Marine Policy 138 (2022) 104996

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Implementation of blue carbon offset crediting for seagrass meadows, macroalgal beds, and macroalgae farming in Japan

Tomohiro Kuwae [a,b,*], Atsushi Watanabe [b,c], Satoru Yoshihara [d], Fujiyo Suehiro [d], Yoshihisa Sugimura [e]

[a] Coastal and Estuarine Environment Research Group, Port and Airport Research Institute, 3-1-1 Nagase, Yokosuka 239-0826, Japan
[b] Japan Blue Economy Association (JBE), 3-1-1 Nagase, Yokosuka 239-0826, Japan
[c] The Ocean Policy Research Institute, the Sasakawa Peace Foundation, 1-15-16, Toranomon, Minato-ku, Tokyo 105-8524, Japan
[d] Environmental Planning Department, Yachiyo Engineering Co., Ltd, 5-20-8 Asakusabashi, Taito-ku, Tokyo 111-8648, Japan
[e] Department of Joint Research on Environment & Disaster in Coastal and Port Areas, Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan.

ARTICLE INFO

Keywords:
Climate change
Blue economy
Blue finance
Nature-based solutions (NbS)
Carbon credit
J-Blue Credit

ABSTRACT

The “blue carbon” concept and the role of blue carbon stored in shallow coastal ecosystems in mitigating climate change have attracted attention worldwide. In addition to typical blue carbon ecosystems, such as mangroves, tidal marshes, and seagrass meadows, macroalgal beds and macroalgae farming are also gaining recognition as potential blue carbon sinks. Effective policies and methodologies are important for the conservation and expansion of blue carbon sinks, as well as the consequent reduction of atmospheric carbon dioxide (CO_2). One of the most effective methods is carbon offset credit schemes. However, to date, almost all credit schemes have been implemented for mangroves and saltmarshes. None has been implemented for seagrass meadows, macroalgal beds, and macroalgae farming, although their CO_2 uptake potentials are large. Here, we review three blue carbon offset credit projects for seagrass meadows, macroalgal beds, and macroalgae farming implemented in Japan. We show the blue carbon offset crediting projects of (1) Yokohama City, the first in the world; (2) Fukuoka City, the second such project in Japan; and (3) the first Japanese national governmental demonstration project. Furthermore, we highlight their characteristics by comparing them with the other blue carbon offset projects. Finally, we discuss the need to accelerate blue carbon offset credit projects and related initiatives in the future.

1. Introduction

The concepts of nature-based solutions (NbS) and the utilization of coastal green-gray (also termed “blue” or “natural”) infrastructure are attracting increasing attention from both policy and practical perspectives [53,57,69]. Shallow coastal ecosystems (SCEs), such as mangroves, saltmarshes, seagrass meadows, and macroalgal beds, are good examples of these concepts, considering their roles as part of the global carbon cycle and as a natural defense against sea level rise [28]. Blue infrastructure and ocean-based NbS projects can lead to sustainable revenue-generating opportunities. Furthermore, they can help in realizing a blue economy for local communities through comprehensive investments (also known as “blue finance”) in the conservation of coastal ecosystems and biodiversity, as well as in optimal blue infrastructure (e.g., [59]).

In a report jointly published in 2009 by the United Nations Environment Programme (UNEP) Planning Unit; the United Nations Food and Agriculture Organization (FAO); and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) [41], “blue carbon” is defined as carbon captured by marine organisms. The ocean is a particularly important carbon reservoir because blue carbon stored in seafloor sediments can remain undecomposed and unmineralized for long periods of time (up to several thousand years). The role of blue carbon in SCEs as a climate mitigation measure has attracted attention worldwide. Typical SCEs, including mangroves, tidal marshes, and seagrass meadows, are now being called “blue carbon ecosystems” [35].

Blue carbon initiatives are currently moving from the advocacy stage to the social penetration, policymaking, and implementation stages (International Partnership for Blue Carbon; https://bluecarbonpartnership.org/). Approximately 20% of the countries that have joined the

* Corresponding author at: Coastal and Estuarine Environment Research Group, Port and Airport Research Institute, 3-1-1 Nagase, Yokosuka 239-0826, Japan.
E-mail addresses: kuwae@p.mpat.go.jp, t_kuwae_2000@yahoo.co.jp (T. Kuwae).

https://doi.org/10.1016/j.marpol.2022.104996
Received 15 September 2021; Received in revised form 5 January 2022; Accepted 6 January 2022

Paris Agreement have pledged to use SCEs as a climate change mitigation option in their nationally determined contributions. These countries are moving towards measuring national blue carbon amounts and are accounting for them in their greenhouse gas inventories. Approximately 40% of those countries also have pledged to use SCEs to adapt to climate change as part of conservation, protection, and reforestation initiatives, as well as through planning efforts such as integrated coastal zone management and fisheries management [17,37]. Australia [24] and the United States [7] have also begun including blue carbon in their numerical emissions reduction targets and calculating blue carbon according to the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands ([22]IPCC 2014). The 25th Conference of the Parties (COP), or COP25, to the United Nations Framework Convention on Climate Change (UNFCCC), held in Spain in 2019 was positioned as a "Blue COP". Notably, the importance of the ocean as part of the global climate system was mentioned for the first time in the document adopted at COP25.

In conjunction with these international efforts, local communities have begun recognizing the importance of blue carbon and are undertaking efforts toward its social implementation. Private companies, regional administrative organizations, and individual managers and engineers have expressed a strong interest in future socioeconomic development that incorporates the conservation or restoration of blue carbon ecosystems as new business opportunities ([61]; Nobutoki et al., 2019). In this context, Japan has clearly stated its intention to pursue the potential of blue carbon as a CO_2 sink in its "Long-Term Strategy as a Growth Strategy Based on the Paris Agreement" approved by the Cabinet in 2019. Other countries have also developed policy frameworks and conducted case studies related to blue carbon (e.g., [5,13,20,25,30,33,66,70,71]).

One of the most efficient and effective ways to promote climate change mitigation is the implementation of emissions trading systems (ETSs). The two main types of ETS are "cap-and-trade" and "baseline-and-credit." Cap-and-trade systems impose a cap on aggregate emissions levels but allow trades of allowances between covered entities. Baseline-and-credit systems define an emissions baseline and reward verified emissions reductions beyond the baseline amount with tradable offset credits. Offset credits, as an incentive for climate change mitigation, are well-established for forest and agricultural ecosystems.

ETS has voluntary and compliance markets [48,51]. Voluntary markets have been developed to credit actions taken to reduce greenhouse gas emissions, primarily by private-sector companies ([34]Tierra Resources LLC and Climate Trust). Compliance markets, which deal with mandatory emission reductions imposed by regulations, are driven by the demand for allowances and offsets by regulated greenhouse gas emitters. Private companies that purchase carbon credits in a compliance market to compensate for their emissions, or offsets, often tend to seek low-cost offsets, regardless of the origin of the credits [63]. In this case, blue carbon will have to compete with other low-priced offsets derived from a variety of emission-reduction measures, making it difficult to secure the funds needed for conservation. In contrast, in the voluntary market, private offset buyers purchase offsets to support broader strategic priorities, such as corporate social responsibility (CSR) and contributions to the United Nations Sustainable Development Goals (SDGs). Therefore, the origin of the credits and the story behind their creation becomes important and may influence the purchase price. Against this background, blue carbon credits have been mainly traded in the voluntary market.

Forest carbon credits have already been traded extensively in both compliance and voluntary carbon markets [62], and previous studies have documented specific transactions [49,54,64]. The possibility of trading soil carbon credits has also been studied [31,36,72], and credits for carbon sequestration by agriculture have begun to be traded in voluntary markets (e.g., Nori, which was founded in 2017; https://nori.com/about). However, there currently are no reports on the market size of soil credits or credit prices.

The potential of oceanic blue carbon as a source of credits through protection in offshore areas has been highlighted recently, but there is currently a lack of scientific knowledge and policy experience on this topic (MPA [39]). Hutto et al. [21] discusses phytoplankton, kelp, fish, and whales as oceanic blue carbon (or marine blue carbon). The role of carbon removal and storage in the transport of kelp and phytoplankton biomass to deep-sea sediments and in the deadfall of fish and whales to the deep sea has been become increasingly recognized. In turn, carbon accumulated in the upper layers of deep-sea sediments may be released into the atmosphere when they are disturbed by bottom-trawl fishing. The amount released has been estimated to be comparable to that from the aviation and agricultural sectors [50]. Preventing the loss of marine blue carbon through trawling by establishing marine protected areas and increasing the amount of marine blue carbon deposited by increasing the number of fish and whales could lead to the creation of blue carbon credits.

Several voluntary carbon markets have certified blue carbon offset methodologies and implementation protocols [25,51]. These markets are almost all for mangroves and saltmarshes [51]. To the best of our knowledge, there is no voluntary market for seagrass meadows, macroalgal beds, and macroalgae farming, although their CO_2 uptake potentials are large [11,32,68].

Here, we review three blue carbon offset credit projects being implemented in Japan in seagrass meadows, including the world's first three projects that incorporate macroalgal beds and macroalgae farming. Specifically, the blue carbon offset credit projects include: (1) the project in Yokohama City, the world's first; (2) the project in Fukuoka City, the second such project in Japan; and (3) the first Japanese national governmental demonstration project. Then, we show the challenges encountered in implementing these projects in terms of people, goods, money, and mechanisms, and how the problems were solved. Finally, we discuss issues and directions for future project expansion.

2. Carbon offset credits

The socioeconomic aims of blue carbon initiatives include improving the capital value and economic benefits of SCEs, improving their cost effectiveness as public works, and promoting local business [60]. The economic benefits include economic incentives, including carbon offset credits (carbon trading), payments for ecosystem services (PES), and income from funds [16,40].

Historically, carbon offset credits have been implemented using a top-down approach. Here, international markets are first established, and credit markets at the national and local government levels are subsequently created [15]. However, in the new framework adopted at COP21 in 2015, which is legally binding after 2020 as part of the Paris Agreement, mitigation measures are undertaken in a unique way by each country, and the basic policy includes a mutual verification mechanism (i.e., the pledge and review approach; [4]). Thus, to implement the new framework of the Paris Agreement, both global and local climate change countermeasures will be promoted. In addition, the use of monetary incentives to appeal to the private sector requires a bottom-up approach in which markets are newly established at the spatial scale of local governments and privately led projects are developed.

For the social implementation of carbon credit schemes, independent methods for the measurement, reporting, and verification (MRV) of credits are needed [64]. These methods involve accurate, objective, and quantitative measurements of carbon based on scientific and technological knowledge, transparent reporting, and verification. The submission of greenhouse gas inventories to the UNFCCC Convention Secretariat is based on the MRV principle. Mitigation of climate change by storing atmospheric CO_2 in the sea via natural systems can be achieved by three approaches: (1) creating new target ecosystems (i.e., carbon reservoirs and atmospheric CO_2 sinks); (2) reducing the decline of target ecosystems through restoration and conservation; and (3) improving the management of target environments and ecosystems (i.e., improving carbon storage rates and the CO_2 uptake rate per unit area).

Various guidelines for measuring carbon storage and CO_2 uptake by blue carbon ecosystems and for creating credits for blue carbon have been developed. Australia has included blue carbon ecosystems in its national greenhouse gas accounts. The Australian Government's Emissions Reduction Fund has developed comprehensive guidelines for that purpose [24]. Other organizations that have produced guidelines include the IPCC ([22]IPCC 2014), Conservation International, UNESCO, the International Union for Conservation of Nature [19], UNEP and the Center for International Forestry Research [6], and the Verified Carbon Standard [65], which is an independent carbon trading certification body in the United States. In Japan, guidance documents describing measurement methods for seagrass meadows, tidal flats, embayments, and port facilities have been prepared [61].

3. Implementation of blue carbon offset crediting for seagrass meadows and macroalgal beds in Japan

The voluntary market credit system is operated and managed mainly by the US and Europe, with rules created by Verra (US), Gold Standard (Switzerland), and Plan Vivo (UK). Plan Vivo, for example, has created the world's first community-based blue carbon credit for the conservation and regeneration of mangrove forests in the Gazi region of Kenya. The project, Mikoko Pamoja, includes the Kenya National Marine Fisheries Research Institute (KMFRI) and British and American organizations as actors and funders. However, one challenge remains—Plan Vivo's methodology does not include sediment, which is a major carbon reservoir.

Verra, formerly known as the Verified Carbon Standard (VCS), has been working to develop methodologies for blue carbon ecosystems. In 2015, it published a methodology (VM0033) that can be adapted to the restoration of seagrass beds and saltmarshes. In September 2020, Verra extended the methodology to the conservation of wetlands (revised VM0007). VM0007 has been used to register the world's first project on the conservation of mangrove ecosystems, including sediments, in Cispatá, in the Gulf of Morroquillo, Colombia; the project is supported by Conservation International and Apple. In May 2021, Apple purchased 17,000 tonnes of CO_2 equivalents (t-CO_{2e}) to offset its comprehensive carbon footprint for fiscal year 2020. In Pakistan's Sindh Province, a 60-year conservation and regeneration project for 350,000 ha of mangrove forests has also applied to offer offsets and is currently being verified by Verra. However, projects targeting seagrass beds and saltmarshes using VM0033 have not been registered to date.

In the following section, we review three blue carbon offset credit projects for seagrass meadows, macroalgal beds, and macroalgae farming in Japan (Table 1).

3.1. *Offset crediting by the Yokohama Blue Carbon Project*

3.1.1. *Background*

In the Yokohama City Action Plan for Global Warming Countermeasures, the city of Yokohama set a target of reducing greenhouse gas emissions by 7% by 2021 and 30% by 2030, compared to 2013 levels. Yokohama City is a member of the C40 Cities Climate Leadership Group (C40; https://www.c40.org/) and the Local Governments for Sustainability (ICLEI; https://www.iclei.org), international networks of cities that are actively working to combat climate change. In addition, it was selected in 2015 as the only Asian member of the Carbon Neutral Cities Alliance (CNCA; https://carbonneutralcities.org).

The Yokohama Blue Carbon Project, which began in 2014, aims to create a variety of synergistic effects between the environment (e.g., through water purification and biodiversity conservation), society (e.g.,

Table 1
Current blue carbon (BC) credit schemes.

		Yokohama BC Credit	Fukuoka BC Credit	J-Blue Credit
Year established		2015	2019	2021
Carbon market		Voluntary	Voluntary	Voluntary, but also compliance targeted
Developer and secretariat		Yokohama City	Fukuoka City	Japan Blue Economy Association (JBE) approved by the Japanese government
Estimated project budget		5,600,000 yen (2020)	1,850,000 yen (2020)	990,000 yen (2021)
Subsidies		None	None	None
Validation and Verification Body (VVB)		Not established	Not established	Established with members independent of the secretariat (JBE)
Approver		Yokohama City	Fukuoka City	JBE
Spatial coverage		Within Yokohama City and some collaborating local governments	Within Fukuoka City	Nationwide
Inclusion into national emission trading systems (ETS)		Not yet	Not yet	Targeted by 2023
Project activities	BC sink creation/restoration/ conservation (IPCC methodology applied)*1	Seagrass meadows (Tier 1)	Seagrass meadows (Tier 3)	Seagrass meadows (Tier 3)
		Macroalgal beds (N/A)	Macroalgal beds (N/A)	Macroalgal beds (N/A)
		Macroalgae aquaculture (N/A)		
	CO_2 emission reduction	Yes*2	Not yet	Not yet
Number of participating groups	Credit creaters	10	1	1
	Credit buyers	19	35	3
Trading amount		120.3 t CO_2 (2020)	43.4 t CO_2 (2021)	22.8 t CO_2 (2021)
Trading price		Fixed: 8000 yen/t CO_2*3	Fixed: 8000 yen/t CO_2	Dynamic: >13,158 yen/t CO_2 (determined by negotiated transactions in 2021)*4

* 1 see IPCC (2014)[22]
* 2 see Nobutoki et al. [43]
* 3 https://mainichi.jp/articles/20200201/ddl/k45/010/477000c
* 4 https://www.blueeconomy.jp/archives/j-bluecredit-2020/

through enhancement of amenities and the Yokohama brand), and the economy (e.g., by increasing supplies of resources and food, and increasing tourism) by implementing global warming countermeasures [43]. In addition to "blue carbon," which refers to the utilization of SCEs as CO_2 sinks, this project introduced the concept of "blue resources," which are resources tailored for effective utilization of the abundant marine energy, food, and biomass resources for CO_2 emission reduction (Fig. 1). In addition, the project employs the "Friendly Ocean" concept to promote citizen collaboration in ocean development, environmental education, and environmental awareness.

The Yokohama Blue Carbon Project certifies the amount of greenhouse gas absorbed and reduced by blue carbon or blue resources as blue carbon credits, and promotes carbon offsetting by trading these credits. Since the project's initiation in 2014, the number of credits created and used, as well as the number of users, has been increasing each year ([55]; [29]Kuwae et al., 2022). Although social penetration by this scheme has been gradually increasing, all of these credits were derived from blue resources until 2018. However, in 2019, Yokohama City introduced the certification and offsetting of blue carbon credits to revitalize the project.

3.1.2. Calculation methodology

The blue carbon offset credit scheme is based on both the IPCC Guidelines ([22] IPCC 2014), which outline methodologies for calculating the CO_2 sink capacity of blue carbon ecosystems (mangroves, tidal marshes, and seagrass meadows), and the methodologies described by Kuwae et al. [27], which are based on compilations of domestic and international data. Furthermore, in line with the IPCC Guidelines ([22] IPCC 2014), these methodologies can be used to estimate the CO_2 sink capacities of macroalgal beds and tidal flats, as well as those of other blue carbon ecosystems throughout Japan. Although this scheme is a social experiment and unique to Yokohama City, to the best of our knowledge, this is the first project in the world that issued credits from the CO_2 sink capacities of seagrass meadows, macroalgal beds, and macroalgae aquaculture.

The IPCC Guidelines ([22] IPCC 2014) and Kuwae et al. [27] both calculate the CO_2 sink capacity of an SCE as the product of the area (ha) of the target ecosystem (referred to as "activity data") and the amount of CO_2 absorbed per unit area (removal coefficient):

Annual CO_2 sink capacity (t CO_2/year) = activity data (ha) × removal coefficient (t CO_2/ha/year) (1)

The default (Tier 1) value (1.58 t CO_2/ha/year) in the IPCC Guidelines ([22]IPCC 2014) was used as the removal coefficient for eelgrass beds (*Zostera marina*), and removal coefficients estimated by Kuwae et al. [27] were used for macroalgal beds (*Sargassum*, 2.7 t CO_2/ha/year; wakame and arame kelps (*Undaria*, *Ecklonia*, and *Eisenia*), 4.2 t CO_2/ha/year). The CO_2 sink capacity of macroalgae farms was calculated as the product of the net primary production of the macroalgae and the residual rate (the percentage of net primary production that is stored for a long period in the ocean carbon pool without reverting to CO_2) [27]:

Annual CO_2 sink capacity (t CO_2/year) = net primary production (t CO_2/year) × residual rate (7.7%) (2)

3.1.3. Implementation

Eq. (1) was used to calculate the CO_2 sink capacity in 2019 of the eelgrass beds maintained and managed at Sea Park Yokohama (35.3394°N, 139.6360°E) by Yokohama City. The distribution area of eelgrass was determined by conducting a global positioning system (GPS) logger survey during the eelgrass blooming season in June 2019 and using location information provided by park managers. The recorded area was 7.8 ha, the estimated CO_2 sink capacity of the eelgrass beds

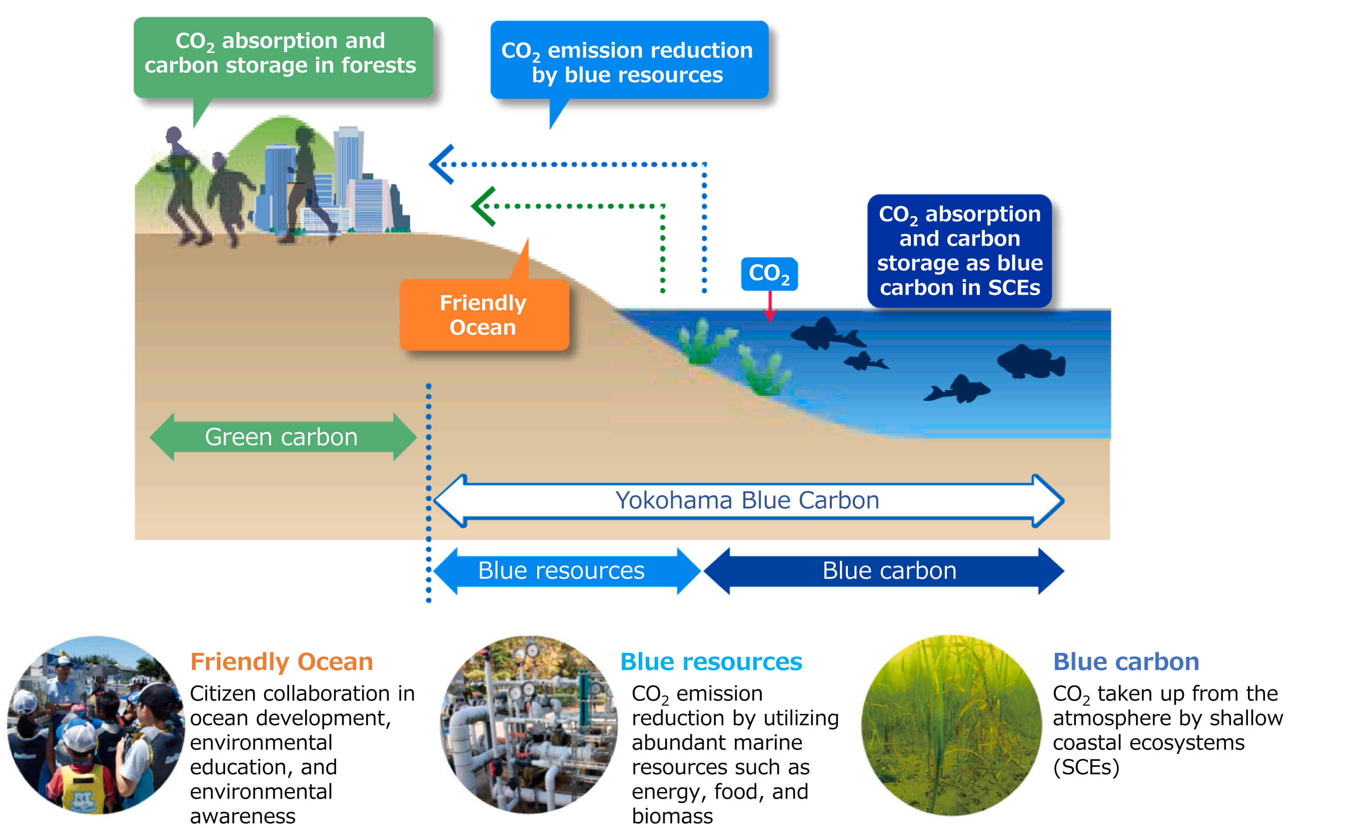

Fig. 1. Framework of the Yokohama Blue Carbon Project. Modified from [55].

was 12.3 t CO_2/year, and the certified credit amount was 12.3 t CO_2, based on the baseline scenario being zero (if no eelgrass beds are present before management, this case should have an "additionality" of 100%; i. e., it has 100% additional CO_2 removal compared to the business-as-usual condition) ([55]; [29]Kuwae et al., 2022).

Equation (2) was used to calculate the CO_2 sink capacity of the wakame (*Undaria*) cultivated (22.8 t wet weight) by the Kanazawa Branch of the Yokohama City Fisheries Cooperative Association (35.3312°N, 139.6375°E) in 2019. The estimated CO_2 sink capacity was 0.2 t CO_2/year and certified credit amount was also 0.2 t CO_2, based on the baseline scenario being zero (aquaculture should have 100% additionality).

The scheme initially targeted blue carbon and blue resources within the Yokohama City area. However, increased awareness of blue carbon initiatives in Yokohama has led to the expansion of this scheme to other municipalities, which are collaborating with Yokohama City to develop blue carbon offsets [55].

The number of credit applicants and the total amount of certified credits for blue resources have been increasing each year. In 2017, Yokohama City established a methodology for calculating reductions in CO_2 emissions achieved by replacing tugboats fueled by heavy oil first with LNG-fueled tugboats and then, in 2018, with hybrid tugboats. For details of the methodologies of other blue resources, see Nobutoki et al. [43].

At the beginning of the project, credits were mainly used to offset CO_2 emissions generated by short-term events. However, by the third year (2016) of the project, credits were being used to offset CO_2 emissions from ongoing corporate activities ([55];[29] Kuwae et al., 2022). Credits were used by individuals for the first time in 2019.

3.2. *Offset credit system of Fukuoka City*

3.2.1. *Background and framework*

In Fukuoka City, the "Hakata Bay NEXT Conference" was established in 2018 to promote collaboration among citizens, fisheries, businesses, educators, and the municipality in carrying out environmental,

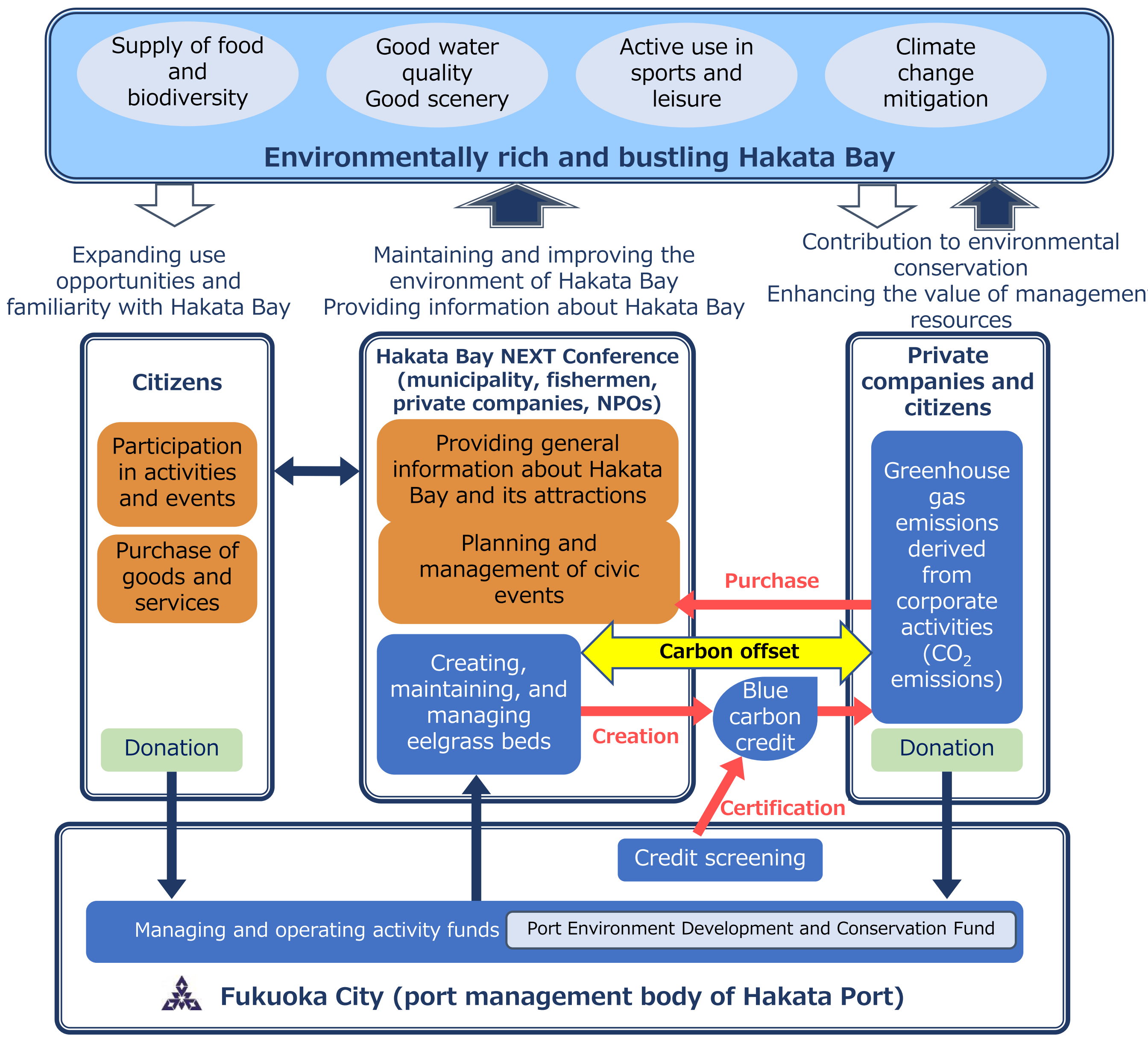

Fig. 2. Framework of the Fukuoka City blue carbon offset credit system.
Modified from [56].

economic, and societal improvements to the rich environment of Hakata Bay in Fukuoka City and pass it on to future generations [56]. Currently, the conference is working on conservation, restoration, and utilization of the Hakata Bay environment with a focus on eelgrass bed creation. As part of these activities, a blue carbon offset credit scheme was established, as was a funding scheme that utilizes a portion of ship entry fees and donations from companies as financial resources for environmental conservation and restoration activities (Fig. 2). The offset credit scheme is the second for blue carbon in Japan after that created in Yokohama City, while the funding scheme is the first in the country.

In Fukuoka City's blue carbon offset credit scheme, the amount of CO_2 absorbed from the creation, maintenance, and management of eelgrass and macroalgal beds in Hakata Bay is designated as a blue carbon credit owned by Fukuoka City. The credit is sold, and the proceeds from the sale are returned to the Hakata Bay NEXT Conference to fund its environmental conservation activities, including activities related to eelgrass beds (Fig. 2). The funding scheme utilizes income from port operations (2.5% of port fees) and donations from companies and individuals for Hakata Bay conservation and project creation. Moreover, an additional 2.5% of port fees are collected and deposited in the Port Environment Improvement and Conservation Fund for future projects.

3.2.2. Carbon offset credit scheme and implementation

The CO_2 sink capacity of the target eelgrass beds at Hakata Bay was calculated as described for the Yokohama City scheme, that is, by using Equation (1) and the methodologies described in the IPCC Guidelines ([22]IPCC 2014) and Kuwae et al. [27]. However, the Fukuoka City scheme used the modeled (Tier 3) value (2.7 t CO_2/ha/year) for the removal coefficient of eelgrass beds. Modeled values were also used for the removal coefficients of macroalgal beds (*Sargassum*, 1.09 t CO_2/ha/year; wakame kelp (*Undaria*), 0.45 t CO_2/ha/year) [56]. The eelgrass bed and the macroalgal bed projects are both considered as eligible targets for offset credits because the former are managed beds, and intensive efforts are underway to establish the latter on new seawalls.

In a survey conducted in May 2019, when the turbidity of seawater was relatively low in Hakata Bay (33.6136°N, 130.3125°E), the total area of the eelgrass beds was estimated by generating a composite image based on aerial images obtained by a multicopter (aerial drone), visually classifying the cover classes, and calculating the area of each cover class. The distribution area and cover class of eelgrass beds in the offshore area, which were difficult to determine from the aerial images, were corrected using visual surveys by divers. An area survey of macroalgal beds was conducted visually by divers.

The estimated areas of eelgrass beds and macroalgal beds was 15.6 and 2.9 ha, respectively. The resulting estimated CO_2 sink capacities were 42.1 and 1.3 t CO_2/year, respectively, and the amounts of certified credits were 42.1 and 1.3 t CO_2, respectively, based on the baseline scenario being zero (newly created habitats should have 100% additionality) [56].

3.2.3. Funding scheme and implementation

In 2020, Fukuoka City's general budget of 38,533,000 yen included 100,000 yen for the Hakata Bay Environment Conservation and Creation Project. Another 3,625,000 yen (equivalent to 2.5% of port fees) was allocated from the Port Environment Improvement and Conservation Fund Reserve for the project. In addition, 3,625,000 yen in port fees and 100,000 yen in anticipated donations were budgeted for the project.

3.3. Offset crediting demonstration by the Japanese National Government

3.3.1. Background

In 2020, the Japanese Ministry of Land, Infrastructure, Transport and Tourism [38] approved the foundation of the Japan Blue Economy Association ([23] JBE https://www.blueeconomy.jp/en/) as a Collaborative Innovation Partnership (CIP), a type of government-approved private cooperative. JBE was the first CIP for the marine environment in Japan. The ministry also decided to implement an offset credit demonstration project in collaboration with JBE.

A variety of the initiatives in JBE are implemented by researchers, engineers, and practitioners in different fields and positions. All of these actors are included on an equal footing under the supervision of the government to promote collaboration among various partners such as private companies, municipalities, non-governmental organizations (NGOs), and non-profit organizations (NPOs). JBE is developing detailed methodologies for blue economy projects based on scientific and technological evidence, and quantitative evaluations of ecosystem services and their economic values. The anticipated contributions of JBE to partners include the following:

(1) NPOs/NGOs: Raising national awareness of coastal environmental initiatives implemented at local sites and obtaining funding for those initiatives.
(2) Private companies: Quantifying their environmental, social, and corporate governance (ESG) efforts as key performance indicators and contributing to society through their SDG-related activities, including SDG 14 (Life Below Water), SDG 13 (Climate Action), and SDG 6 (Clean Water and Sanitation).
(3) Citizens and educators: Developing and identifying methods for measuring how much CO_2 is taken up by vegetation growing on shorelines in their own communities.

3.3.2. Characteristics of the carbon offset scheme

The national demonstration project and the "J-Blue Credit" carbon offset scheme are currently set up for the voluntary market (Fig. 3). Later, the compliance market will also be targeted after blue carbon has been included in the national baseline-and-credit system of Japan. JBE, as secretary of the national demonstration project, is not dependent on subsidies but is managed as an independent corporation. This makes the scheme different from those operated by local governments, as detailed below.

3.3.2.1. Multiple Methodological Options. First, JBE prepares multiple methodological options for determining removal coefficients and activity data (areas). As incentives for options that are technically difficult but result in more certain (more accurate and reliable) estimates, the rate of credit certification is increased (the rate of credit reduction resulting from uncertainty of the estimates is decreased) and transaction fees are decreased. In contrast, negative incentives such as high fees and a low rate of credit certification are provided for options that are technically easy.

3.3.2.2. Continuous review and revision. Second, established methodologies are subject to continuous review and revision by JBE, whereas the methodologies of many domestic and international credit schemes are more or less fixed. A flexible scheme in which methodologies are reviewed and revised considering the rapid progress in science and technology (e.g., area determination using both aerial and above-water sailing drones and remote sensing) should improve certainty and reduce costs, although project management may become more burdensome. Simplifying methodologies should help facilitate cost reductions and efficient project development, particularly for smaller scale projects, and move the carbon market forward [42].

3.3.2.3. Variable Transaction Prices. Third, JBE has introduced dynamic pricing mechanisms, such as direct trading and auctions. When local governments are in charge of mediating transactions, the unit price of credit transactions is often fixed by referring to existing forest credit systems that apply fixed prices and have extensive trading records (e.g., J-Credit). Although fixed prices may minimize the risk of disputes

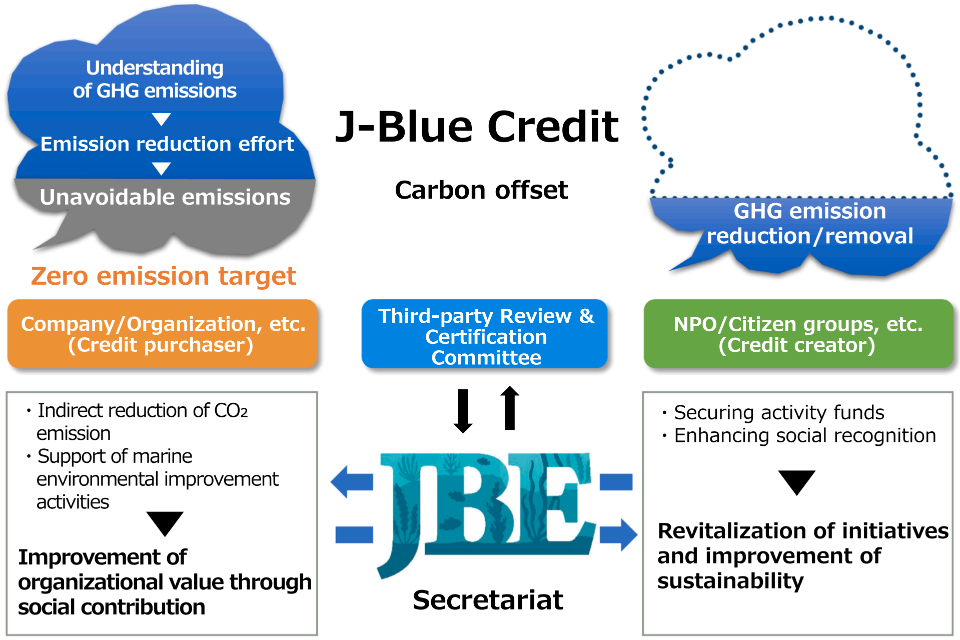

Fig. 3. Framework of the offset crediting demonstration by the Japanese National Government.

among the creators and purchasers of credits, they may not reflect the balance between supply and demand. In interviews about their reasons for purchasing blue carbon credits, buyers indicated that they appreciated or sympathized with not only climate change measures but also other co-benefits aligned with the buyer's goals and branding messages. By allowing the price to vary, these co-benefits can be

Fig. 4. Example of certificates of (a) the J-Blue Credit and (b) the carbon offset using the credit.

reflected in the transaction price, thereby increasing the unit price.

3.3.3. Case study

A case study was conducted in the Yokohama Bay Side Marina (35.3837°N, 139.6506°E), where both eelgrass and *Sargassum* beds were newly created. Eelgrass seedlings were planted in the newly sand-capped seabottom, and *Sargassum* seedlings were transplanted in the newly constructed submerged breakwater. This was done via the collaboration of Yokohama City Fishery Cooperative Association, Association for Shore Environment Creation, and Amamo Revival Collaboration in Kanazawa-Hakkei, Tokyo Bay Area (Fig. 4). The offset credit scheme adopted principles from the Core Carbon Principle ([58] TSVCM 2021) and methodologies from both the IPCC Guidelines ([22] IPCC 2014) and Kuwae et al. [27]. The CO_2 sink capacity of SCEs was calculated with Equation (1). From the candidate options prepared for the JBE scheme, modeled values of 4.9 and 2.7 t CO_2/ha/year were selected as removal coefficients of the eelgrass and *Sargassum* beds, respectively [27]. An arial survey of both beds was conducted in March 2017. The total area of these beds was estimated by generating a composite image based on aerial images taken by a multicopter (drone), visually classifying the cover classes, and then calculating the area of each cover class.

The estimated areas were 10.3 and 0.3 ha for the eelgrass and *Sargassum* beds, respectively. The resulting CO_2 sink capacities were 50.2 and 0.6 t CO_2/year, respectively, while the certified credit amounts were 22.6 and 0.27 t CO_2, respectively. These values were calculated assuming baseline scenario values of zero (newly created habitats should have 100% additionality) and with the understanding that the credit reduction policy considered the uncertainty of the activity data and removal coefficient used. Credits were purchased by three private companies indexed in the NIKKEI 225 (https://www.blueeconomy.jp/files/20210315MB-JBC.pdf) and used to offset CO_2 emissions from ongoing corporate activities (Fig. 4).

4. Keys for successful implementation

Overall, members of the Japanese public are supportive of blue carbon projects. One possible reason for this support is that various related entities (local governments, companies, fishers, NPOs, etc.) participate in the conservation and restoration projects to generate carbon offset credits; hence, the credit buyers may be more sympathetic to the projects as a whole, rather than just the carbon credits themselves. There are many stakeholders, such as managers, users, and implementers of conservation activities, in the same marine areas. Conflicts can arise, for example, between participants in marine leisure and conservation activities, but mediation between stakeholders by municipalities and other groups such as the Hakata Bay NEXT Conference may be a factor in the success of these blue carbon projects.

Nevertheless, to realize a successful project, it is necessary to manage and invest human, material, and financial resources under an appropriate system or mechanism. Therefore, we extracted and compared these elements for each project.

4.1. Mechanisms

In March 2011, Yokohama City formulated the “Yokohama City Action Plan for Global Warming Countermeasures” based on the Yokohama City Ordinance on the Conservation of Living Environment. As part of the global warming countermeasure projects in this plan, the city has been working on using its own certified credits through the Yokohama Blue Carbon Project. Even though scientific knowledge on blue carbon is scarce and social implementation has been slow, Yokohama City was the first entity in the world to establish its own system (local credit system) and promote measures against global warming in the sea area.

Meanwhile, Fukuoka City formulated the Hakata Bay Environmental Conservation Plan in January 2008 with the aim of conserving water quality and promoting the conservation, regeneration, and creation of the rich natural environment of Hakata Bay. In 2016, the second plan was formulated with the objectives of preserving a habitat where abundant macroalgae and seagrasses grow, expanding their growing areas, and providing habitat where young fish can grow.

The Japanese national government has established the CIP system of government-approved private corporations and related laws to promote collaboration among industry, government, academia, and the private sector. As explained in Section 3.3, JBE utilizes this CIP system and works with companies, local governments, NGOs, NPOs, and other organizations to promote research and study in an environment fostering cross-industrial cooperation.

4.2. Human resources

Human resources are critically important to the success of these projects. In the case of the Yokohama Blue Carbon Project, the following can be considered as success factors with regard to the people involved. First, Yokohama City, as a model city, had already been implementing a wide variety of measures to combat global warming in coastal areas through partnerships among industry, government, academia, and private organizations. Its citizens have developed a sense of identity and civic pride in the sea through the promotion of the “Ocean City Yokohama” policy. Successive Yokohama City officials have been enthusiastic about the project. As a result of all these factors, Yokohama City was able to pioneer its own scheme ahead of the rest of the world despite having incomplete scientific knowledge about blue carbon and a general lack of social implementation. Importantly, the very positive attitude of both credit creators and credit users toward the environment matched the purpose of this project.

In the case of Fukuoka City, various entities, including private citizens, citizen groups, fishers, businesses, educators, and the government, have successfully worked together toward the conservation and creation of marine ecosystems. A foundation had been laid for cooperation among industry, government, academic, and private-sector entities. Furthermore, the Hakata Bay NEXT Conference was established to promote collaboration among these various stakeholders.

JBE has been led by people who have supported local government initiatives. Notably, the representatives of the Japanese national government have been also hosting blue carbon study groups and discussion committees for several years. In addition, the JBE supports collaborative work with companies, local governments, NGOs, NPOs, and other organizations to promote research and study.

4.3. Material resources

Material or physical resources are also an important part of these projects. In the case of Yokohama City, eelgrass restoration was conducted at Sea Park Yokohama. The Sea Park is a sandy beach artificially created by the City of Yokohama in 1988; it is owned by the City of Yokohama. Eelgrass restoration activities started here in about 2001, and the continued efforts led to the recovery of the eelgrass beds. The fact that the sea area within the Hakkeijima Sea Paradise in Yokohama could be used as a field for a demonstration experiment of macroalgae farming was another important factor in the project’s success.

In the case of Fukuoka City, the formation of a place where citizens could familiarize themselves with the water was planned around 1989 as part of the port administration. Against this background, the maintenance and management of natural eelgrass beds and the creation of macroalgal beds on bio-symbiotic blue infrastructure have been implemented in the waters of Hakata Port.

In the case of JBE, a sea area in the Port of Yokohama was selected as the first demonstration site for the J-Blue Credit. Restoration of eelgrass beds has been carried out in this sea area since 2013. In addition, a macroalgal bed creation experiment conducted by the government from

2010 to 2012 resulted in the formation of a *Sargassum* bed, and fishers are now harvesting while managing the resource.

4.4. Financial resources

Financing is critically important for any project. In the case of Yokohama City, the project was selected as a CNCA Innovation Fund project (an international fund) and was able to proceed using foreign funding. Over time, additional funding was secured from Yokohama City (e.g., the Global Warming Countermeasures Promotion Fund). Furthermore, the sale of credits generated income for the project implementer.

In the case of Fukuoka City, financial resources were secured through the creation of a new funding scheme that utilized port charges. With the establishment of the blue carbon offset system, a framework was created through which companies can purchase eelgrass as part of their CSR activities or ESG management, thereby financially supporting the activities of the Hakata Bay NEXT Conference. Costs for the founding of the JBE and the national demonstration project were minimized by streamlining administrative procedures and personnel.

We anticipate that these three projects can be sustained in the future without additional funding (e.g., from subsidies) if the scale of the projects (e.g., project area, volume of trading, and the number of participants) remains at the current level. However, if the scale increases, it will be necessary to consider ways to increase funding.

5. Challenges for future blue carbon offset schemes

5.1. Quantification and reducing uncertainty

The accumulation of scientific and technological knowledge is still very important for connecting blue carbon initiatives to policymaking and implementation [35]. Here, we propose four areas of blue carbon research, based on Kuwae and Hori [26], which require further quantification relevant to carbon offset credit schemes.

(1) Key data on carbon stocks and flows for various SCEs still need to be gathered using conventional methods. In particular, more continuous long-term, large-scale in situ observation data as well as monitoring data obtained by remote-sensing technologies are needed to measure changes in the distribution areas of target ecosystems.
(2) New measurement techniques need to be established for carbon stocks and flows that researchers have not been able to quantify using conventional methods [51], especially seasonal fluctuations and the drifting amount of macrophyte biomass, as well as the formation of refractory dissolved organic matter in SCEs ([28] and the references therein). The underlying processes and mechanisms also need to be elucidated using new measurement techniques.
(3) The spatio-temporal variability of measured carbon stocks and flows needs to be estimated, particularly in response to long-term disturbances, such as climate change [1,67] and altered food web structures [2], and to short-term disturbances, such as storm events [3].
(4) Potential negative ecological effects of over-planting need to be identified. These can include a decrease in the number of infaunal bivalves resulting from reduced food availability and increased sedimentation [14].
(5) The temporal scale required for a functional response from restored SCEs needs to be evaluated [28]. The importance of the temporal scale used is clear: 5–20 years may be needed for the soil organic carbon pool or carbon accumulation rate of restored and managed sites to achieve the levels that natural sites generally take for blue carbon ecosystems (mangroves, tidal marshes, or seagrass meadows) [44]. These temporal scales are comparable to those required for the recovery of coastal habitats [10].

5.2. Expanding the scope of carbon offsetting

Blue carbon ecosystems have been shown to mitigate climate change [9]. However, we should not limit ourselves to these ecosystems when considering ways to mitigate climate change and provide other co-benefits. The scope of blue carbon offset schemes should be broadened to include other ecosystems that can also play important roles in climate change mitigation [8,18,27,32]. For example, tidal mudflats can be viewed as a type of intertidal blue carbon ecosystem (similar to tidal marshes and mangroves). Although they lack large vegetation, their microphytobenthos can absorb atmospheric CO_2 and their soils can store the captured carbon [47]. Moreover, similar coastal ecosystems and carbon storage mechanisms can be found in microbial mat systems and coastal sabkhas in arid regions [52]. Among potential blue carbon ecosystems, the macroalgal beds and macroalgae aquaculture areas discussed in this study are gaining recognition (e.g., [28] and the references therein). However, to the best of our knowledge, worldwide only these three Japanese sites discussed here have been implemented. Although estimates are few and extremely uncertain, macroalgal beds in SCEs may be the largest contributor to the net CO_2 uptake rate [26].

5.3. Considering co-benefits and monetization

Although this study focused on the specific ecosystem service of climate regulation, SCEs provide various ecosystem services, and thus, represent natural capital. Managing this natural capital is vital to take advantage of co-benefits such as food provision, recreation, environmental purification, health, and employment creation, in addition to contributing to food security, ecosystem integrity, and biodiversity [45]. However, highlighting climate change countermeasures, in which society is becoming increasingly interested, can help in initiating or accelerating the conservation and restoration of SCEs.

Ensuring that the effectiveness and importance of SCEs are widely perceived and understood by various coastal stakeholders, researchers, engineers, and economists is of primary importance when quantifying SCE functions and monetization and ideally crediting the full range of the provided benefits [12,46].

While considering the cost-effectiveness of SCEs, it is preferable to first quantify all of their functions and consider the trade-offs among them, and then to monetize them according to the results they produce. This method is preferable to basing the monetization of SCEs' benefits on willingness-to-pay, as determined by questionnaire surveys [28]. The direct evaluation of multifunctionality supported by numerical evidence is more likely to satisfy coastal stakeholders and to help secure public financing or attract funds from private companies and investors [63].

5.4. Challenges to expanding credit trading

Although the quantitative social impact of blue carbon offset credits is currently minimal, given the potential of blue carbon for mitigating climate change, expanding the volume and enhancing the social impact of credit trading are important. Some future challenges to be addressed are as follows.

First, the motivation of both credit creators and buyers needs to be improved. For example, the Japanese government has set a goal to account for blue carbon in the national inventory by 2024. Making blue carbon offset credit schemes contribute directly to such a national indicator can be expected to improve the motivation of credit creators. In addition, for credit buyers, being able to reflect the blue carbon credits they offset in the nationally determined contributions of the Paris Agreement will enable them to contribute directly to the international community's goals. Furthermore, it will motivate them to contribute to their own corporate social responsibility (CSR) as well as other ESG indicators.

Second, it is necessary to enhance offset credit transaction products to generate interest from more participants. One idea to increase the number of participants is to present an array of trading products by assessing the economic value of co-benefits and allowing them to be traded together with carbon. Consequently, credit creators can expect to increase their sales proceeds by increasing both the unit price and the transaction volume. In turn, credit buyers will be motivated by the ability to choose trading products that better fit their goals and branding messages.

Third, increasing the number of demonstration projects and accumulating good practices will contribute to raising awareness and interest in blue carbon offsetting. In turn, this can further motivate participants.

Finally, we should not forget the role of the credit secretariat, which mediates transactions. Currently, because the amount of blue carbon credits traded worldwide is low, it is difficult to maintain the system in a stable and sustainable manner with the income from intermediary fees. Increasing the trading volume and the unit price by increasing the number of participants is thus important for the smooth operation of the secretariat. In addition, a system such as a validation and verification body, which is independent of the credit secretariat as established by JBE, is important to ensure the credibility of the system through enhanced validation and verification. This credibility is essential for increasing the number of participants in the credit system.

CRediT authorship contribution statement

TK conceived the idea and led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Data Availability

All data are included in the text.

Acknowledgment

We thank Masanori Furuya of Tokyo ARS Law Office and Rikuro Ikeda of Carbon Free Consulting Corporation for implementing J-Blue Credit. This study was in part financially supported by the Japan Society for the Promotion of Science (KAKENHI 18H04156).

Conflict of interest

The authors have no conflict of interest to declare.

References

[1] A. Arias-Ortiz, O. Serrano, P. Masqué, et al., A marine heatwave drives massive losses from the world's largest seagrass carbon stocks, Nat. Clim. Chang 8 (2018) 338–344.
[2] T.B. Atwood, R.M. Connolly, E.G. Ritchie, et al., Predators help protect carbon stocks in blue carbon ecosystems, Nat. Clim. Chang 5 (2015) 1038–1045.
[3] D.R. Cahoon, P. Hensel, J. Rybczyk, et al., Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras, after Hurricane Mitch, J. Ecol. 91 (2003) 1093–1105.
[4] T.L. Cherry, S. Kallbekken, H. Sælen, et al., Can the Paris Agreement deliver ambitious climate cooperation? An experimental investigation of the effectiveness of pledge-and-review and targeting short-lived climate pollutants, Environ. Sci. Policy 123 (2021) 35–43.
[5] S. Crooks, D. Herr, J. Tamelander, et al., Mitigating Clim. Change Restor. Manag. Coast. Wetl. -shore Mar. Ecosyst.: Chall. Oppor. (2011). ⟨https://www.uncclearn.org/sites/default/files/inventory/wb87.pdf⟩.
[6] S. Crooks, I. Emmer, D. Murdiyarso, et al., Guiding principles for delivering coastal wetland carbon projects, Rep. U. Nations Environ. Program Cent. Int. For. Res. (2014). ⟨http://www.cifor.org/publications/pdf_files/Books/BMurdiyarso1402.pdf⟩.
[7] S. Crooks, A.E. Sutton-Grier, T.G. Troxler, et al., Coastal wetland management as a contribution to the US National Greenhouse Gas Inventory, Nat. Clim. Chang 8 (2018) 1109–1112.
[8] S. Crooks, L. Windham-Myers, T.G. Troxler, Defining blue carbon: the emergence of climate context for coastal carbon dynamics, in: L. Windham-Myers, S. Crooks (Eds.), A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice and Policy, CRC Press, 2019, pp. 1–8.
[9] C.M. Duarte, I.J. Losada, I.E. Hendriks, et al., The role of coastal plant communities for climate change mitigation and adaptation, Nat. Clim. Chang 3 (2013) 961–968.
[10] C.M. Duarte, S. Agusti, E. Barbier, et al., Rebuilding marine life, Nature 580 (2020) 39–51.
[11] C.M. Duarte, A. Bruhn, D. Krause-Jensen, A seaweed aquaculture imperative to meet global sustainability targets, Nat. Sustain (2021), https://doi.org/10.1038/s41893-021-00773-9.
[12] L. Emerton, Using valuation to make the case for economic incentives: promoting investments in marine and coastal ecosystems as development infrastructure, in: M. Essam (Ed.), Economic Incentives for Marine and Coastal Conservation: Prospects, Challenges and Policy Implications, Earthscan Press, London, 2013.
[13] EX-ACT, Ex-ante carbon balance tool, blue carbon and fisheries, Food and Agriculture Organization,, 2017. ⟨http://www.fao.org/3/a-i8342e.pdf⟩.
[14] K. Gagnon, E. Rinde, E.G. Bengil, et al., Facilitating foundation species: The potential for plant–bivalve interactions to improve habitat restoration success, J. Appl. Ecol. 57 (2020) 1161–1179.
[15] C. Gavard, D. Kirat, Flexibility in the market for international carbon credits and price dynamics difference with European allowances, Energy Econ. 76 (2018) 504–518.
[16] D.T. Herr, D. Agardy, F. Benzaken, et al., Coastal "blue" carbon: a revised guide to supporting coastal wetland programs and projects using climate finance and other financial mechanisms, IUCN, Gland, Switz. (2015), https://doi.org/10.2305/IUCN.CH.2015.10.en.
[17] D. Herr, E. Landis, Coastal blue carbon ecosystems. Opportunities for Nationally Determined Contributions: Policy Brief. IUCN, Gland, Switz., Nat. Conserv., Wash., DC (2016).
[18] O. Hoegh-Guldberg, E. Northrop, J. Lubchenco, The ocean is key to achieving climate and societal goals, Science 365 (2019) 1372–1374.
[19] J. Howard, S. Hoyt, K. Isensee, et al., Coastal blue carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, Int. Union Conserv. Nat., Arlingt., VA (2014).
[20] J. Howard, E. McLeod, S. Thomas, et al., The potential to integrate blue carbon into MPA design and management, Aquat. Conserv Mar. Freshw. Ecosyst. 27 (2017) 100–115.
[21] S.H. Hutto, M. Brown, E. Francis, Blue carbon in marine protected areas: Part 1; A guide to understanding and increasing protection of blue carbon. National Marine Sanctuaries Conservation Science Series ONMS-21-07. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Off. Natl. Mar. Sanctuaries (2021).
[22] IPCC, 2013 Supplement to the 2006 IPCC guidelines for national greenhouse gas inventories, in: T. Hiraishi, T. Krug, K. Tanabe, et al. (Eds.), wetlands, IPCC, Geneva, 2014, p. 2006.
[23] Japan Blue Economy association JBE. ⟨https://www.blueeconomy.jp/en/⟩.
[24] J. Kelleway, O. Serrano, T. Cannard, et al., Technical review of opportunities for including blue carbon in the Australian government's Emissions Reduction Fund, CSIRO, Canberra (2017).
[25] J. Kelleway, O. Serrano, J.A. Baldock, et al., A national approach to greenhouse gas abatement through blue carbon management, Glob. Environ. Change 63 (2020), 102083.
[26] T. Kuwae, M. Hori, Blue Carbon in Shallow Coastal Ecosystems, Springer,, Singapore, 2019, p. 373.
[27] T. Kuwae, G. Yoshida, M. Hori, et al., Nationwide estimation of the annual uptake of atmospheric carbon dioxide by shallow coastal ecosystems in Japan, J. JSCE B2 75 (2019) 10–20.
[28] T. Kuwae, S. Crooks, Linking climate change mitigation and adaptation through coastal green–gray infrastructure: a perspective, Coast Eng. J. 63 (2021) 188–199.
[29] T. Kuwae, S. Yoshihara, F. Suehiro, et al., "Implementation of Japanese blue carbon offset crediting projects.", in: F. Nakamura (Ed.), Green infrastructure and climate change adaptation: function, implementation and governance, Springer, 2022, pp. 353–377.
[30] D.A. Laffoley, G. Grimsditch, The management of natural coastal carbon sinks. IUCN, Gland (2009) 53. ⟨https://portals.iucn.org/library/sites/library/files/documents/2009-038.pdf⟩.
[31] J. Lee, M. Ingalls, J.D. Erickson, E. Wollenberg, Bridging organizations in agricultural carbon markets and poverty alleviation: an analysis of pro-Poor carbon market projects in East Africa, Glob. Environ. Change 39 (2016) 98–107.
[32] C.E. Lovelock, C.M. Duarte, Dimensions of Blue Carbon and emerging perspectives, Biol. Lett. 15 (2019), 20180781.
[33] Lutz SJ, Neumann C., Bredbenner A. (2014) Building blue carbon projects: an introductory guide. https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/317/original/building_blue_carbon_projectsLowRes.pdf?1489067674.
[34] Tierra Resources LLC and the Climate Trust. Available at: http://tierraresourcesllc.com/coastal-protection-projects/louisianablue-carbon-study/Accessed 15 May (2018).
[35] P.I. Macreadie, A. Anton, C.M. Duarte, et al., The future of Blue Carbon science, Nat. Commun. 10 (2019) 3998.
[36] P. Marenya, E. Nkonya, W. Xiong, J. Deustua, E. Kato, Which policy would work better for improved soil fertility management in sub-Saharan, Afr., Fertil. Subsid. Or. Carbon Credits? Agric. Syst. 110 (2012) 162–172.

[37] A. Martin, E. Landis, C. Bryson, et al., Blue carbon: nationally determined contributions inventory. Appendix to: Coastal blue carbon ecosystems: opportunities for nationally determined contributions, GRID, Arendal, Nor. (2016).

[38] MLIT, Ministry of Land, Infrastructure, Transp. Tour. (2020). ⟨https://www.mlit.go.jp/report/press/port06_hh_000216.html⟩.

[39] MPA News (2020). Selling carbon credits to fund MPAs, part 2: Could MPAs sell credits based on their fish stocks? ⟨https://mpanews.openchannels.org/news/mpa-news/selling-carboncredits-fund-mpas-part-2-could-mpas-sell-credits-based-their-fish⟩.

[40] B.C. Murray, L. Pendleton, W.A. Jenkins, et al., Green payments for blue carbon: economic incentives for protecting threatened coastal habitats. Nicholas Institute for Environmental Policy Solutions, Rep. NI 11 (04) (2011). ⟨https://nicholasinstitute.duke.edu/sites/default/files/publications/blue-carbon-report-paper.pdf⟩.

[41] C. Nellemann, E. Corcoran, C.M. Duarte, et al., *Blue Carbon: a rapid response assessment*. United Nations Environmental Programme, GRID-Arendal, Birkeland Trykk , Birkeland (2009).

[42] B.A. Needelman, I.M. Emmer, M.P.J. Oreska, et al., Blue carbon accounting for carbon markets, in: L. Windham-Myers, S. Crooks, T. Troxler (Eds.), A Blue Carbon Primer: the State of Coastal Wetland Carbon Science, Policy, and Practice, CRC Press, Boca Raton, 2018.

[43] M. Nobutoki, S. Yoshihara, T. Kuwae, Carbon offset utilizing coastal waters: Yokohama blue carbon project, in: T. Kuwae, M. Hori (Eds.), Blue Carbon in Shallow Coastal Ecosystems, Springer, Singapore, 2019, pp. 321–346.

[44] J.J. O'Connor, B.J. Fest, M. Sievers, et al., Impacts of land management practices on blue carbon stocks and greenhouse gas fluxes in coastal ecosystems- A meta-analysis, Glob. Chang Biol. 26 (2020) 1354–1366.

[45] T. Okada, Y. Mito, E. Iseri, et al., Method for the quantitative evaluation of ecosystem services in coastal regions, PeerJ 6 (2019), e6234.

[46] T. Okada, Y. Mito, Y.B. Akiyama, et al., Green port structures and their ecosystem services in highly urbanized bay, Cost. Eng. J. (2021) 1–13.

[47] S. Otani, T. Endo, CO_2 flux in tidal flats and salt marshes, in: T. Kuwae, M. Hori (Eds.), Blue Carbon in Shallow Coastal Ecosystems: Carbon Dynamics, Policy, and Implementation, Springer, Singapore, 2019, pp. 223–250.

[48] G.P. Peterson St-Laurent, S. Hagerman, G. Hoberg, Barriers to the development of forest carbon offsetting: insights from British Columbia, Canada, J. Environ. Manag. 203 (2017) 208–217.

[49] C.M. Regan, J.D. Connor, D.M. Summers, et al., The influence of crediting and permanence periods on Australian forest-based carbon offset supply, Land Use Policy 97 (2020), 104800.

[50] E. Sala, J. Mayorga, D. Bradley, et al., Protecting the global ocean for biodiversity, food and climate, Nature 592 (2021) 397–402.

[51] Y. Sapkota, J.R. White, Carbon offset market methodologies applicable for coastal wetland restoration and conservation in the United States: a review, Sci. Total Environ. 701 (2020), 134497.

[52] L. Schile-Beers, J.P. Megonigal, J.B. Kauffman, et al., Carbon sequestration in arid blue carbon ecosystems: a case study from the United Arab Emirates, in: L. Windham-Myers, S. Crooks, T.G. Troxler (Eds.), A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice And Policy, CRC Press, 2019, pp. 327–339.

[53] A.D.L. Steven, K. Appeaning Addo, G. Llewellyn, et al., Coastal Development: Resilience, Restoration and Infrastructure Requirements, World Resources Institute, Washington, DC, 2020. ⟨http://www.oceanpanel.org/blue-papers/coastal-development-resilience-restoration-and-infrastructurerequirements⟩.

[54] G.P. St-Laurent, S. Hagerman, G. Hoberg, Barriers to the development of forest carbon offsetting: Insights from British Columbia, Canada, J. Environ. Manag. 203 (2017) 208–217.

[55] F. Suehiro, H. Suzuki, S. Yoshihara, et al., Study on the world's first credit certification for blue carbon in eelgrass fields in Yokohama City, J. JSCE G3 76 (2020) 49–53.

[56] Y. Sugimura, T. Kobayashi, Y. Mito, et al., The establishment and future prospects of blue carbon offset system at Hakata Port, J. JSCE G 77 (2021) 31–48.

[57] A.E. Sutton-Grier, K. Wowk, H. Bamford, Future of our coasts: the potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems, Environ. Sci. Policy 51 (2015) 137–148.

[58] Taskforce on Scaling Voluntary Carbon Markets, Core carbon principle, Final Rep. (2021). ⟨https://www.iif.com/Portals/1/Files/TSVCM_Report.pdf⟩.

[59] T. Thiele, G. Alleng, A. Biermann, et al., Blue infrastructure finance: a new approach, integrating nature-based solutions for coastal resilience, IUCN, Gland, Switzerland, 2020.

[60] S. Thomas, Blue carbon: knowledge gaps, critical issues, and novel approaches, Ecol. Econ. 107 (2014) 22–38.

[61] T. Tokoro, K. Watanabe, K. Tada, et al., Guideline of blue carbon (CO_2 absorption and carbon sequestration) measurement methodology in port areas, Tech. Note Port. Airpt. Res. Inst. no 1309 (2015).

[62] G. Vacchiano, R. Berretti, R. Romano, R. Motta, Voluntary carbon credits from improved forest management: policy guidelines and case study, IForest 11 (2018) 1–10.

[63] M.A. Vanderklift, et al., Constraints and opportunities for market-based finance for the restoration and protection of blue carbon ecosystems, Mar. Policy 107 (2019), 103429.

[64] G.C. van Kooten, Forest carbon offsets and carbon emissions trading: problems of contracting, For. Policy Econ. 75 (2017) 83–88.

[65] Verified Carbon Standard Methodol. Tidal Wetl. seagrass Restor. 2015.⟨http://www.v-c-s.org/methodologies/methodology-tidal-wetland-and-seagrass-restoration-v10⟩.

[66] J.A. Villa, B. Bernal, Carbon sequestration in wetlands, from science to practice: an overview of the biogeochemical process, measurement methods, and policy framework, Ecol. Eng. 114 (2018) 115–128.

[67] K. Watanabe, K. Seike, R. Kajihara, et al., Relative sea-level change regulates organic carbon accumulation in coastal habitats, Glob. Change Biol. 25 (2019) 1063–1077.

[68] K. Watanabe, G. Yoshida, M. Hori, Y. Umezawa, H. Moki, T. Kuwae, Macroalgal metabolism and lateral carbon flows can create significant carbon sinks, Biogeosci 17 (2020) 2425–2440.

[69] World Bank, 2017. Implementing nature based flood protection: principles and implementation guidance. http://documents.worldbank.org/curated/en/739421509427698706/Implementing-nature-based-flood-protection-principles-and-implementation-guidance.

[70] L. Wylie, A.E. Sutton-Grier, A. Moore, Keys to successful blue carbon projects: lessons learned from global case studies, Mar. Policy 65 (2016) 76–84.

[71] L. Wyndham-Meyers, S. Crooks, T. Troxler, A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice and Policy, CRC, Taylor & Francis, Boca Raton, 2018, p. 352.

[72] V. Yadav, G.P. Malanson, E. Bekele, C. Lant, Modeling watershed-scale sequestration of soil organic carbon for carbon credit programs, Appl. Geogr. 29 (2009) 488–500.