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Incorporating Blue Carbon as a Mitigation Action under the United Nations Framework Convention on Climate Change

Technical Issues to Address

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Photo: Katie Fuller 2009/Marine Photobank

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Summary

Coastal and marine ecosystems (CMEs) store large amounts of carbon in soil sediments and vegetation. When these systems are disturbed through conversion or degradation this emits carbon dioxide (CO_2), a greenhouse gas (GHG) whose growing atmospheric concentration is altering the climate system. Attention to this source of "blue carbon" emissions has been fairly recent, motivated by new scientific studies quantifying its magnitude. The United Nations Framework Convention on Climate Change (UNFCCC), as part of its mission to reduce threats to our global climate system, promotes the sustainable management, conservation, and enhancement of sinks and reservoirs of all GHGs, including those in CMEs. Yet there are no specific mechanisms within the UNFCCC that focus on blue carbon. This paper reviews where CMEs and blue carbon may be addressed within existing UNFCCC mechanisms, such as those dealing with land use, land-use change, and forestry (LULUCF) and reduced emissions from deforestation and degradation (REDD+), at the project and national levels. For blue carbon reservoirs to be included in policy mechanisms, they must be measured, reported, and verified (MRV'd). This paper examines a number of technical factors associated with MRV and other related issues, such as establishing baseline carbon stocks (or reference emissions levels), assessing risks of nonpermanence of carbon storage in CMEs, and the possibility of leakage from activity targeted to reduce blue carbon emissions or enhance blue carbon storage in one place, but which shifts emissions to another. These issues for blue carbon have many parallels with the terrestrial activities covered under LULUCF and REDD+, but approaches to these issues must be customized to address the uniqueness of CME systems.

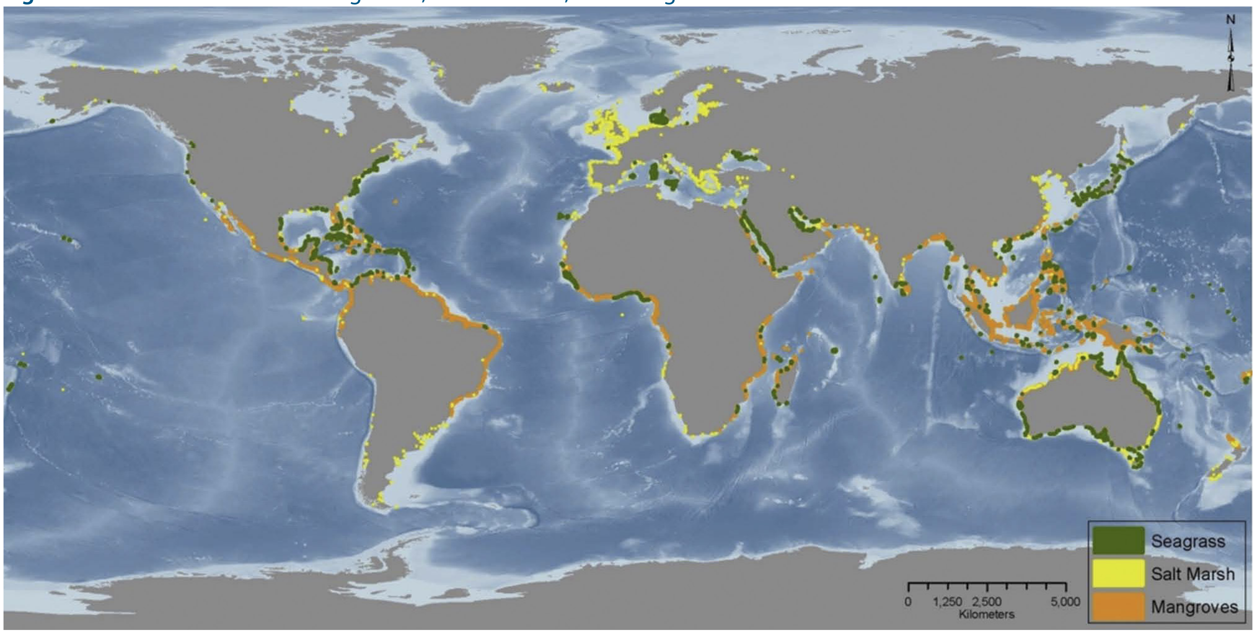
1. Introduction

Emerging scientific evidence indicates that the conversion of coastal and marine ecosystems (CMEs) such as mangroves, tidal salt marshes, and seagrass meadows, is becoming a significant source of greenhouse gas (GHG) emissions throughout the world (Pendleton, Donato, et al. 2012). These systems in their natural state provide a tremendous reservoir of "blue carbon" in their vegetation and soil sediments. When disturbed via conversion or degradation, the carbon pools may be burned or oxidized via aerobic exposure and release relatively large amounts of CO_2 to the atmosphere, where it accumulates with other GHGs and raises climate change risk. These CMEs often release more CO_2 than an equivalent area of tropical forest (Donato et al. 2011). Tropical forest area loss, which occurs over a much wider area and is larger in absolute terms than blue carbon emissions, has appropriately drawn policy attention under the UNFCCC, through its REDD+ (reducing emissions from deforestation and degradation) mechanism. The recent emergence of data on blue carbon emissions, however, raises the question of whether and how best to include efforts to mitigate these emissions in the UNFCCC as well.

This paper begins by recapping where within the UNFCCC efforts to mitigate blue carbon emissions might reside, and what types of incentive mechanisms may be available to pay for emission reductions. Section 2 synthesizes the recent literature that has examined policy options for blue carbon and looks at how these might fit into the UNFCCC framework. This section outlines a set of options, including those that operate at project scales (CDM) and national scales (Kyoto Protocol LULUCF, REDD+ and NAMAs).

If these blue carbon mitigation opportunities exist within the UNFCCC, there are a number of technical issues that must be resolved to quantify emission reduction efforts at the appropriate scale. These issues are the primary focus of this paper. They include (1) measurement, reporting, and verification (MRV); (2) baselines, reference levels, and additionality; (3) permanence of emission reductions; and (4) leakage. The main body of the paper addresses how these technical issues apply specifically to CMEs and blue carbon, drawing contrasts where appropriate to how other activities in land use, land use, change and forestry (LULUCF) address these issues at different scales. The paper ends with a brief recap of the technical challenges and proposed solutions for some key problems raised.

Figure 1. Global distribution of seagrasses, tidal marshes, and mangroves



Data sources: Seagrass and salt marsh coverage data are from the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC); mangrove coverage data are from UNEP-WCMC in collaboration with the International Society for Mangrove Ecosystems (ISME) (from Pendleton, Donato, et al. 2012).

2. Blue Carbon under the UNFCCC

Because of the apparent GHG mitigation potential of CMEs there has been active conversation concerning the role blue carbon can have under the UNFCCC (Murray, Watt, et al. 2012; Herr and Pidgeon 2012). Herr et al. (2012) provide an overview of a possible integration of blue carbon into existing UNFCCC policy. These approaches are summarized below.

To begin, the importance of CMEs as reservoirs of carbon are specifically established within the Convention. Article 4.1(d) of the UNFCCC states[1] that all parties shall

> [p]romote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and *oceans as well as other terrestrial, coastal and marine ecosystems.* (italics added)

This passage provides a clear and specific foundation for the inclusion of CMEs and blue carbon in the convention; however, blue carbon—whether through avoided emissions from habitat loss or carbon stock enhancement—has not been recognized as a distinct mitigation activity to date. This may be more a matter of classification and terminology rather than overt omission. Blue carbon is a descriptive term that captures carbon stored and potentially lost from CMEs, and not an officially recognized category under the UNFCCC. Toward that end, attention to this carbon reservoir and emissions therefrom at the UNFCCC level need not require the establishment of an entire new category of activity. As discussed below, blue carbon mitigation activity may fall into other established categories under the UNFCCC. The associated UNFCCC mechanisms and incentives, outlined below, may operate at the project scale, the national scale, or both. While UNFCCC mechanisms and incentives address both mitigation of and adaptation to climate change, the focus of this paper is on the former.

At this point in time, the UNFCCC process has two parallel paths for mitigation: (1) The Kyoto Protocol, which includes a series of binding commitments from countries to reduce GHG emissions, and (2) The Durban Platform, a process

1. United Nations Framework Convention on Climate Change, accessed November 28, 2012, http://unfccc.int/essential_background/convention/background/items/1362.php.

agreed to at the 17th Conference of Parties (COP 17) to the UNFCCC[2] in Durban, South Africa, to replace the Kyoto Protocol with a new agreement by 2015. Each of these paths has relevant "plug-in" points for blue carbon as described below.

Kyoto Protocol

Blue carbon may have bearing on two provisions of the Kyoto Protocol: (1) national accounting of sources and removals by sinks from land use, land use change, and forestry (LULUCF), and (2) the Clean Development Mechanism. We briefly discuss how blue carbon can be addressed under each.

National LULUCF accounting

All countries—both Annex I countries that hold emission reduction obligations and non-Annex I countries that do not—are required to report sources and sinks from LULUCF activity. Articles 3.3 and 3.4 of the Kyoto Protocol require countries to report on the changes in carbon stock and GHG emissions relating to LULUCF activities for each year of the commitment period. Moreover, when these reported LULUCF activities result in a net removal of GHGs, an Annex I Party can issue removal units (RMUs) on the basis of these activities as part of meeting its commitment under the Protocol.

It is important to note, however, that countries have leeway on what to include under LULUCF, and thereby could, in principle, include a more comprehensive accounting that includes blue carbon categories. If these categories are included, there is some incentive to protect these carbon sources, especially in Annex I countries with commitments. In that regard, the focus may be on inclusion of tidal salt marshes, which are more abundant in the temperate zone where many Annex I countries exist. Mangroves are tidal forests and thus readily includable under the category of forest. Most mangrove area is located in non-Annex I countries. It is not clear whether seagrass meadows are readily includable under LULUCF, as they are submerged in coastal waters.

Clean Development Mechanism

The Clean Development Mechanism (CDM) is a mechanism by which non-Annex I countries can host emission reduction (or carbon removal/sequestration) projects, which generate certified emission reduction (CER) credits that Annex I countries can purchase and use to meet national obligations under the Kyoto Protocol. Since its inception, the only LULUCF type of activity that has been approved under the CDM is afforestation and reforestation (A/R), which until recently had been focused primarily on the establishment of traditional forest systems. However in 2011, the CDM Executive Board approved a methodology for afforestation and deforestation of degraded mangrove habitats.[3]

An earlier CDM-approved methodology[4] establishes a precedent for direct inclusion of blue carbon in the CDM, though it is in the category of restoring systems, which take many years to accumulate carbon. This is a somewhat less impactful activity than one involving avoided loss of systems and the resulting emissions therefrom. In that regard, the UNFCCC is currently considering possible expansion of LULUCF activities within CDM,[5] which could consider avoided conversion of mangroves, as well as the inclusion of other blue carbon categories.

Durban Platform

COP 17, held in December 2011 in Durban, South Africa, temporarily extended the Kyoto Protocol beyond 2013, while forging an agreement to develop a successor plan to Kyoto by 2015 involving legally binding obligations by all countries. Such a plan likely would not be fully enacted earlier than 2020.

The so-called Durban Platform may draw from mechanisms currently existent under the Kyoto Protocol, as well as mechanisms developed since the Bali Action Plan in 2007 established the Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA). Two mechanisms of relevance for blue carbon are reducing emissions from deforestation and degradation (REDD+) and nationally appropriate mitigation actions (NAMAs), discussed in turn here.

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2. Also known as CMP 7, for the 7th Conference of Parties serving as the Meeting of Parties to the Kyoto Protocol.
3. CDM Executive Board, "AR-AM0014: Afforestation and Deforestation of Degraded Mangrove Habitats," accessed November 28, 2012, http://cdm.unfccc.int/methodologies/DB/CKSXP498IACIQHXZPEVRJXQKZ3G5WQ.
4. CDM Executive Board, "AR-AMS0003: Simplified Baseline and Monitoring Methodology for Small Scale CDM Afforestation And Reforestation Project Activities Implemented on Wetlands," accessed November 28, 2012, https://cdm.unfccc.int/methodologies/DB/8LLTGVPG1SMMB1AMGSU0ZEYVO9P45P/view.html.
5. To this end a work program was set up to consider, develop, and recommend modalities and procedures for possible additional LULUCF activities under the Clean Development Mechanism.

Reduced emissions from deforestation and degradation (REDD+)

REDD+ is a financial mechanism designed to contain emissions from deforestation and degradation, as well as induce carbon stock enhancement from forests, targeted at developing countries. The specific sources of funding are still under negotiation, specifically the role of carbon markets as a demand-side source of payments for emission reductions.

As for blue carbon, there is a general recognition that mangroves are likely covered under REDD+, provided that countries choose to define mangroves as part of their forests, develop MRV systems and reference emissions levels, and enact environmental, social, and governance safeguards that apply to them (Murray, Watt, et al. 2012). Inclusion of tidal salt marshes and seagrasses would require an expanded definition of activity covered under REDD+ or a new mechanism that comprehensively covered forests, agriculture, wetlands, and other land uses.

Nationally appropriate mitigation actions (NAMAs)

The Bali Action Plan (BAP) established at COP 13 in Bali Indonesia proposed NAMAs by developing countries to mitigate emissions as part of future agreements under the Convention. These actions would be in recognition of the common but differentiated responsibilities of all countries to the convention and, as their name suggests, attuned to the conditions of each country. Although there is no formal definition of NAMAs, the general expectation is that they are initiated by developing countries, but would be supported by finance and technology transfer from developing countries. Methods of finance (carbon market of global fund payments) have not been determined. NAMAs may be an appropriate venue for blue carbon activity in several key countries (Climate Focus 2011). To date, out of close to 50 submissions only 4 countries (Congo,[6] Eritrea,[7] Ghana,[8] and Sierra Leone[9]) mention CMEs explicitly in their NAMA documentation.

Countries could be free to choose whether blue carbon qualifies as a NAMA, but should they choose to include them, they would need to be measured, reported, and verified (MRV'd) subject to standards not yet fully developed. In the context of blue carbon, priority components of NAMAs could include the following (Herr et al. 2012):

- capacity building
- national data collection
- reference emissions levels
- assessing drivers of loss and degradation
- MRV methodologies
- demonstration projects

The following section addresses MRV issues that arise should blue carbon be included in UNFCCC-sanctioned activity.

3. Measurement, Reporting, and Verification of Carbon in Blue Carbon Systems

Measurable, reportable, and verifiable (MRV) is a concept identified by the 2007 BAP as integral to all climate mitigation efforts.[10] MRV comprises a series of steps leading to greater transparency and comparability in national GHG reporting and mitigation actions (NAMAs) as well as in individual, project-level (subnational) GHG mitigation efforts. MRV is necessary for accurate tracking of GHG emission reductions and the issuing of accurate amounts of carbon credits on the project level, and especially for improving credibility regarding climate mitigation actions during the negotiations of a successor climate agreement via the Durban Platform.

The BAP left open the question of *how* to measure, report, and verify GHG reduction from mitigation actions. Thus, there has been ongoing discussion under the UNFCCC about the specifics of MRV since 2007. Specifically, at COP 15

6. Henri Djombo, letter to the UNFCCC Climate Change Secretariat, February 3, 2010, accessed November 27, 2012, http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/congocphaccord.pdf.
7. Tesfai Ghebreselassie, e-mail communication to the UNFCCC Climate Change Secretariat, March 16, 2010, accessed November 27, 2012, http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/eritreacphaccord_app2.pdf.
8. Sherry Ayittey, letter to the UNFCCC Climate Change Secretariat, February 15, 2010, accessed November 27, 2012, http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/ghanacphaccord_app2.pdf.
9. Statement of Sierra Leone, accessed November 27, 2012, http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/sierraleonecphaccord_app2.pdf.
10. UNFCCC, Decision 1/CP.13 in FCCC/CP/2007/6/Add.1*, accessed November 27, 2012, http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf.

the Copenhagen Accord began to elaborate, among other items, that in MRV (1) the most recent Intergovernmental Panel on Climate Change (IPCC) Guidelines are to be used, (2) remote sensing and ground data are to be used in combination, and (3) transparency, consistency, accuracy, and certainty are to be advanced as far as practicable. Currently, negotiations are attempting to develop clearer definitions and frameworks for the concept. Reporting in general under the UNFCCC has been following approved guidelines and guidance since 1996. These guidelines, together with a well-defined MRV methodology, can inform MRV in CMEs.

IPCC guidance

National GHG inventory and emission-level reporting both in Annex I and non-Annex I countries follows guidelines developed by the IPCC, generally referred to as Good Practice Guidelines (GPG). The IPCC documents relevant to terrestrial ecosystems are *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006), *Good Practice Guidance for Land Use, Land-Use Change, and Forestry (GPG-LULUCF)* (IPCC 2003a), *Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types* (IPCC 2003b), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000a), and *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997). The 2006 IPCC Guidelines have not been accepted for use by the UNFCCC but are more complete and up-to-date than the 1996 IPCC Guidelines and may provide the key guiding principles for national reporting in Annex I countries starting in 2015. As a supplement to the 2006 Guidelines, the IPCC has recently started developing a methodology for carbon in wetlands[11] which could also cover CMEs.

The IPCC Guidelines that provide the methodology for national reporting—including the latest 2006 Guidelines—do not explicitly mention CMEs or blue carbon. However, the methodology described for measurement of carbon in terrestrial ecosystems under LULUCF (more recently, agriculture, forestry, and other land use [AFOLU]) could be used in CMEs, especially mangrove forests, in a straightforward manner. Seagrass meadows and salt marshes, where most of the carbon is stored in the soil, could follow IPCC Guidelines on soil carbon measurement (Pendleton, Donato, et al. 2012). This report attempts to identify what technical issues might arise when IPCC guidelines and guidance are used for CMEs, as well as possible ways to overcome these issues at the national scale.

On the **project scale**, such as an expanded CDM, GHG mitigation projects must follow IPCC reporting guidelines, in addition to which, these projects also need to explicitly account for additionality, permanence, and leakage. In this report our aim is to address each of these issues separately from the perspective of blue carbon. Discussions of these three separate phenomena are included below.

Measurement of carbon stock and emissions

Measurement is the first necessary component of MRV and refers to determining the amount of carbon emissions resulting from the disturbance of CMEs, emissions avoided due to protecting them, or carbon sequestered by establishing or enhancing them. Reliable carbon measurement acts result in consistent, transparent, comparable, and accurate data for reporting purposes. As mentioned earlier, measurement and thus reporting may be on national or project scales, with each posing a slightly different set of issues regarding difficulty of implementation, cost, available technology, and data reliability.

National-scale measurement

From the perspective of national measurement of blue carbon, we need to consider the national communications (NC) as well as NAMAs. Specifically, under the Revised 1996 IPCC Guidelines, blue carbon could be considered under the LULUCF (LUCF in the 1996 Guidelines) sector. We note that only mangrove forests seem to qualify under this category. The 1996 Guidelines do not classify salt marshes and seagrasses as either "grassland" (underwater), or "wetlands" (coastal). Also, for the purposes of national reporting, only those ecosystems affected by humans and thus causing anthropogenic GHG emissions are considered. The detailed methodology is well described in the 1996 Guidelines, but we outline here the main components that need to be measured.

For CMEs emissions and removals from soils should be measured and included under the land-use change category, due to the prominent role that pools play in storage. For mangrove forests, annual growth increment and annual harvest would be measured to calculate net CO_2 emissions and removals. The 1996 Guidelines note that if national-level

11. *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. Accessed November 28, 2012, http://www.ipcc-nggip.iges.or.jp/home/wetlands.html.

harvesting cannot be measured or measurements are not complete, statistics of fuelwood consumption published by the United Nations Food and Agriculture Organization (FAO) can be used instead of or in combination with missing measurements. Additional published data sources are found in the Reference Manual (Vol. 3) of the Revised 1996 IPCC Guidelines.[12]

The GPG-LULUCF (IPCC 2003a) supplements the Revised 1996 IPCC Guidelines (IPCC 1997) and provides additional information specifically about measurements needed at the national level for belowground biomass, deadwood, and litter in forests.[13] This information is found in the section titled "Forests," and should be applicable to mangroves without any changes. The GPG-LULUCF provides three tiers for estimating emissions, with increasing levels of data requirement and thus accuracy. Tier 1 uses default emission factors that are estimated indirectly and collected nationally, Tier 2 uses country-specific data, and Tier 3 uses high-resolution measurements repeated over time at subnational levels. The guidelines also state that belowground biomass can be estimated using root-to-shoot ratios, and that litter and deadwood can be assumed constant in Tier 1. In Tier 3, litter and deadwood can be measured as the product of the change in their amount and a carbon content fraction. The "Grasslands" section, which could be used as guidance for seagrasses and salt marshes, states that carbon in soils could be measured by sampling the top 30 cm of soil. Also, it suggests that aboveground biomass for grasses not be measured, and that belowground biomass be estimated from the known fraction of belowground to aboveground plant biomass.

The complexity of incorporating wetlands management practices in national GHG inventories is recognized in chapter 7 of the 2006 IPCC Guidelines. Due to the limited number of published studies, the guidance on estimating and reporting emissions from managed wetlands is focused on a restricted set of terrestrial wetlands, specifically peatlands and flooded lands.[14] Further work may be necessary for application to blue carbon in CMEs.

In summary, on the national level, if using Revised 1996 Guidelines and guidance for CMEs, the following needs to be measured and accounted for the year used as a baseline, and each subsequent reporting year:

- carbon stored in live and dead biomass above- and belowground,
- carbon stored in soil,
- carbon sequestration and emission rates (flux),
- annual growth rate,
- area coverage,
- change in area coverage, and
- removed biomass (mangroves).[15]

Project-scale measurement

For project-level reports under the CDM-LULUCF (AFOLU), and possibly under REDD+, the same data are needed as in national-scale measurements but only for the project area. In addition to this, projects need to account for additionality, permanence, and leakage. To determine additionality—whether carbon emissions are reduced compared to business-as-usual—two types of data are needed: (1) current loss rates and (2) carbon emission factors due to loss of coastal vegetation. Loss rates and emission factors combined, under the assumption of future market, technology, and policy conditions, can be used to project the business-as-usual scenario tied to the project baseline. Issues with additionality specific to blue carbon are discussed in section 4. Permanence, the issue with carbon sequestration in the AFOLU sector being partially or completely reversible through subsequent disturbances (natural or anthropogenic), is a topic widely discussed in the literature (Murray, Galik, et al. 2012). Permanence in blue carbon ecosystems is discussed in section 5. Leakage, which arises when carbon emissions *outside* of the project area increase due to the mitigation activity *on* the project area, is a critical issue on the project level. Blue carbon ecosystems have leakage issues specific to them; these are discussed in section 6. The next section discusses the data requirements and our ability to measure these data in CMEs.

12. Volume 3 of IPCC (1997).
13. See also chapters 5.2–5.4 in Crooks et al. (2011).
14. Crooks et al. 2011.
15. Data needed when following the UNFCCC Common Reporting format for Annual Inventories (Annex I), based on FCCC/CP/1999/7, http://unfccc.int/resource/docs/cop5/07.pdf.

Currently available technology to measure blue carbon

In a UNFCCC-like setting, above- and belowground live and dead biomass, soil carbon, carbon flux, annual growth rate, areal extent, and change in area must be measured for complete accounting of blue carbon ecosystems. There are several published research papers[16] about data available specifically from mangrove systems. These data include carbon stored in biomass and soil, areal extent, and loss rates, but not carbon flux.[17] While some data are already available, in this report we focus on the issues regarding *obtaining* these data on the national and project levels for a given area. Guidance specific to CMEs are currently being developed by the Blue Carbon Scientific Working Group and include the development of a quantification methodology as well as planning and management guidelines for coastal carbon.[18]

Mangroves

Measuring **biomass, area, and change in area** on the national level may be accomplished using a combination of remote sensing and ground data collection and verification. A relevant summary of available remote sensing technology, as well as costs associated with data retrieval, is found in Wertz-Kanounnikoff et al. (2008) or in Wang et al. (2010). Without going into much detail about available remote sensing technology, we briefly discuss two technologies that could be used both on the national and project levels to measure areal extent, change in areal extent, and aboveground carbon, excluding soil carbon as well as carbon flux.

A recent paper by Lu et al. (2012) compares and contrasts Landsat satellite and LiDAR (Light Detection and Ranging) technologies for the estimation of aboveground biomass in forests. Medium-resolution (15–60 m) remote sensing imagery from Landsat 7 ETM+ is available free of charge from the U.S. Geological Survey (USGS),[19] covers the entire globe, and could be used to derive mangrove forest data for national inventories. For a given area, these data are available every 16 days, at a temporal resolution fine enough to detect change of areal cover over time. However, large uncertainties surround this data for sites with high biomass density or those having complex forest structure such as a mature forest in a moist tropical region. Furthermore, the inability of remote sensing technology to accurately capture the biomass reduction consequences of forest degradation is an issue with Landsat (DeFries et al. 2007). Also, Landsat is site dependent, in that biomass estimator algorithms developed for one region cannot be used in other regions without modification.

According to Lu et al. (2012) LiDAR technology offers more accuracy than Landsat, especially in terms of canopy height measurements, but alone cannot provide sufficiently accurate biomass estimates. Therefore, the researchers suggested that LiDAR and Landsat imagery be used together, to ensure more accurate biomass (and carbon) estimates. LiDAR imagery is more costly, generally on the order of $7–$10 per hectare for acquisition and processing (Hummel et al. 2011). It has been shown to produce results comparable to those based on field data collection but at a fraction of the cost. In conclusion, Landsat and LiDAR together could be used for the measurement of blue carbon in aboveground biomass, areal extent, and change in area in mangroves, similarly to terrestrial forest ecosystems.

Soil carbon is by far the largest carbon pool in mangrove forests, storing up to 99% of total carbon in CMEs (fig. 2) (Pendleton, Murray, et al. 2012). Carbon storage in soils under mangroves is difficult to quantify because the depth of the carbon-rich soil varies, no global soil carbon dataset exists, and remote sensing cannot be used for this purpose. However, sampling designs similar to those used in terrestrial ecosystems can be used in mangroves as well (Donato et al. 2011). Also, there are published soil carbon values for mangroves in the literature to which observed values could be compared (Chmura et al. 2003).

In summary, collecting ground data for mangroves is fundamentally the same as for terrestrial forests, and some of the same methods[20] can be used to estimate biomass, including allometric equations (Komiyama, Ong, and Poungparn 2008). Also, because the same methods are used, the accuracy of measurements in mangroves is comparable to that in terrestrial forests. For example, measuring **dead biomass** requires the use of sampling and transects, which poses the same issues as measuring soil carbon in other forest ecosystems (Harmon and Sexton 1996). Also, methods for measuring **growth rate** in terms of height or diameter at breast height (dbh) are the same as for other forests and involve some of the same tools and techniques. Similarly, the latest **carbon flux** measurement techniques have been able to produce

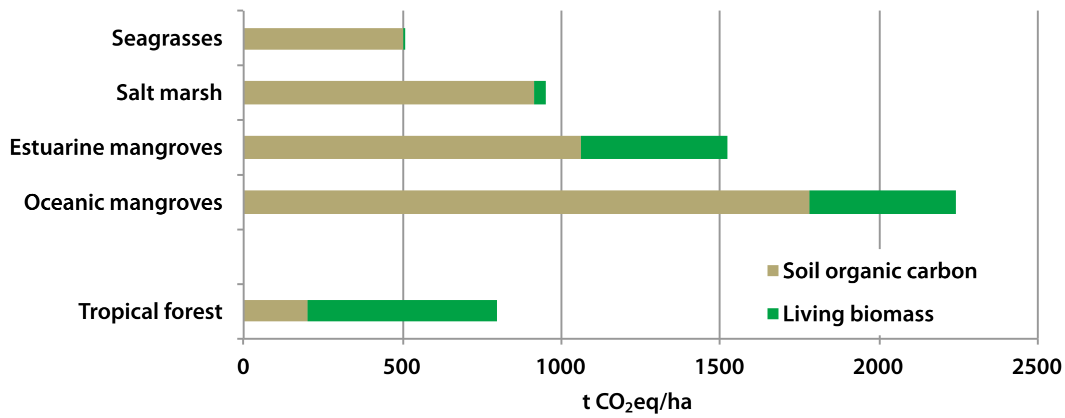
16. See Cebrian (2002) and Chmura et al. (2003).
17. For a more detailed description of available data see Sifleet, Pendleton, and Murray (2011).
18. More details on the Working Group can be found at http://www.marineclimatechange.com/marineclimatechange/bluecarbon_2_files/Blue_Carbon_Working_background.pdf.
19. National Aeronautics and Space Administration, "The Numbers Behind Landsat," http://landsat.gsfc.nasa.gov/data/.
20. For a detailed overview of these methods, see Donato et al. (2011).

reliable datasets to evaluate fluxes over time between terrestrial ecosystems and the atmosphere (Baldocchi 2003). These techniques can also be used in the establishment of current carbon emission rates as well as in the long-term monitoring of carbon fluxes in mangroves.

Seagrasses and salt marshes

These ecosystems are different from terrestrial ecosystems in two ways: they are generally underwater, and they store a higher percentage of total carbon in the soil than mangroves (fig. 2). Nevertheless, principles similar to those applied in other AFOLU sectors apply to the measurement of areal extent and biomass of seagrasses and salt marshes. Areal extent may be measured using boat-based videographic imaging techniques (Haag, Kennish, and Sakowicz 2008) or underwater LiDAR. Ground sampling can also be performed using underwater transects, while biomass and soil carbon can also be measured this way, as in mangrove or terrestrial ecosystems. Current technology is also capable of measuring fluxes of carbon and methane in these ecosystems (Magenheimer et al. 1996; Mateo et al. 2006).

Figure 2. Global averages for carbon pools (soil organic carbon and living biomass) of focal coastal habitats based on literature review



Tropical forests are included for comparison. *Note:* Only the top meter of soil is included in the soil carbon estimates. *Source:* Murray et al. (2011).

Difference and challenges in project-scale and national-scale measurements

Because the same technology and methodology can be used, national measurements of carbon, carbon flux, areal extent, and soil carbon in mangroves can be comparable in accuracy to measurements in terrestrial ecosystems such as forests. However, national-scale measurements in seagrasses and salt marshes are more challenging to perform accurately, because only sampling seems to be a reasonable approach to determine carbon storage and emissions or areal extent. For all three CMEs, when using remote sensing technologies along with ground data, the feasibility of "wall-to-wall" coverage must be evaluated, and this is clearly dependent on the size of the area under consideration. Thus, from the perspective of accuracy, national and project-level measurements are different, because wall-to-wall coverage tends to be more difficult to obtain on the national level than on the local level.

Another difference between the two scales is that uncertainties in measurement precision, which depend on scale, may be larger on the national scale, since smaller areas can be measured with greater intensity and thus more precision. Imprecision does not itself undermine blue carbon measurement on the national scale, but determining the magnitude of imprecision may be challenging. The issue can be especially of concern when considering seagrasses and salt marshes, which can be easily omitted from calculations on either scale when their location is unknown. Even when location and areal extent of CMEs are known, the carbon-rich soil beneath them can vary greatly in depth and carbon concentration (Fourqurean et al. 2012; Bridgham et al. 2006). Estimating this variation can only be accomplished by increasing sampling intensity, which could be cost prohibitive over large areas.

Reporting and verification

The current UNFCCC framework for national-level reporting could include blue carbon under LULUCF (AFOLU) activities with the aim of producing more accurate national-level accounting of GHGs. The Marrakesh Accords as well as UNFCCC Draft Decision -/CP.17[21] specify that a Party may choose not to account for a given pool in a commitment period if transparent and verifiable information is provided that the pool is not a source of GHG emissions. However, as discussed above, CMEs have been shown to be a large source of carbon emissions globally and thus further consideration may be warranted (Pendleton, Donato, et al. 2012). The situation is the same when considering the CDM, where accounting for soil organic carbon may not be neglected in A/R projects, even though soil carbon becomes an emissions sink rather than source in those types of sequestration activities. By and large, then, if blue carbon is to enter into the emissions inventories or mitigation portfolio in any way, it would appear that soil carbon must be measured and reported.

Regarding the reporting of carbon in mangroves, measurements could be included in national reporting under the following categories: "Changes in forest and other woody biomass stocks," "Forest and grassland conversion," "CO_2 emissions and removals from soil," or "Other forests." Measurements in seagrasses and salt marshes could possibly fit under "Forest and grassland conversion" or "CO_2 emissions and removals from soil." The reporting of soil carbon is addressed in IPCC Guidelines and guidance for LULUCF (AFOLU) activities and could be followed when reporting carbon in the soils of CMEs.

As in terrestrial ecosystems, long-term monitoring and verification of carbon sequestration in CMEs are closely tied to the ability to measure carbon. Thus, monitoring and verification might pose issues in seagrasses and salt marshes while not so much in mangroves, and are harder to implement at the national scale rather than at the project scale. As with measurement, the effectiveness of verification and monitoring activities depends largely on the capacity to implement them in countries' CMEs. Monitoring can be thought of as measurements repeated multiple times in the future, so it must also follow IPCC Guidelines and guidance in a facilitating policy environment. Because seagrasses and salt marshes are harder to measure accurately than mangroves, and because soil carbon may only be imprecisely estimated due to variations in soil depth and carbon content, higher levels of uncertainty will arise in monitoring efforts over time in the former systems.

4. Establishing Baselines in Blue Carbon Systems: The Concept of Additionality

A baseline refers to the emissions or sequestration profile over time against which actual emissions (sequestration) is compared to estimate reductions that may be creditable. The term *baseline* is generally used in the context of CDM projects, while a *reference emissions level* (REL) refers to a similar idea under national accounting approaches, such as those envisioned to generate compensated emission reductions under REDD+. In this report we used the terms baseline and reference (emission) levels interchangeably.

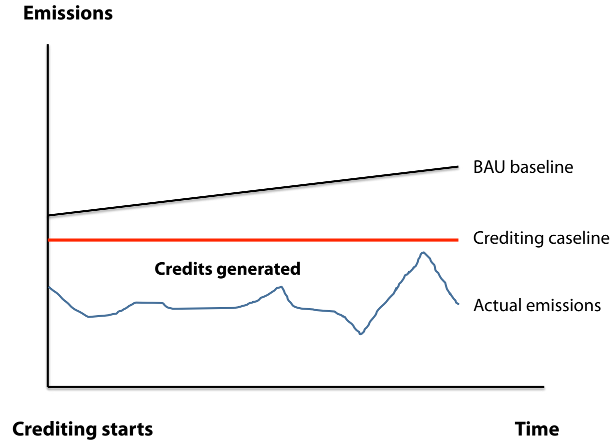
We distinguish between historical, business-as-usual, and crediting baselines. Historical baselines refer to observed emissions (sequestration) from the (usually recent) past. Business as usual (BAU) refers to the profile we would expect to occur under future market and policy conditions without any policies targeted at blue carbon. Often BAU baselines are estimated by taking the historical baseline and simply extrapolating it into the future, suggesting the past is prelude to the future. However, there is no particular reason to expect that to be the case, and others have used land-use projection models to estimate dynamic future-oriented baselines or RELs (Busch et al. 2012).

Closely connected to the concept of a BAU baseline, *additionality* refers to the increase in sequestration or increase in emissions avoided relative to what would have otherwise occurred. Offset programs typically require reductions to be *additional*, so that total emissions do not rise when credits are exchanged. Toward that end, a crediting baseline is the basis on which such credits would be generated. In the case of emission reduction credits, a crediting baseline should be no higher than the BAU baseline. Under some circumstances, the crediting baseline could be lower than BAU, reflecting that the emissions source (e.g., country) undertakes some of the emission reductions relative to BAU without receiving credit, and receives credits for further reductions beyond that. Fig. 3 depicts a forward-looking time profile with a BAU baseline, crediting baseline, and actual emissions. Suppose this situation referred to a country's emissions from

21. "Guidance on Systems for Providing Information on How Safeguards Are Addressed and Respected and Modalities Relating to Forest Reference Emission Levels and Forest Reference Levels as Referred to in Decision 1/CP.16," http://unfccc.int/files/meetings/durban_nov_2011/decisions/application/pdf/cop17_safeguards.pdf.

blue carbon loss. Here BAU emissions are expected to rise over time, but the country takes responsibility for leveling them out without credit (the gap between BAU and crediting baselines). The country, however, does receive credits for bringing emissions below the crediting baseline.

Figure 3. Baselines and crediting for blue carbon emission reductions



While global blue carbon emissions have been estimated based on area, annual area loss, and carbon loss in coastal ecosystems (Pendleton, Donato, et al. 2012), this has not been done on smaller scales. Baselines can be established on the national and project scales. Regarding the national scale, UNFCCC Decision 2/CP.13[22] states that "reductions in emissions or increases resulting from the demonstration activity should be based on historical emissions, taking into account national circumstances." This might be a difficult hurdle to overcome in countries where historical data is not available. Nonetheless, the baseline is such a critical aspect in GHG mitigation efforts that its calculation or estimation must be addressed.

On the national scale, carbon emission factors or carbon stock, combined with area change date, can be used to calculate RELs. An emission factor is defined as the average emission rate of a given GHG for a given source, relative to units of activity.[23] The IPCC has compiled an emission factor database (EFDB)[24] but it currently does not include emission factors for CMEs. When no other data are available, historical emissions, emission factors, or carbon stock from the published literature could be used. Alternatively, carbon flux measurements using technology described earlier could be performed to establish country-specific emission factors for CMEs.

In addition to emission factors or carbon stock, loss rates on the national scale also need to be calculated. This could be an issue in countries where reliable historic data are not available or where the policy environment is not favorable. Also, it appears that historic loss rates for mangroves could be slightly less difficult to obtain than for seagrasses and salt marshes because of existing historical remote sensing imagery, such as Landsat, which does not cover below-water or intertidal ecosystems. As for existing data, the FAO has data on mangrove losses[25] but not on seagrasses or salt marshes. Therefore, current national databases on loss rates in CMEs must be updated before credible baselines can be established.

As indicated above, future BAU baselines (RELs) may be developed using land-use change models calibrated with carbon data rather than by simply extending the historical baseline. Using this approach for blue carbon systems would require data that clearly delineate these systems and model changes in response to market, policy, and other factors. As is typically the case with land-use models, future projection is based on empirical relationships found in historical data. This means not only that data on mangroves, salt marshes, and seagrass must be delineated, but that estimation of the relationships between loss rates and the factors explaining them (e.g., population density, road networks and commodity markets) must be established empirically. To our knowledge, such models do not currently exist and would need to be further developed, as, for instance, they are now being done for REDD+.

22. FCCC/CP/2007/6/Add.1*, accessed November 28, 2012, http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf#page=8.
23. "Frequently Asked Questions," accessed November 28, 2012, http://unfccc.int/ghg_data/online_help/frequently_asked_questions/items/3826.php#9.
24. "EFDB," accessed November 28, 2012, http://www.ipcc-nggip.iges.or.jp/EFDB/main.php.
25. "Global Mangrove Statistics," accessed November 28, 2012, http://www.fao.org/forestry/mangrove/statistics/en/.

Establishing baselines (both historical and BAU) at the project level may or may not be more difficult to accomplish than on the national scale, despite the advantage of being able to obtain wall-to-wall coverage. Generally, whether or not a historic carbon baseline can be established depends on available data of the country hosting the project, since it is unlikely that historic data are available on the project level. Current technology, described under the measurement section earlier, is able to estimate carbon flux, storage, and areal extent at the project level. This data, together with regional, national, or even global estimates of loss rates could be used to set a business-as-usual baseline in principle, but the more aggregate the estimate used for project purposes, the more likely it is to generate inappropriate baselines for the conditions at hand.

5. Permanence in Blue Carbon Systems

Permanence, the propensity of reduced emissions not to re-enter the atmosphere, is a major concern regarding carbon sequestration in terrestrial ecosystems, especially when credits generated are used to offset emissions elsewhere (Dutschke and Angelsen 2008). Specifically, in CMEs the possibility of nonpermanence (or reversal) means that stored carbon is subsequently disturbed either though natural or anthropogenic means. These natural and anthropogenic disturbances have been described in mangroves (Alongi 2008), seagrasses (Short and Wyllie-Echeverria 1996), and salt marshes (Bertness 1999; Adam 2002; Gedan, Silliman, and Bertness 2009). The disturbance of carbon can result in its release into the atmosphere as CO_2 and thus render temporary the climate mitigation benefit. The UNFCCC has dealt with this issue first by adequately accounting for the risk of reversal and then by implementing various mechanisms to maintain project-level system integrity in terrestrial ecosystems (Murray, Galik, et al. 2012). These mechanisms could also be used for blue carbon systems under the UNFCCC.

Unique characteristics of blue carbon systems in terms of permanence

When considering permanence in CMEs, unique types of risk need to be considered. As in terrestrial ecosystems, larger areas tend to have less *proportionate* risk of loss from reversal than smaller ones, so nonpermanence on the national scale must be viewed differently from reversal on the project scale. Specifically, in national reporting of blue carbon, reversal risk tends to be a matter of small percentages, but at the level of a small project, losses can be relatively large (e.g., most or all of the area). While the effect of scale is similar between CMEs and terrestrial ecosystems, the risk factors affecting reversal are different in blue carbon systems. Performing reversal risk analyses could potentially follow methods similar to those described for other LULUCF activities.

As in all natural ecosystems, risk factors in CMEs can also be classified as natural or anthropogenic. Natural risk factors include hurricanes, earthquakes, and disease, while anthropogenic factors include pollution, land-use change, aquaculture, and other means of habitat destruction. In contrast to terrestrial ecosystems, coastal areas tend to have less variation in carbon stocks caused by natural events such as hurricanes. This is because the largest carbon pool in coastal areas—soil carbon—typically remains intact after these events, with some exceptions in the case of the rare disruptive events that alter the coastline. Terrestrial forests, by contrast, can experience relatively larger losses due to fires (van der Werf et al. 2003) and hurricanes (McNulty 2002; Chambers et al. 2007) because much of their carbon is stored in aboveground biomass rather than in soil carbon (fig. 2). Intentional reversals—which could occur, for example, if a carbon project initially maintained carbon through avoided conversion of a mangrove to a shrimp farm but lost it when the project developer changed his mind and converted anyway—can lead to large losses of soil carbon (Murray et al. 2011).

Other types of reversal risk such as those related to climate change, agricultural demand, ineffective project management, or political risk should generally be similar in nature to what is found in terrestrial systems, though the magnitudes could differ due to variation in biophysical, economic, and institutional factors.

Identification of possible solutions for nonpermanence

Several mechanisms have been developed to address nonpermanence in land-based carbon sequestration (Marland, Fruit, and Sedjo 2001), including discounting of credits (Kim, McCarl, and Murray 2008), temporary crediting (Chomitz and Lecocq 2003), insurance schemes (Subak 2003), and buffer pool contributions. Because the underlying issue is the same, these approaches can also be used in blue carbon systems. Work on the cost-effectiveness of these measures to address reversals under the UNFCCC is ongoing (Murray, Galik, et al. 2012). The preliminary results show that while most risk associated with reversal can be addressed by existing mechanisms, it may ultimately depend on the host country to assess and manage the residual risk these mechanisms do not capture.

6. Leakage in Blue Carbon Systems

The IPCC defines leakage as "the unanticipated decrease or increase in GHG benefits outside of the project's accounting boundary . . . as a result of the project activities" (IPCC 2000b). In other words, leakage refers to direct emissions moving elsewhere as a result of emission reduction or avoiding emissions in the project area (Murray 2009). We can distinguish between subnational and international leakage. In carbon sequestration efforts, the key driver in subnational, or project-level, leakage is usually the shifting of activity from the project area to some other area that is not subject to carbon incentives or accounting. An example of this is when shrimp farming activity taking place in coastal zones is simply moved outside of the project boundary after a GHG mitigation project begins, thereby negating some, all, or more than all GHG mitigation benefit of the project. International leakage occurs when emissions are reduced in one country (on net, even after accounting for subnational leakage), but the activity that was generating the emissions (e.g., aquaculture or agriculture) is displaced to another country, where it generates emissions. International leakage is not endemic to blue carbon per se, but is a consequence of internationally incomplete carbon obligations or incentives.

Research has found that project-level leakage in forestry is generally smaller in absolute terms but larger in proportion to the project benefits, when compared to a larger (e.g., national) program (Murray, McCarl, and Lee 2004). Also, market integration has an effect on leakage. Specifically, the level of integration is positively related to the level of leakage that may occur. This is likely also true for leakage in CMEs. This means that possibilities for leakage on the project level need to be carefully analyzed and accounted for in blue carbon systems as in other systems under the UNFCCC.

To account for leakage on the project level in blue carbon systems, alternative activities and leakage channels on the project area need to be described and analyzed (Wunder 2008). Drivers of mangrove loss are generally agriculture, aquaculture, and wood harvests; drivers of seagrass loss are typically water quality degradation and mechanical damage; and drivers of salt marsh loss include agriculture, urban and industrial development, and sediment starvation (Pendleton, Donato, et al. 2012). In each blue carbon project these and other alternative uses need to be analyzed in terms of market integration to estimate the leakage potential. Recent work on leakage quantification under REDD+ can also be applied to blue carbon. Several methods exist for the quantification of project-level leakage, with only one (Verified Carbon Standard) being able to quantify both project-level and national-level leakage under REDD+ (Henders and Ostwald 2012).

One way to minimize leakage generally is to expand coverage. This could mean expanding the number of countries participating in mitigation efforts (Murray and Olander 2008) or expanding the activities covered to include blue carbon and related CME and terrestrial activities, or both. The UNFCCC could include on a voluntary basis broader LULUCF (AFOLU) activities as part of the CDM or an integrated REDD+ approach. Currently only activities in the forest sector are included formally in REDD+. However, countries may eventually choose to pursue a fuller landscape approach that integrates other LULUCF activities, such as those related to nonforested mangrove areas, salt marshes, and seagrasses, into their national REDD+ strategy and monitoring and MRV efforts.

Specific characteristics of blue carbon systems in terms of leakage

Leakage in blue carbon systems does not seem differ from leakage in terrestrial systems, since the levels of integration of economic activities driving conversion are also key in both systems. Also, loss drivers in CMEs have their equivalent activities in terrestrial ecosystems (e.g., land-use change for agricultural use) with the main link between the two being the increasing demand for the production of food, wood harvesting, or development in their respective areas. It makes intuitive sense, and there is also some evidence in the literature on forest carbon projects, that demand elasticity for the goods produced in alternative activities have an effect on the extent of the leakage (Sohngen and Brown 2004; Murray, McCarl, and Lee 2004). Specifically, considering the case of mangroves we may assume that the demand for the alternative good produced (often shrimp) is "inelastic," which is often the case with food. Thus, avoiding the conversion of a given area of mangroves (for shrimp farming, for example) will likely shift the activity and its subsequent GHG emissions to a different area unless specific actions to prevent this are undertaken. Therefore, these elasticities must be measured and used to estimate the leakage effect in CMEs. It can be concluded that the same principles apply for leakage in blue carbon systems as in other ecosystems under the UNFCCC. This also means that options to deal with leakage are the same; these include monitoring, increasing the project scale or redesigning the project altogether, discounting, or shifting into alternative livelihoods (Wunder 2008).

7. Summary of Technical Issues and Possible Solutions

Blue carbon in CMEs has the potential to play an important role in climate mitigation efforts in some parts of the world. Moreover, current scientific methods[26] appear sufficient (Crooks, Emmett-Mattox, and Findsen 2010) to credibly measure carbon stores and flux in blue carbon ecosystems. In principle, blue carbon could fit into national reporting under LULUCF (AFOLU) or project-based approaches such as the CDM, both with current eligible activities, such as mangrove restoration, or with an expanded CDM with avoided conversion activities. From the perspective of the UNFCCC and the Kyoto Protocol, there seem to be few conceptual hurdles for mitigation activities in blue carbon ecosystems to becoming part of a list of effective climate mitigation tools. From many points of view, carbon stored in mangroves, seagrasses, and salt marshes is similar to carbon in terrestrial ecosystems such as forests, or carbon in soil. As part of the process to negotiate a post-2012 climate agreement, the inclusion of blue carbon has been part of the ongoing discussions surrounding REDD+, NAMAs, and expanded coverage of LULUCF (AFOLU).

Regardless of the specific mechanism employed within the UNFCCC, if countries opt to include blue carbon in the mitigation portfolio, they will need to address technical issues about how to MRV blue carbon stocks and emissions, and they will need to deal with crediting and accounting issues such as baselines (additionality), permanence (reversals), and leakage. Measuring carbon in mangroves can be a relatively straightforward extension of well-established forest carbon methods, but measuring carbon in seagrasses or salt marshes on both the national and project scales can be more difficult. That is because most of the carbon is stored in the soil, and thus remote sensing methods, which are helpful for cost-effectively measuring aboveground carbon stocks such as trees and other vegetation, are more difficult to apply. Thus there may be more reliance on intensive site sampling methods. The IPCC is addressing these measurement issues in a revised report on good practices for carbon measurement.

Establishing baselines (historical and BAU) in blue carbon systems may be a difficult hurdle to overcome because historical data and current emission factors and loss rates are not readily available on the national scale for all types of systems. Considering the issue of permanence, blue carbon appears to be a more stable carbon reservoir than terrestrial carbon systems such as forests if kept intentionally in place. Because carbon is stored in the soil, disturbances do not result in the same level of carbon loss as in terrestrial ecosystems that store the majority of carbon in live biomass. Finally, carbon leakage in CMEs seems to be as dependent on the level of economic integration as it is in terrestrial ecosystems.

26. Summarized, for example, PWA and SAIC (2009).

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