Harmonizing Blue Carbon Accounting Protocols for Coastal Ecosystems in the East Asian Seas Region

A COMPARATIVE ANALYSIS OF BLUE CARBON STANDARDS AND METHODOLOGIES FROM VERRA, JAPAN, KOREA, CHINA, INDONESIA, AND THE PHILIPPINES

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Introduction

The conservation and management of coastal and marine ecosystems, known for their significant carbon sequestration potential, have gained prominence due to their critical role in climate change mitigation and biodiversity conservation. These ecosystems, termed 'blue carbon' ecosystems encompass mangrove forests, seagrass meadows, tidal marshes. The increasing focus on these ecosystems is driven by their ability to capture and store carbon, thereby reducing greenhouse gases (GHG) in the atmosphere.

Recognizing the importance of blue carbon ecosystems, the 15th EAS Partnership Council approved the development of a PEMSEA blue carbon program which is currently managed by the PEMSEA Resource Facility (PRF) with the advice and support of Dr. Keita Furukawa, EAS PC Technical Session Chair and advisers-members of the PEMSEA Network of Learning Centers. PRF developed a skeletal roadmap with four components, to look into the supply, market, accounting and certification of blue carbon.

This paper written by Kristina di Ticman is a foundational document on the blue carbon accounting component aimed at developing a harmonized blue carbon accounting protocol in the East Asian Seas region. The proposal to develop a harmonized blue carbon accounting protocol was agreed at the 2nd General Assembly of the PEMSEA Network of Learning Center.

The paper provides a review and comparative analysis of blue carbon accounting protocols from various countries, namely China, Indonesia, Japan, the Philippines and RoKorea, alongside the voluntary standards set by VERRA, a leading a non-profit organization that develops and manages standards for sustainable development, climate action, and responsible business practices. The accounting protocols from EAS countries vary from government issued and/ or recognized accounting methodologies to university owned methodologies as made available to PEMSEA. The review highlights similarities, identifies gaps and proposes recommendations for harmonization to establish a standardized BC accounting protocol for PEMSEA country partners.

This comparative analysis aims to help inform PEMSEA's decision in developing robust blue carbon standards, thereby facilitating effective carbon sequestration initiatives and contributing to global climate change mitigation efforts.

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For more information on PEMSEA's Blue Carbon program, please check out our Blue Carbon webpage or write to info@pemsea.org and/or subscribe to our e-bulletin

I. Blue Carbon Accounting Methodologies

VERRA

The VERRA standards, as encapsulated in the VM0007-REDD Methodology Framework (v1.7) and VM0033-Methodology for Tidal Wetland and Seagrass Restoration (v2.1), provide detailed guidelines for quantifying, monitoring, and verifying greenhouse gas (GHG) emissions reductions and carbon sequestration in various ecosystems. The primary objective of these documents is to ensure the generation of accurate and verifiable carbon credits that support global climate mitigation efforts.

The targeted ecosystems under these methodologies include tropical and temperate forests, peatlands, salt marshes, tidal freshwater marshes, mangroves, and seagrass meadows. These ecosystems are crucial for their carbon storage potential, involving various carbon pools such as aboveground biomass, belowground biomass, deadwood, litter, and soil organic carbon.

The methodologies specify the measurement of key GHGs: Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O). To ensure the reliability of GHG estimates, VERRA recommends accounting for uncertainty by using confidence intervals and applying conservative assumptions and discount factors. This approach helps in quantifying and managing the uncertainty associated with carbon stock and emissions estimates, ensuring conservative and credible reporting.

Various sources of data can be utilized under these standards, including field measurements, remote sensing data, GIS data, historical land use records, published values, models, proxies, default factors, and IPCC emission factors. Technologies and field techniques mentioned include GPS for geographic positioning, GIS for spatial analysis, remote sensing for monitoring vegetation and land-use changes, soil coring for soil carbon estimation, and allometric equations for biomass calculation. These tools and methods enable precise data collection and analysis, essential for accurate carbon accounting.

Verification and certification of projects are conducted under the Verified Carbon Standard (VCS). Independent third-party auditors and validators assess project compliance with VCS requirements, ensuring the credibility and accuracy of reported emissions reductions and carbon sequestration. Regular monitoring and periodic reassessment of project baselines further strengthen the verification process.

However, the methodologies are not without limitations. The initial costs and technical expertise required for implementing these standards can be high, potentially limiting accessibility for smaller projects or communities with limited resources. Additionally, while the guidelines are comprehensive, they may require adaptation to specific local conditions, adding complexity to project implementation.

The VERRA standards offer a robust and scientifically grounded framework for blue carbon crediting. Their rigorous methods and verification processes ensure reliable carbon accounting, making them a valuable tool for climate mitigation. Despite some challenges, these standards are highly adaptable and can be generalized for use in various ecological settings. Countries worldwide can adopt these methodologies to enhance their carbon sequestration efforts, contributing to global climate goals. By providing a standardized approach, the VERRA methodologies facilitate the integration of blue carbon projects into national and international carbon markets, promoting widespread adoption and impact.

Japan (JBlueCredit)

The J Blue Credit standards provide comprehensive guidelines for measuring, verifying, and certifying CO_2 absorption in Japan's marine ecosystems, such as seagrass beds, seaweed beds, mangroves, and tidal flats, supporting the nation’s goal of carbon neutrality by 2050. These standards ensure environmental sustainability by quantifying the CO_2 sequestration capacity of these ecosystems through detailed accounting and verification methods.

The carbon pools considered include CO_2 stored in submarine soil, deep sea organic matter, and dissolved organic matter in seawater. Field data collection involves aerial photographs, drone imagery, GPS data, and visual field observations to map distribution and biomass. Wet weight samples of seaweed and seagrass are collected to determine biomass per unit area, and cover class data is recorded using a square frame on the seafloor. Specific calculation formulas use these measurements and absorption coefficients from literature and observational data to estimate total CO_2 sequestration.

The verification and crediting process, managed by the J-Blue Credit Assessment and Certification Committee, includes application evaluations, on-site assessments, and data verification. Applicants use an Online Application System for transparent and efficient processing. Regular monitoring, with data collected at least twice a year, and third-party verification ensure the accuracy and integrity of the crediting process.

These reproducible standards, supported by national databases like Umishiru and EADAS, promote accurate CO_2 absorption measurements and sustainable management of marine ecosystems. They create a replicable model for Japan's broader carbon neutrality efforts, enhancing the ability to certify and trade carbon credits while fostering environmental stewardship and economic sustainability.

Korea

The Korean Blue Carbon Accounting Protocols aim to establish a comprehensive and standardized framework for accurately measuring, reporting, and verifying (MRV) greenhouse gas (GHG) emissions and carbon sequestration in Korea's coastal wetlands. These protocols are designed to support national efforts in combating climate change, enhancing environmental management, and fulfilling international climate commitments by providing detailed guidelines for blue carbon accounting.

The focus of these protocols is on key blue carbon ecosystems, including tidal marshes, seagrass meadows, and various coastal wetlands. These ecosystems play a crucial role in carbon sequestration, making their accurate assessment essential for understanding and mitigating climate change impacts. The protocols address various carbon pools such as biomass, which includes both above-ground and below-ground biomass, dead organic matter, and soil carbon.

For data collection and computational methods, the protocols utilize several approaches. The gain-loss method estimates changes in carbon stocks by accounting for gains, such as carbon accumulation, and losses, like carbon emissions. The stock difference method calculates changes in carbon stocks by comparing initial and final stock values over a specified period. Core sediment sampling involves collecting samples from coastal wetlands, subsampling at intervals, and conducting analyses such as wet-sieving, freeze- drying, homogenization, decalcification, and elemental analysis. Additionally, the protocols rely on modelling and literature values from reports, journals, and statistics to validate and refine models for carbon stock estimation.

Accounting for uncertainty is a critical aspect of these protocols. Different types of uncertainties, such as measurement uncertainty, model uncertainty, and reporting uncertainty, are considered. The protocols suggest various tools to manage these uncertainties, including statistical methods, sensitivity analysis, and uncertainty propagation techniques. These tools help in quantifying and minimizing the impact of uncertainties on the reported data.

Verification methods include regular internal monitoring and verification by third-party agencies to ensure the accuracy and credibility of the reported data. The involvement of independent third-party verification agencies enhances the reliability of the blue carbon accounting process, ensuring compliance with national and international standards.

The strengths of these documents and procedures lie in their rigorous and standardized approach, which ensures accurate and comprehensive data collection. However, some limitations include the need for extensive fieldwork and reliance on empirical data, which can be resource-intensive. Despite these challenges, the protocols are designed for practical application across various coastal wetland ecosystems, ensuring their wide applicability. They enhance the accuracy and comprehensiveness of Korea's national greenhouse gas inventory, support effective environmental management and restoration of coastal wetlands, and inform climate policies and strategies at both national and international levels. By adhering to these protocols, Korea ensures a robust and standardized approach to blue carbon accounting, contributing significantly to global efforts in climate change mitigation and fostering sustainable environmental practices.

China

There are two sets of methodologies for blue carbon accounting from China reviewed here: one by the Ministry of Natural Resources (MNR) and another by Xiamen University for the Fujian Forestry Certified Emission Reduction (FFCER).

Methods proposed by the Ministry of Natural Resources (MNR)

MNR has developed advanced and comprehensive methodologies for quantifying and monitoring blue carbon sinks, focusing on various ecosystems such as mangroves, seagrass beds, coastal salt marshes, and cultured macroalgae and bivalve molluscs. These methodologies aim to provide accurate measurements of greenhouse gases, carbon pools, and to ensure robust data collection and reporting practices.

Their primary objective of blue carbon accounting protocols is to provide detailed guidelines for measuring and monitoring carbon sinks in coastal and marine ecosystems. These protocols are designed to support the country's efforts in reducing greenhouse gas emissions, enhancing carbon sequestration, and participating in carbon trading markets.

The targeted ecosystems for these methodologies include mangrove ecosystems, seagrass bed ecosystems, coastal salt marsh ecosystems, and areas where cultured algae and bivalve molluscs are found. These diverse ecosystems are integral to the overall strategy of enhancing blue carbon sinks and mitigating climate change.

The methodologies focus on several carbon pools within these ecosystems. These include aboveground and belowground biomass, dead organic matter such as dead wood and litter, and sediment. For cultured algae and bivalve molluscs, the carbon pools also include the biomass of these organisms.

The data sources for these methodologies are comprehensive and include remote sensing data, literature reviews, historical surveys, and on-site surveys. For mangrove ecosystems, changes in biomass and sediment carbon stocks are calculated using methods like the Profit and Loss Method, Treasury Difference Method, and library difference method. Seagrass beds and coastal salt marshes use similar approaches, focusing on burial rate and carbon density. Cultured algae and molluscs are assessed using sampling techniques that measure dry-to-wet ratio, mass ratio, carbon content, and overall carbon sink capacity.

China MNR's blue carbon accounting protocols include specific instructions for managing uncertainty. The methodologies require detailed uncertainty assessments at every stage of data collection and analysis, utilizing statistical methods to quantify uncertainty and incorporating error margins in the final reports. These protocols ensure that all potential sources of error are identified and mitigated, and that the final carbon stock estimations are both accurate and reliable.

Verification processes are an integral part of the methodologies to ensure the integrity of the collected data. This includes comprehensive quality control (QC) and quality assurance (QA) measures. The methodologies stipulate regular instrument calibration and data validation to maintain accuracy. Additionally, periodic re-measurements and comparisons with established benchmarks are mandated to verify the reliability of the data. These processes help to ensure that the data collected are consistent and meet the required standards.

One of the strengths of MNR's blue carbon accounting protocols is their comprehensive nature, covering a wide range of ecosystems and incorporating robust data collection and computational methods. The use of advanced technologies such as GNSS, GIS, remote sensing, and isotope dating further enhances the accuracy and reliability of the data.

The methodologies are highly applicable to a range of projects aimed at enhancing blue carbon sinks. Their reproducibility is supported by the detailed guidelines and standardized procedures outlined in the documents. The involvement of national and local authorities, academic institutions, and specialized research centers ensures that these methodologies are both scientifically sound and aligned with national policies.

China's approach to blue carbon accounting and monitoring demonstrates a high level of sophistication, integrating detailed protocols, accurate measurement techniques, and comprehensive data collection strategies to effectively quantify and enhance carbon sinks in coastal and marine ecosystems.

Methods from Fujian Forestry Certified Emission Reduction (FFCER) prepared by Xiamen University

The "Methodology for the Mangrove Forest Restoration Carbon Sink Project in Fujian Province" (Version V01) aims to measure and monitor carbon sinks in mangrove ecosystems, facilitating carbon trading and promoting mangrove restoration in Fujian Province. The methodology is designed to standardize the design, emission measurement, and monitoring processes to ensure the proper reporting of emission reductions, thereby supporting Fujian's green economy and carbon trading initiatives.

This methodology focuses specifically on mangrove ecosystems, which are recognized for their significant carbon sequestration capabilities. It identifies several key carbon pools to be measured: above-ground biomass, below-ground biomass, dead wood, and soil organic carbon. Litter and wood products are excluded from the selected carbon pools due to high turnover rates and the prohibition of mangrove logging in China. The focus on these pools ensures comprehensive monitoring of carbon stocks within the project boundary.

Data for the methodology is gathered using various sources, including geospatial data (e.g., satellite images, aerial photos), GNSS or other satellite positioning systems, and field data collection. Biomass equations specific to the major mangrove species in Fujian Province are used for accurate calculations.

The methodology employs a stock-difference approach to calculate changes in carbon stocks over time. Equations are provided to compute annual changes in carbon stocks for each carbon pool, taking into account biomass growth and greenhouse gas emissions. The methodology integrates default factors, field measurements, and published values to ensure accuracy.

To address uncertainties, the methodology employs stratified sampling (categorical sampling) to improve the accuracy of biomass assessments. It requires the use of confidence intervals and transparent reporting of data, rationale, assumptions, and justifications. The inclusion of conservative estimates ensures reliability and robustness in the reported data.

Verification of the methodology is conducted by independent third-party organizations recognized by the competent authorities. These verifications ensure that all project activities comply with the methodology's requirements and that emission reductions are accurately reported. Verification includes the submission of vector graphics files for project boundaries and evidence of land ownership or use rights.

The methodology is specifically applicable to mangrove restoration projects within Fujian Province, including bare beach afforestation, converting ponds into mangrove forests, and reforestation after removing Spartina alterniflora. Its detailed procedures and reliance on widely accepted scientific principles make it reproducible in similar coastal regions with appropriate adjustments for local conditions. The methodology's emphasis on transparency and verification further supports its applicability and reproducibility in different contexts.

This comprehensive approach ensures that the methodology not only contributes to carbon sequestration efforts but also promotes sustainable mangrove restoration and management practices, supporting broader environmental and economic goals.

Indonesia

Indonesia's blue carbon accounting standards and protocols aim to systematically measure and monitor the carbon sequestration potential of coastal ecosystems such as mangroves and seagrasses. These protocols align with the nation's commitments under the Paris Agreement, particularly within the framework of the Nationally Determined Contributions (NDCs). The primary objective is to establish a comprehensive, standardized approach for quantifying and reporting carbon stocks and emissions reductions to mitigate climate change effectively.

The target ecosystems for Indonesia's blue carbon accounting are mangroves and seagrasses. These ecosystems are crucial for carbon sequestration due to their high productivity and ability to store carbon in both biomass and sediment. The accounting protocols encompass various carbon pools, including aboveground biomass, belowground biomass, soil organic carbon, dead wood, and litter. These pools represent different components of the ecosystem where carbon is stored, providing a holistic view of the total carbon sequestration capacity.

The methods for data collection and computation involve a combination of geometric methods, allometric equations, and remote sensing data. Key measurements include biomass (both specific gravity and biomass expansion factors) and organic matter (using volume, geometric methods, and allometric equations). Soil samples are analyzed in laboratories to determine the carbon organic percentage and bulk density. The Ministry of Environment and Forestry (MoEF) oversees the integration of these diverse data sources, ensuring alignment with national climate goals. The methodologies include statistical analyses to quantify confidence intervals, regular calibration of instruments, and validation of methods. An acceptable error tolerance of up to 20% for sampling techniques is specified, and robust Quality Assurance and Quality Control (QA/QC) procedures are implemented to maintain data integrity.

Verification of blue carbon data involves rigorous QA/QC procedures and repeated measurements to ensure reproducibility. The protocols specify stratified systematic sampling or simple random sampling and grouping of sites based on land cover maps derived from satellite imagery, with a resolution of at least 30 meters, following IPCC guidelines. These measures ensure that the data collected is reliable and verifiable.

The applicability of these protocols extends to various coastal regions within Indonesia, providing a standardized framework for local and national implementation. The methods are designed to be reproducible, with clear guidelines on field sampling specifications, including plot shapes, sizes, and sampling depths. This reproducibility ensures that different teams can achieve consistent results, contributing to the robustness of the national blue carbon database.

Philippines

The guidelines and protocols established for monitoring and accounting blue carbon ecosystems (BCEs) in the Philippines are designed to ensure comprehensive and accurate measurement of carbon sequestration in mangrove and seagrass ecosystems. The primary objective is to develop a standardized approach for assessing carbon pools, monitoring greenhouse gas (GHG) emissions, and understanding the dynamics of these crucial ecosystems to inform better management and conservation strategies.

In the Philippines, the focus is on mangroves and seagrasses, which are vital for carbon sequestration and coastal protection. The primary carbon pools in these ecosystems include aboveground biomass (e.g., trees and plant tissues), belowground biomass (e.g., roots and rhizomes), and soil organic carbon. These components collectively contribute to the ecosystem’s capacity to sequester carbon and are essential indicators for carbon stock assessments.

Data collection relies on various sources, including satellite imagery (e.g., Sentinel-2), UAVs, and field-based programs like Seagrass-Watch and SeagrassNet. Methods for computing carbon stocks involve field measurements and allometric equations for aboveground and belowground biomass, as well as the loss on ignition method for soil organic carbon.

For mangrove ecosystems, sediment samples are taken to a depth of 1 meter using appropriate coring equipment. Sampling is conducted within circular plots of a specified radius, aligned along transects, with multiple plots established per station. Each plot is measured for species composition, tree counts, and diameter at breast height (DBH) of adult trees. For seagrass ecosystems, sediment cores are taken to a designated depth, with water depth measured using standard techniques. Ground-truthing involves multiple plots distributed across different zones (e.g., near shore, middle shore, and offshore), with seagrass cover assessed using standardized plot sizes.

The guidelines emphasize the importance of rigorous data collection and validation to minimize uncertainty. Multi-parameter water quality profiling and continuous monitoring sensors enhance the accuracy of measurements. Data validation is achieved through laboratory analysis and cross-referencing field data with remote sensing inputs.

Verification of carbon stocks and ecosystem health is facilitated through collaboration with local governments, NGOs, and academic institutions. Standardized protocols and consistent monitoring ensure data reliability and enable reproducibility of results across different study sites and time periods.

The protocols provide a comprehensive framework for blue carbon monitoring, integrating advanced remote sensing technologies with field measurements. However, there are limitations, such as the lack of a centralized national database, which necessitates local collaborations for data sharing. Despite this, the involvement of citizen scientists and local communities enhances data collection and promotes stewardship of coastal ecosystems.

These guidelines are applicable across various coastal regions in the Philippines and can be adapted to other tropical and subtropical regions. The standardized methods ensure reproducibility of results, allowing for consistent long-term monitoring and comparison of data. The protocols' flexibility in incorporating both advanced technologies and community- based monitoring practices make them robust and scalable for broader application.

Summary

The reviewed blue carbon accounting protocols from VERRA and the countries of Japan, Korea, China, Indonesia, and the Philippines exhibit a range of methodologies and techniques designed to measure, report, and verify GHG emissions and carbon sequestration. While there are shared approaches, such as the use of field-collected data, literature values, and advanced modeling, there are also notable differences in specific techniques and calculation methods. These variations highlight the need for harmonization to ensure consistent and reliable blue carbon accounting across the region.

The comparison matrix provided in the following sections will explore the similarities, gaps, and points for harmonization among these protocols. By identifying common practices and areas of divergence, this analysis aims to facilitate the development of standardized blue carbon accounting protocols that PEMSEA partners can widely adopt.

II. Blue Carbon Accounting Methodologies

	VERRA	Japan	Korea	China		Indonesia	Philippines
				MNR	Xiamen U		
Focus	Carbon Crediting	Carbon Crediting	Reporting and Inventory	Monitoring and Management	Carbon Crediting	Reporting and National Inventory	Monitoring and Conservation
GHG measured	CH_4, N_2O, CO_2	CO_2	CH_4, N_2O, CO_2	CH_4, N_2O, CO_2	CH_4, N_2O, CO_2	CH_4, CO_2	CO_2
Carbon stock metrics	GHG Emissions (from biomass and soil) Verified Carbon units, buffer Uncertainty	CO_2 absorption Atmospheric CO_2 Certainty	Carbon Stock CO emissions Uncertainty	Carbon Stock CH_4 emission Uncertainty	Carbon Stock CO_2 emissions Uncertainty	Carbon Stock	Carbon Stock
Reporting units	t CO_2e /ha/yr	t CO_2 /yr	t CO_2 /ha	t CO_2 /ha	t CO_2 /ha	t CO_2 /ha	t CO_2 /ha, Mg/ha

	VERRA	Japan	Korea	China		Indonesia	Philippines
				MNR	Xiamen U		
Ecosystem types covered	Tidal Wetlands Seagrass Meadows Mangrove Forests Herbaceous Vegetation in Wetlands	Mangroves Tidal Flats Seagrass Seaweed Aquaculture	Tidal Marshes Seagrass Meadows Coastal Wetlands	Mangrove Seagrass Coastal Salt Marsh Cultured algae and bivalve molluscs	Mangroves	Mangroves and seagrasses	Mangroves and Seagrasses
Carbon pools	Aboveground (tree and non tree) Belowgroun d Litter Dead wood Soil Wood Products	Submarine soil and deep sea as organic matter derived from grass algae. Seawater as persistent dissolved organic matter released from grass algae.	Biomass Dead organic matter Soil Carbon	Biomass (aboveground, belowground) Dead Organic Matter (dead wood + litter) Sediment Cultured Algae and Bivalve molluscs	Biomass (above ground, belowground) Dead wood Soil organic carbon	Aboveground biomass Belowground biomass Soil organic carbon Dead wood Litter	Aboveground biomass Belowground biomass Soil organic carbon

	VERRA	Japan	Korea	China		Indonesia	Philippines
				MNR	Xiamen U		
Carbon calculation input sources	Proxies Field data collection Literature values Default factors Models, or IPCC emission factors	Field data collection Literature values	Field data collection Literature values Models	Field data collection Literature values Historical surveys	Field data collection Default factors	Field data collection	Field data collection
Carbon Calculation methods	Total Stock approach Stock loss approach Loss on Ignition method Biomass Expansion Factor Allometric Equations	Weight per unit area Absorption coefficient	Gain-loss method Stock-difference method	Profit and Loss Method Treasury Difference Method Library Difference Method Burial rate Carbon density Carbon content Dry-to-wet ratio Mass ratio	Stock-difference principle Biomass equations	Geometric method Allometric equations Biomass expansion factor Carbon organic percentage Bulk density	Allometric equations Loss on Ignition method

	VERRA	Japan	Korea	China		Indonesia	Philippines
				MNR	Xiamen U		
Field Sampling Specifications	Sample plot sizes according to forest, vegetation, and soil inventory practices	Acoustic Survey (3 to 100m depth) Underwater Drone (3 to 50m in length)	Soil Core Depths: Up to 100 cm	Mangroves: 10m x 10m (tree- type), 5m x 5m (shrub-type) 1m length for carbon burial rate sampling	Rectangular plots: 10m x 10m	Plot Shape: Square, rectangular, and circular plots recommended Plot Size: Circular plots: Minimum total area: 0.25 m² (litter), 4 m² (seed), 25 m² (stake), 100 m² (poles), 400 m² (trees). Soil Samples: Depths: 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm. Subsamples: ~300 grams. Stratified systematic sampling or random sampling with 20% error tolerance. Grouping based on land cover maps with ≥30 m resolution.	Mangroves: Sediment cores up to 1m depth. Seagrass: Sediment cores up to 120 cm depth. Ground-truthing: 50x50 cm plots. Water Quality: Depths using Niskin sampler or bucket.

	VERRA	Japan	Korea	China		Indonesia	Philippines
				MNR	Xiamen U		
Field Data Collection Techniques	Soil Coring for Soil Carbon Estimation Sampling of Herbaceous Vegetation (Dry mass) Use of Marker Horizons Stratification and Sampling Framework Monitoring of Water Levels	RS Survey: Satellite, aerial, drone, underwater camera, acoustic Sampling: Weight of seaweeds and seagrasses measured inside the frame Seagrass and Seaweed Beds: Survey during thriving period for best accuracy Distribution Area: Visual observation, aerial photograph, GPS	Core Sediment Sampling Subsampling at Intervals, Wet- Sieving, Freeze-Drying and Homogenization, Decalcification and Elemental Analysis, Radioactive Dating	Mangroves: Area/distribution, Vegetation community characteristics/ survey, soil sampling Surface elevation-marker layer monitoring system, Isotope Dating Seagrass: Area/ distribution, Vegetation Characteristics, Soil sampling Coastal salt marsh: Area/distribution, vegetation characteristics, soil sampling Algae and Molluscs: Sampling	RS and GNSS for boundaries Stratified sampling of plots, vegetation measurements Dead wood and Soil Sediment sampling	Stratified Sampling of plots, Vegetation measurements, Vegetation (seedling/ underplant), root, dead tree litter collection/ sampling, soil coring	Soil core sampling, water quality measurements, Vegetation measurement

Focus of the Standards

The blue carbon accounting protocols reflect distinct focuses across different countries. VERRA and Japan's JBlueCredit primarily cater to carbon crediting projects, providing comprehensive methodologies for quantifying, monitoring, and verifying GHG emissions reductions and carbon sequestration. These protocols facilitate the generation of verifiable carbon credits, supporting participation in global carbon markets. In contrast, Korea focuses on national GHG reporting and coastal wetland inventories, emphasizing accurate and comprehensive data collection. China has dual focuses: the Ministry of Natural Resources (MNR) methodologies are geared towards monitoring and managing blue carbon sinks, utilizing advanced remote sensing and computational methods, while the Xiamen University methodology supports carbon crediting, particularly for mangrove restoration projects. Indonesia and the Philippines are developing frameworks with a focus on integrating carbon data into national goals and community-based monitoring practices.

Green House Gases

The primary GHGs considered across these standards include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). VERRA, Korea, China, and Indonesia measure CH_4, N_2O, and CO_2, highlighting a comprehensive approach to capturing the significant GHGs involved in blue carbon ecosystems. In contrast, Japan and the Philippines focus exclusively on CO_2, indicating a more targeted approach in their carbon accounting protocols.

In terms of carbon stock metrics, the methodologies vary in complexity and scope. VERRA's standards encompass GHG emissions from both biomass and soil, verified carbon units, and include provisions for managing uncertainty. Japan's protocols emphasize CO_2 absorption and atmospheric CO_2, with a focus on certainty in their measurements. Korea's metrics include carbon stock and CO_2 emissions, with an emphasis on accounting for uncertainty. China's approach similarly includes carbon stock and CH_4 emissions, with measures to address uncertainty. Indonesia and the Philippines focus on carbon stock metrics, ensuring a straightforward approach to measuring carbon sequestration.

The reporting units also vary across the standards. VERRA reports in terms of t CO_2e/ha/yr, providing a comprehensive annualized measure of carbon dioxide equivalent per hectare. Japan reports in t CO_2/yr, focusing on annual CO_2 absorption. Korea, China, Indonesia, and the Philippines report in t CO_2/ha, with the Philippines also using Mg/ha as an additional unit of analysis. This variation in reporting units reflects the differing methodologies and priorities in carbon accounting across these regions.

Ecosystem Types Covered and Carbon Pools Measured

The accounting protocols demonstrate a diverse range of target ecosystems and carbon pools across VERRA and the various countries. VERRA's protocols encompass a broad range of ecosystems including tidal wetlands, seagrass meadows, mangrove forests, and herbaceous vegetation in wetlands. This comprehensive approach is similar to Japan's JBlue Credit standards, which also target diverse ecosystems such as mangrove ecosystems, tidal flats, seagrass ecosystems, seaweed ecosystems, and aquaculture. Both VERRA and Japan demonstrate a wide-ranging focus on both coastal and marine environments. In contrast, Korea's focus is more specific, targeting tidal marshes, seagrass meadows, and coastal wetlands, which are critical for the country's coastal management. China's protocols include a broad spectrum similar to VERRA and Japan, including mangrove ecosystems, seagrass bed ecosystems, coastal salt marsh ecosystems, and cultured algae and bivalve molluscs. Indonesia and the Philippines both concentrate on mangroves and seagrasses, reflecting a targeted approach towards the most significant blue carbon ecosystems in their regions.

In terms of carbon pools, VERRA and China provide the most comprehensive coverage. VERRA measures aboveground (tree and non-tree) biomass, belowground biomass, litter, dead wood, soil, and wood products. Similarly, China includes biomass (aboveground and belowground), dead organic matter (dead wood and litter), sediment, and cultured algae and bivalve molluscs in the MNR methodologies. The Xiamen University methodology for Fujian Province focuses on aboveground biomass, belowground biomass, dead wood, and soil organic carbon, excluding litter and wood products due to high turnover rates and the prohibition of mangrove logging. Japan's JBlue Credit focuses on marine carbon pools such as submarine soil, deep-sea organic matter derived from grass algae, and seawater as persistent dissolved organic matter. Korea's protocols are more streamlined, measuring biomass, dead organic matter, and soil carbon, ensuring a thorough but focused accounting of carbon stocks. Indonesia and the Philippines focus on aboveground biomass, belowground biomass, and soil organic carbon, with Indonesia also including dead wood and litter.

Carbon Calculation Methods

All countries and VERRA utilize field data collection as a primary source. VERRA additionally uses proxies, literature values, default factors, models, and IPCC emission factors. Japan and Korea use literature values, while China supplements field data with historical surveys and advanced computational methods in the MNR methodologies. The Xiamen University methodology emphasizes field data collection and using biomass equations specific to major mangrove species. Indonesia and the Philippines rely heavily on field data collection.

VERRA employs a variety of calculation methods including the total stock approach, stock loss approach, loss on ignition method, biomass expansion factor, and allometric equations. Japan uses weight per unit area and absorption coefficient methods. Korea utilizes the gain-loss and stock difference methods. China's methods are diverse, including the profit and loss method, treasury difference method, library difference method, burial rate, carbon density, carbon content, dry-to-wet ratio, and mass ratio. The Xiamen University methodology uses a stock-difference approach, incorporating equations to compute annual changes in carbon stocks for each carbon pool, including biomass growth and greenhouse gas emissions. Indonesia uses geometric methods, allometric equations, biomass expansion factor, carbon organic percentage, and bulk density. The Philippines use allometric equations and the loss on ignition method.

All protocols recognize the importance of field data collection and the measurement of key carbon pools such as aboveground and belowground biomass and soil carbon. Common methods include the use of allometric equations and biomass expansion factors. VERRA and China have the most comprehensive range of carbon pools and diverse methods for calculation. Japan's focus on marine carbon pools and unique methods like weight per unit area and absorption coefficient set it apart. Korea, Indonesia, and the Philippines have a more streamlined approach, with specific methods tailored to their ecological contexts.

Field Data Collection Techniques

The table provides a streamlined comparison of field data collection techniques used by VERRA and various countries for blue carbon accounting. VERRA's techniques include soil coring for soil carbon estimation, sampling of herbaceous vegetation, using marker horizons, stratification and sampling framework, and monitoring water levels. Japan's JBlue Credit guidelines utilize advanced technologies such as satellite, aerial, drone, and underwater camera surveys, alongside traditional methods like visual observations and GPS for determining ecosystem boundaries and biomass.

Korea employs core sediment sampling with advanced laboratory techniques such as wet-sieving, freeze-drying, homogenization, decalcification, and elemental analysis, including radioactive dating. China (MNR)'s methods encompass detailed surveys of mangroves, seagrasses, coastal salt marshes, and algae and molluscs, using surface elevation-marker layer monitoring systems and isotope dating. The Xiamen University methodology employs geospatial data, GNSS, and field data collection to gather data, and includes detailed guidelines for biomass equations specific to major mangrove species in Fujian Province. Indonesia's protocols involve stratified sampling of plots, vegetation measurements, soil coring, and dead tree litter collection. The Philippines focus on soil core sampling, water quality measurements, and vegetation assessment.

VERRA adheres to sample plot sizes according to established practices in forest, vegetation, and soil inventories, ensuring standardized data collection. Japan employs advanced technologies such as acoustic surveys, ranging from 3 to 100 meters in depth, and underwater drones with lengths from 3 to 50 meters, for precise marine data collection. Korea specifies soil core depths up to 100 centimeters, focusing on detailed sediment sampling. China uses varied plot sizes for different ecosystems, including 10m x 10m plots for tree-type mangroves and 5m x 5m plots for shrub-type mangroves, to ensure comprehensive coverage of carbon burial rates. Indonesia recommends different plot shapes and sizes, including circular plots with minimum areas designated for various vegetation types, and employs stratified sampling based on land cover maps with at least 30-meter resolution. The Philippines use sediment cores up to 1 meter depth for mangroves and up to 120 centimeters for seagrass, along with water quality sampling using Niskin samplers or buckets.

In comparing these methods, several commonalities emerge. All protocols recognize the importance of soil coring, vegetation sampling, and stratified sampling techniques for accurate carbon data collection. The use of technology is evident, with Japan employing advanced tools such as acoustic surveys and underwater drones, and China leveraging remote sensing (RS) and geographic information systems (GIS) to determine ecosystem boundaries. These advancements highlight the growing integration of technology in field data collection.

Despite these similarities, the approaches vary to suit specific regional ecosystems. VERRA's methods are based on established inventory practices, while Japan utilizes high- tech methods tailored for marine ecosystems. China applies specific techniques for various coastal and marine habitats, reflecting the diverse ecological contexts each protocol addresses.

Monitoring and Verification, Certification and Reproducibility

Monitoring and verification are integral components of all the protocols. VERRA mandates regular monitoring and third-party verification to validate carbon stock changes and ensure the credibility of reported data. This approach is mirrored in the protocols from Japan and Korea, which also require detailed monitoring and verification processes. China's protocols

include advanced methods such as surface elevation-marker layer monitoring systems and isotope dating, ensuring continuous and accurate monitoring of carbon stocks. The Xiamen University methodology includes verification by independent third-party organizations and requires transparent reporting of data, assumptions, and justifications. Indonesia emphasizes rigorous QA/QC procedures, while the Philippines integrate community-based monitoring practices. The emphasis on systematic monitoring and independent verification across all protocols highlights a shared commitment to maintaining data integrity and transparency.

Certification processes in the protocols are designed to validate the credibility of carbon credits and ensure compliance with established standards. VERRA provides a robust framework for certification, involving third-party audits and the issuance of verified carbon units. Japan's JBlue Credit guidelines also include comprehensive certification procedures to facilitate participation in carbon markets. China's Xiamen University methodology supports carbon crediting through standardized design, emission measurement, and monitoring processes, ensuring the proper reporting of emission reductions.

These comprehensive methodologies across different countries and VERRA reveal both strengths and areas needing improvement. The next section will discuss the existing gaps and provide recommendations for harmonization to create a cohesive and effective blue carbon accounting framework for Southeast and East Asia.

III. Gaps and Considerations for Harmonization

Gaps

One notable gap is the varied focus of protocols across different countries. VERRA and Japan's protocols primarily aim at carbon crediting, facilitating participation in international carbon markets. In contrast, Korea's protocols emphasize national reporting and inventory, while China focuses on monitoring and management of blue carbon sinks. Indonesia prioritizes national inventory, and the Philippines aims at monitoring and conservation. These differing objectives result in varied methodologies and levels of detail, potentially hindering the development of standardized practices. Additionally, some countries lack comprehensive frameworks for integrating blue carbon projects into their national climate strategies, which limits the potential for a harmonized approach.

Inconsistencies in GHG accounting arise from the different gases measured by each protocol. While VERRA, Korea, China, and Indonesia measure CH_4, N_2O, and CO_2, Japan and the Philippines focus solely on CO_2. Furthermore, the level of detail in GHG measurement and reporting varies, with some countries not addressing the uncertainty in their measurements, impacting the reliability and comparability of the data.

While all protocols cover key ecosystems like mangroves and seagrasses, the inclusion of other ecosystems varies. For example, Japan includes seaweed ecosystems and aquaculture, which are not universally covered in other protocols. This variation limits the scope of blue carbon accounting. Furthermore, some protocols do not address all relevant ecosystem types, which could lead to incomplete carbon accounting.

The range of carbon pools measured also varies across protocols. VERRA and China have the broadest coverage, while some protocols do not include detailed measurements of all relevant carbon pools, such as dead wood and litter. Differences in the depth and detail of carbon pool measurements affect the comparability of data, posing a challenge for standardization.

The reliance on different data sources, including field data collection, literature values, and models, varies across protocols. This variation impacts the consistency and reliability of data. Moreover, not all protocols include guidelines for integrating remote sensing and GIS data, which are crucial for accurate ecosystem mapping and monitoring.

The methods used for calculating carbon stocks differ significantly across protocols. Various methods, such as allometric equations, biomass expansion factors, geometric methods, the total stock approach, stock loss approach, and gain-loss method, lead to inconsistencies in data calculation and accuracy. Some protocols lack specific guidelines for using advanced computational methods, affecting the precision of carbon stock estimates. Additionally, not all countries include detailed methodologies for each carbon pool, affecting the consistency of carbon stock assessments.

Field data collection techniques vary widely among protocols. Some employ advanced technologies like acoustic surveys and underwater drones, while others rely on traditional methods. The level of detail in field data collection guidelines also differs, affecting the consistency and reliability of collected data.

Sampling specifications, such as plot sizes and core depths, differ across protocols, impacting the comparability of data. Some protocols lack detailed specifications for sampling, affecting the accuracy and precision of carbon stock measurements.

There are also discrepancies in the monitoring periods and frequency of measurements across different protocols, impacting the comparability of long-term carbon data. VERRA has a comprehensive approach to establishing baseline scenarios, including historical data and projections. However, this aspect is less detailed in some country-specific guidelines, which may focus more on immediate data collection and monitoring. Additionally, some protocols lack detailed guidelines for the periodic reassessment of baselines, which is crucial for maintaining the accuracy and relevance of carbon sequestration data over time.

The rigor and frequency of verification processes also vary, with some countries having less stringent requirements than others. Some protocols do not clearly define the roles and responsibilities of third-party verifiers, impacting the reliability of verification. Additionally, certification frameworks differ, with VERRA and Japan having more comprehensive systems compared to other countries. The absence of robust certification processes in some protocols affects the credibility of reported carbon credits.

By identifying these gaps, it becomes evident that there is a need for harmonization in blue carbon accounting protocols. Standardizing methodologies, measurements, and data collection practices will enhance the reliability and comparability of carbon sequestration data globally, facilitating more effective climate change mitigation strategies.

Considerations for Harmonization

To develop a standardized blue carbon accounting protocol that accommodates both carbon crediting and national inventory objectives, it is essential to integrate blue carbon projects into national climate strategies across Southeast and East Asia. This integration will promote uniformity in project implementation and reporting, enabling a broader application of blue carbon initiatives tailored to regional contexts. Harmonizing these objectives can facilitate a comprehensive approach that supports both international carbon markets and national environmental goals. Key steps could include identifying stakeholders such as experts, data collectors, storage managers, and external verifiers, and clearly defining their roles. Integration into national policies is also crucial to secure funding and create regulatory frameworks that mandate blue carbon accounting as part of national climate commitments. Additionally, criteria for project size and types could also be established to ensure the applicability of projects, ranging from small community-based initiatives to large-scale restoration efforts. This cohesive approach will enhance the reliability, accuracy, and comparability of carbon sequestration data, supporting effective climate change mitigation strategies and facilitating the integration of blue carbon projects into both national and international frameworks.

Standardizing the measurement of all major greenhouse gases (GHGs), including CH_4, N_2O, and CO_2, across all protocols is crucial for ensuring comprehensive and comparable data. Implementing uniform guidelines for addressing uncertainty in GHG measurements will enhance the reliability of reported data.

Expanding the coverage of target ecosystems to include a comprehensive range of coastal and marine habitats, such as tidal flats, seaweed ecosystems, and aquaculture, will ensure a holistic approach to blue carbon accounting. Standardizing the definitions and classifications of ecosystem types will facilitate consistent data collection and reporting.

Standardizing the measurement of all major carbon pools, including aboveground and belowground biomass, soil carbon, dead wood, and litter, is essential for ensuring comprehensive carbon accounting. Ensuring uniform depth and detail in carbon pool measurements will enhance data comparability.

Adopting a combination of standardized computation methods, such as the total stock and stock loss approaches, and common computational methods like allometric equations and biomass expansion factors will ensure comprehensive and consistent carbon stock assessments. Providing detailed methodologies for all carbon pools will improve the accuracy and consistency of carbon stock calculations. Simplifying and adapting these methodologies for regional contexts will facilitate the comparison of carbon sequestration data across different projects and regions, making them more applicable to smaller-scale projects.

Standardizing the use of data sources by ensuring a balanced combination of field data, literature values, and models will enhance the reliability and consistency of data. Including guidelines for integrating remote sensing and GIS data will improve the accuracy of ecosystem mapping and monitoring. Providing detailed guidelines for all aspects of field data collection, including specific sampling specifications such as plot sizes and core depths, will further enhance the accuracy and reliability of the data.

Standardizing monitoring periods and the frequency of measurements is essential for facilitating consistent long-term data collection. Including guidelines for the periodic reassessment of baselines will ensure the ongoing accuracy and relevance of carbon sequestration data. Adopting comprehensive baseline scenario development, similar to VERRA's approach but simplified for regional application, will enhance the credibility and comparability of blue carbon projects.

Harmonizing verification and certification processes across different protocols is essential for ensuring the credibility and acceptance of blue carbon projects. Implementing robust verification processes, tailored to regional contexts, similar to those outlined by VERRA and Japan, will enhance the reliability of reported carbon credits.

While the reviewed documents do not explicitly mention methods for assigning monetary value to ecosystem services or carbon credits, it is essential to consider this point for harmonization. Developing standardized valuation methods will ensure that the economic benefits of blue carbon projects are consistently and accurately recognized. Establishing uniform guidelines for valuing ecosystem services and carbon sequestration in Southeast and East Asia will create a cohesive framework that supports the integration of blue carbon projects into national and international carbon markets. This harmonization will ensure consistency, allowing all credits to be measured and verified against the same criteria. It will enhance transparency, enabling buyers to easily compare credits and understand the environmental impact they are supporting. Additionally, clearer valuation will attract more investors to the region's carbon market, bolstering economic viability and supporting broader climate change mitigation efforts.

By addressing these considerations for harmonization, a standardized blue carbon accounting protocol can be developed for Southeast and East Asia. This will enhance the reliability, accuracy, and comparability of carbon sequestration data, supporting more effective climate change mitigation strategies and facilitating the integration of blue carbon projects into national and international frameworks.

Takeaways and Best Practices

To harmonize blue carbon accounting protocols across Southeast and East Asia, it is essential to learn from the experiences and best practices of established systems. VERRA and various countries in the region can offer valuable insights that can guide the development of standardized and effective blue carbon methodologies. Here are some of the key contributions and lessons that can be drawn from VERRA and the participating countries.

VERRA

VERRA can significantly contribute to the harmonization of blue carbon accounting in Southeast and East Asia by sharing its comprehensive methodologies for establishing baselines, monitoring, and verification. VERRA's experience with stringent verification and certification processes can provide valuable insights into ensuring the credibility of carbon credits. Additionally, VERRA's advanced computational methods and multi-GHG measurement approaches can guide the development of robust and standardized protocols that are applicable across diverse regional contexts.

Japan

Japan's experience with incorporating advanced technologies such as acoustic surveys and underwater drones in blue carbon data collection can greatly benefit the harmonization efforts. Japan's methodologies for including diverse ecosystems like seaweed and aquaculture in blue carbon accounting provide a broader perspective that can enhance the scope of regional protocols. Sharing Japan's approach to measuring CO_2 absorption and atmospheric CO_2 will also help in developing comprehensive GHG measurement standards.

Korea

Korea's detailed protocols for national GHG reporting and inventory can serve as a model for integrating blue carbon projects into national climate strategies. Korea's sophisticated data collection techniques, including core sediment sampling and advanced analytical methods, can be instrumental in improving the precision and accuracy of regional data collection practices. Korea's comprehensive GHG measurement, including CH_4, N_2O, and CO_2, can also help establish uniform standards for GHG accounting.

China

China's advanced use of remote sensing and GIS data in blue carbon accounting positions it as a leader in accurate and efficient ecosystem mapping. China's methodologies for comprehensive carbon pool measurements, including biomass, soil carbon, and dead organic matter, can guide the development of detailed and consistent measurement protocols. Sharing China's approach to monitoring and managing blue carbon sinks can also help in establishing robust long-term monitoring frameworks in the region.

Indonesia

Indonesia's focus on aligning blue carbon projects with national climate objectives and its rigorous QA/QC procedures can contribute to developing standardized and reliable data collection practices. Indonesia's comprehensive sampling methods, including detailed guidelines for plot sizes and core depths, can enhance the consistency of regional data collection. Sharing Indonesia's strategies for integrating blue carbon data into national inventories will also support the harmonization of protocols across the region.

Philippines

The Philippines' emphasis on community-based monitoring and conservation-focused blue carbon accounting practices can provide valuable insights into involving local stakeholders in data collection and monitoring. Sharing the Philippines' detailed field data collection guidelines, including soil core sampling and water quality measurements, can help improve the accuracy and reliability of regional data. The Philippines' conservation strategies can also inform the development of protocols that balance carbon accounting with ecosystem preservation.

By leveraging the strengths and experiences of VERRA and the participating countries, PEMSEA can develop harmonized blue carbon accounting protocols that are robust, comprehensive, and applicable across Southeast and East Asia, supporting effective climate change mitigation strategies in the region.

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