown	Forest Carbon	[65]
HIMA REDD+ Program	Tanzania	Proposed	Mangrove avoided deforestation	Mangrove area unknown	Unknown	Terra Global	[66]
Community Biodiversity Conservation Area of Bouche du Roy	Benin	Proposed	Mangrove avoided deforestation, restoration	8700	VCS	EcoBenin	[67]
Feasibility study on the conservation of the Douala-Edéa forested wetlands	Cameroon	Feasibility Study	Mangrove avoided deforestation, restoration	59,000	Unknown	EcoAct S.A.S	[68]
J-Blue Credit Pilot (Yokohama Marina)	Japan	Feasibility Study	Seagrass and macroalgae restoration	10.6	Unknown	Japan national government	[59]

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The majority of future projects will focus on mangroves, though at least 4 projects proposed or under development focus on seagrasses, alongside potential contributions from candidate BCEs such as macroalgae. Macroalgae is not currently considered a BCE in part due to challenges in ensuring and measuring carbon burial; a new Seascape Carbon Initiative has also been proposed, which could incorporate macroalgae contributions to carbon sequestration and its burial in other ecosystems [45]. Blue carbon credit project size is also expected to increase compared to earlier blue carbon projects, with proposed projects regularly exceeding 15,000 ha. Perhaps the most ambitious blue carbon project on the horizon is the conservation and planting of >325,000 ha of tidal wetlands in the Indus Delta, Pakistan [46].

While the rapid increase in proposed blue carbon projects is welcomed, they have been challenging to develop, in part because BCE carbon pools do not always fall neatly into existing carbon accounting and verification mechanisms. Coastal ecosystems show various differences compared to terrestrial systems, in terms of dominant carbon pools, drivers of loss and degradation, and governance arrangements [69]. This has meant the exclusion of soil carbon pools (that account for the majority of blue carbon), and provided difficulties in incorporating non-forested ecosystems such as seagrasses (for a full discussion of some of the technical, financial and social barriers to establishing VCM projects in seagrass see [70]). However, recent demand for blue carbon projects has also led to the development of more suitable methodologies. In September 2020, Verra released the first blue carbon conservation methodology approved under any major GHG program (VM0007; [71]), which includes strategies for determining permanence due to sea-level rise, soil carbon accumulation, rewetting of saline environments, and other hydrological activities.

The new Verra VM0007 blue carbon method is scientifically robust, but has several limitations, as was noted in its implementation during the Cispata Bay blue carbon project. The method is labour-intensive, and because the blue carbon modules were added to an existing common REDD+ methodology, issues such as reference region size could not be adjusted to better suit the often small scale of blue carbon projects, because it would also affect terrestrial REDD+ projects. As such, Verra is now aiming to extract the blue carbon pieces from VM0007 and add them to VM0033 (a coastal wetland restoration methodology). Other methodologies related to blue carbon are also in various stages of development, incorporating macroalgae, and seascape methods that integrate activities across coastal ecosystems. The next generation of accounting methodologies are focusing on method simplification to provide project developers with conservative carbon estimates that can be used to estimate carbon benefits more quickly, and to identify landscapes that are then suitable for more in depth accounting.

4. Disconnects between blue carbon interest and delivery

While the pipeline for blue carbon projects is likely to increase in the future, it still does not meet the substantial demand from the corporate sector. Blue carbon has not yet been widely operationalised due to several barriers that span political, social, governance and technological domains. Many constraints cross both public and private sector projects, and include uncertainty around land tenure and carbon credit ownership, challenges in incorporating the needs of local communities and ensuring environmental justice, marginalisation of local stakeholders, poor project cost-benefit ratios, and unsupportive regulatory landscapes [8, 72–75]. In combination, these constraints mean that only 5.5–34.2% of biophysically restorable mangrove areas may actually be restorable across Southeast Asia [76]. Furthermore, for-profit conservation models come with risks such as greenwashing and neo-colonialism. All blue carbon stakeholders must operate to high ethical standards, by following proposed codes of conduct that promote fair, just and equitable marine conservation to overcome some of these social barriers [77].

4.1 Financial barriers to blue carbon projects

Financial barriers to blue carbon projects are less well explored than other barriers, because financial mechanisms are considered poorly developed [8] and commercial sector engagement in blue carbon projects has previously been lacking [73]. Ultimately, blue carbon financing is constrained by how active investors are in project development and in supplementing blue carbon project income (Fig 2). Blue carbon project interventions (particularly restoration) can be substantially more expensive to establish, implement and maintain compared to terrestrial management options, and costs vary widely [78]. This is due to the complexity of restoring key hydrological components of the environment and the complexity of governance arrangements in the coastal zone.

Blue carbon projects typically involve high up-front costs, and can have high costs associated with labour-intensive carbon measurement and monitoring. Project costs must be offset by the sale of carbon credits, though uncertainty in carbon accumulation rates under different blue carbon interventions can affect credit delivery [79]. Carbon credit prices are uncertain, particularly if the market for blue carbon credits expands rapidly as is expected. Current blue carbon credit sales attract a premium in comparison to traditional large-scale REDD+ projects, partly because of their strong community focus and co-benefits [80], although this is still generally not sufficient to operate for-profit models.

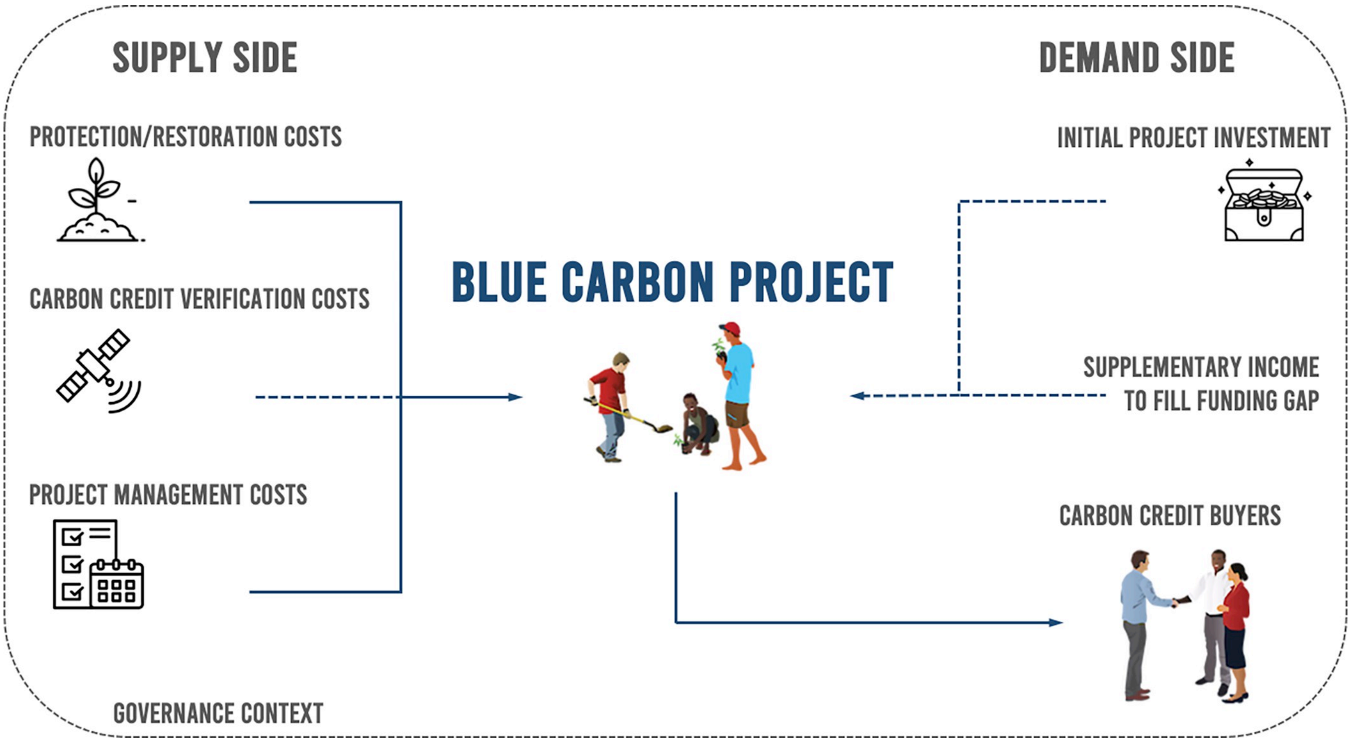

Fig 2. Major supply side and demand side gaps in blue carbon financing. Dotted lines indicate lack of proof of concept.

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High project establishment costs, uncertainty in carbon projections, and the current low cost of carbon credits, mean that blue carbon projects can have a low or negative return on investment [79]. As such, several blue carbon projects face a funding gap. As more data are generated on the costs of blue carbon conservation and restoration, and the price buyers are willing to pay, it will be possible to conduct more thorough cost-benefit analyses that will provide important insights into what funding is required to match the requirements of blue carbon buyers and sellers.

Ultimately, uncertainty in potential return on investments and the current small number of blue carbon projects creates financial risk for investors. The longer track record of investment in scalable, proven terrestrial carbon credit schemes means that the potentially higher risk and greater uncertainties around blue carbon can disincentivise investment compared to other natural climate solutions. As blue carbon projects are still in their infancy, both reducing the risk of early investment into blue carbon projects and supporting a rising price for blue carbon credits are critical to encourage early investment.

Overcoming these financial constraints will require us to refine blue carbon accounting to give a higher degree of accuracy in a more cost-effective manner; to improve the business case for blue carbon projects, with appropriate financial incentives commensurate with investment risk; to better integrate the private sector into project design and co-development; and to better value co-benefits to increase the economic feasibility of blue carbon projects through ecosystem service stacking.

4.2 Shifting governance contexts for financial carbon markets

Financial barriers do not operate in isolation from broader considerations. Ultimately, markets work within, and take on risk according to, the larger scale governance arrangements and jurisdictions within which they operate. In particular, the conflict between selling credits for commercial use vs. accruing credits to meet national climate change mitigation obligations has not yet been solved for key countries with large blue carbon resources [8]. There are ongoing discussions about corporate claims and the need (or not) for corresponding adjustments, since companies do not report to the United Nations Framework Convention on Climate Change (UNFCCC). Several countries have moved ahead with centralising control over carbon credit trading, and pausing commercial carbon trading activities that sell credits to international buyers. In July 2021, a country with one of the highest potentials for commercial blue carbon credit projects globally [29] paused self-declared carbon credit projects by international entities, so that all carbon efforts can be put towards the country's NDCs while avoiding double counting [81]. It was also claimed that another government also recently refused to recognise an agreement between a mangrove blue carbon project and an international buyer due to the centralisation of carbon credits [82]. This is an issue that affects all carbon credit transactions, though there is increasingly clear evidence of its influence on blue carbon projects.

5. Moving beyond credits and carbon

Despite the rapidly growing interest in blue carbon, closing the funding gap required for project establishment, maintenance and verification is still a challenge. While many of the constraints to blue carbon credit projects are surmountable, it may take substantial time to untangle some of the complex socioeconomic and governance issues that currently limit project implementation. The diversity of regulatory and governance contexts and scales where BCEs exist [83, 84] may necessitate a range of funding approaches [73, 85] to provide alternative financing while such barriers are tackled. Thus, it is likely that not-for-profit finance models, including bilateral/multilateral aid and philanthropy will continue to be important, alongside a range of financing mechanisms suitable for ocean conservation that cover a broad range of risks and returns [86].

There are various ways to link carbon activities with non-carbon financing, that can be broadly characterised as public sector approaches and public-private partnerships, philanthropic sources, and private sector financial instruments (Fig 3; S1 Table). Public sector approaches can close the project funding gap using public funds from existing budgets, taxes and other charges, or more innovative tools relating to land titling [87]. A diverse range of philanthropic sources will continue to be important in providing needed upfront funding, as has happened in the Cispatá Bay project. There is also ample scope for existing commercial financial instruments to minimise financial risk, fill the funding gap or supplement funds generated by carbon credits. These include green/blue/municipal/impact bonds to generate stable and fixed incomes while blue carbon projects come online [88]. Indeed, a major bank has shown interest in developing a Mangrove Bond [89]. Payments for Ecosystem Services (PES) beyond carbon may help financialise a range of other ecosystem services, stacking them to increase the overall payment to a project. Common Asset Trusts can extend this by building a portfolio of different ecosystem service investments that target a range of ecosystem services [90]. Ecosystem service insurance has real potential to generate funding for restoring coastal ecosystems and re-establishing their ecosystem services if damaged [91]. A global insurance company has shown interest in investigating insurance instruments for coastal ecosystems [92] based on their coastal protection value, with insurance premiums able to cover the costs of restoration in the first 5 years [93]. Combining insurance premiums from coastal protection alongside carbon credits would value coastal ecosystems as a broader nature-based solution for both climate change mitigation and adaptation.

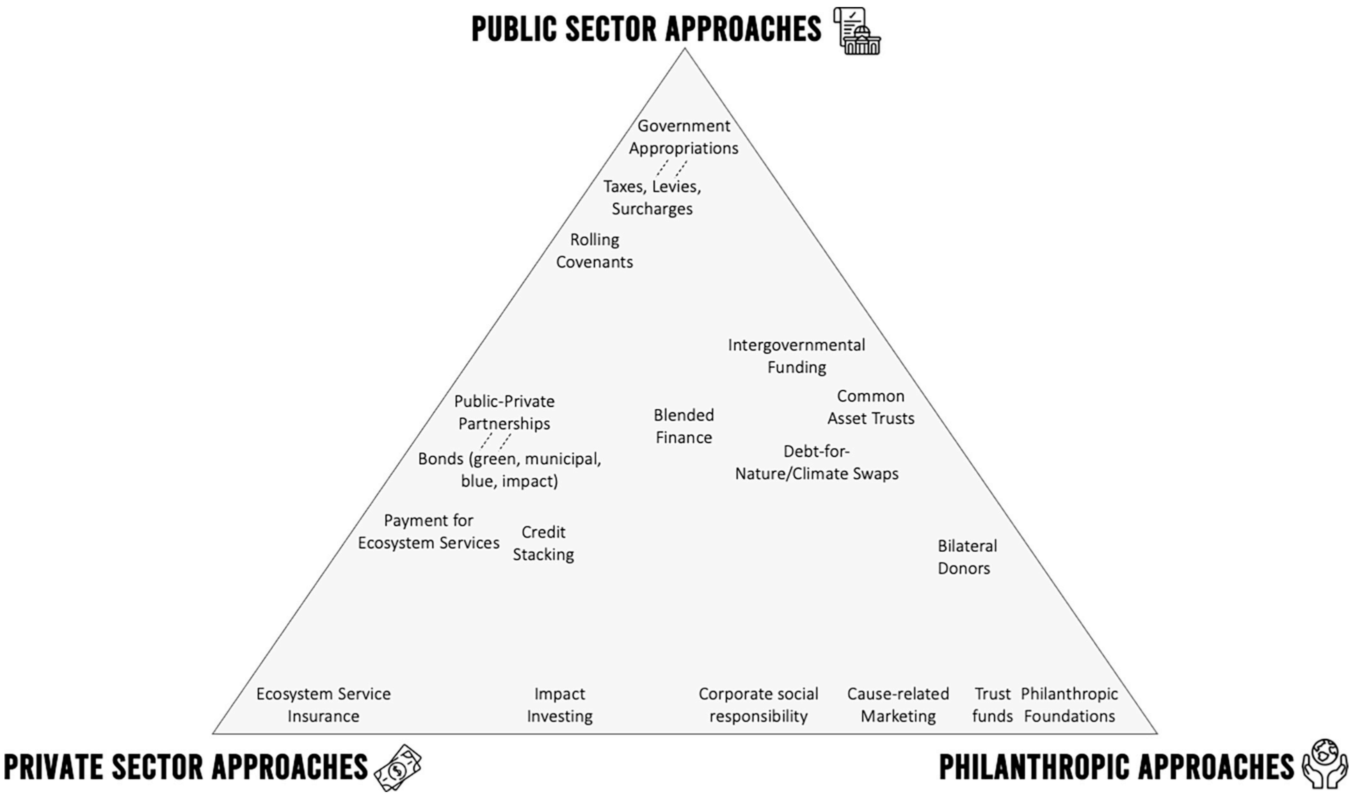

Fig 3. A broad range of financing options exist to co-finance commercial blue carbon credit projects. For information on each strategy see S1 Table.

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Incorporating additional funding mechanisms, and adding instruments that incentivize a broader range of mangrove ecosystem services beyond blue carbon, will allow us to more holistically understand the full value of blue carbon ecosystems. Ultimately, this could move investors away from carbon credits and towards an "ecosystem credit" that encompasses the broader value of a blue carbon ecosystem that can be charged at a premium. Some international NGOs are beginning to push for such a premium credit, including linking blue carbon and coastal protection together within a Blue Carbon Resilience Credit [94], with a feasibility study proposed in Mexico to understand the technical and market feasibility of such an approach [95].

6. Conclusions

The conservation, management and restoration of blue carbon ecosystems has strong potential to be an important natural climate solution to help the world realise its climate change mitigation ambitions. Broader industry and market changes alongside the greater prominence of blue carbon has meant that there is strong and increased demand for blue carbon credits from the private sector. However, credit demand from stakeholders is significantly outstripping the supply available from robust and verified projects. Only 9 blue carbon credit projects have currently been verified or are producing blue carbon credit projects, and while there is a future project pipeline it is unlikely to bring enough blue carbon credits online in the short term to satisfy demand.

In order to increase blue carbon credit supply we need to identify and overcome the varied physical, social and financial constraints to project delivery. Several barriers relate to financial considerations, particularly the cost of project implementations in blue carbon systems compared to terrestrial habitats, a shorter blue carbon project track record compared to other natural climate solutions, and broader governance decisions that affect carbon credit market stability. Not addressing such barriers will mean that blue carbon as a natural climate solution may be considered a riskier investment by some private sector stakeholders. Similar to other coastal ecosystem management interventions, overcoming or adapting to these varied constraints will ultimately require a transdisciplinary approach [96, 97].

It is encouraging to see that private sector demand is driving a rapid increase in proposed blue carbon projects, and project delivery can be improved if actors can close the funding gap that hinders the establishment of many projects, and if project developers can increase a project's return on investment. These steps are important because we have a limited window of opportunity to capitalise on the corporate interest in blue carbon, by overcoming current barriers and incorporating other financial solutions beyond carbon credits. Ultimately, a portfolio of private sector, public sector and philanthropic instruments are needed to increase the viability and success of blue carbon projects in a socially just manner, to reduce risk to investors and the risk of greenwashing, and to ultimately encompass the true value of coastal ecosystems beyond their carbon benefits.

Supporting information

S1 Table. Advantages and disadvantages of co-financing mechanisms appropriate to supplement the incomes of commercial blue carbon credit projects.
(DOCX)

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