CHAPTER 4

COASTAL WETLANDS

Coordinating Lead Authors

Hilary A. Kennedy (UK), Daniel M. Alongi (Australia), Ansarul Karim (Bangladesh)

Lead Authors

Guangcheng Chen (China), Gail L. Chmura (Canada), Stephen Crooks (USA), James G. Kairo (Kenya), Baowen Liao (China), Guanghui Lin (China)

Contributing Author

Tiffany G. Troxler (USA)

Review Editors

Nuria Marba Bordalba (Spain) and Georgi Karl Hiebaum (Bulgaria)

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4.1 INTRODUCTION

This chapter provides guidance on estimating and reporting anthropogenic greenhouse gas (GHG) emissions and removals from managed coastal wetlands.

Coastal wetlands are defined here as organic and mineral soils vegetated by vascular plants that are covered or saturated for all or part of the year by tidal freshwater or salt water (>0.5ppt) at or near the coast. The boundary of coastal wetlands is recognized as the landward extent of tidal inundation and extending seaward to the maximum depth of vascular plant vegetation with 95% of seagrass meadows being found shallower than 40 meters water depth (Duarte 1991).This description is derived from recent definitions in a specialized treatise on coastal wetlands (Perillo et al. 2009) and from a global treatise on all wetlands (Aber et al. 2012). This definition and this chapter thus refer specifically to tidal freshwater and salt marshes, seagrass meadows, and mangrove forests. All vegetation types occur on both mineral and organic soils. The guidance in this chapter applies to all managed coastal wetlands that can occur in any IPCC land category and addresses all IPCC pools (Table 4.1).

Supplementary guidance (Table 4.1) is structured to address greenhouse gas emissions and removals for Land Remaining in a Land-use category (Section 4.2), Land Converted to another Land-use category in which the land that is converted is a coastal wetland (Section 4.3), and Conversion to a Land-Use category that includes coastal wetlands (Section 4.4) regardless of how it is classified. Management activities that have significant impacts on national level CO_2 emissions and removals vary depending on country circumstances. This chapter provides guidance on management activities that will not be relevant for all countries but is meant to be inclusive of those activities that are common in managed coastal wetlands. The guidance is thus structured to aid the inventory compiler to identify areas of managed coastal wetlands and report on management activities that impact greenhouse gas emissions and removals. It should be noted also that depending on how managed coastal wetlands are classified, the effect of the management activity may or may not result in a land-use change. This is an especially important consideration for the guidance provided in this chapter. Inventory compilers should also be mindful that, *significant* greenhouse gas emissions and removals can result in an IPCC Wetlands land category that is *key* regardless of whether a land-use conversion has occurred (in reference to *significant* and *key*, see Chapter 4, Volume 1 of the *2006 IPCC Guidelines*). As such, to ensure complete coverage, this guidance enables the use of the IPCC Land category reporting system. Methodological assumptions and issues more specific to the three categories are discussed in the corresponding sections of this chapter. Readers are referred to Volume 4 of the *2006 IPCC Guidelines* for many of the basic equations to estimate greenhouse gas emissions, but methodological assumptions and other deviations are highlighted throughout the text, especially with regard to new activities including aquaculture and salt production where new methodological guidance is provided. The Decision Tree guides the inventory compiler to the appropriate Tier level estimation methodology as is followed in the *2006 IPCC Guidelines* (Figure 4.1).

TABLE 4.1 MANAGEMENT ACTIVITIES IN COASTAL WETLAND ECOSYSTEMS RELATED TO LAND-USE CATEGORY AND CHAPTER SECTION

LAND REMAINING IN A LAND-USE CATEGORY: Section 4.2 (This section covers management activities that occur in coastal wetland ecosystems and that may or may not result in a conversion to another land-use category.)

Activity	Ecosystems Affected	Subtype
Aquaculture (AQ)	Mangrove forests, Tidal marshes	Fish, shrimp ponds
	Seagrass meadows	Fish cages, pens
Salt Production (SP)	Mangrove forests, Tidal marshes	
	Seagrass meadows	NA[1]
Extraction (EXT)	Mangrove forests, Tidal marshes, Seagrass meadows	Dredging; Port, harbour and marina construction; filling
Harvesting of Aquatic Resources (HARV)	Mangrove forests	Wood, Charcoal, Land clearing
	Tidal marshes	Grazing (cattle, sheep)
	Seagrass meadows	Fish, Shellfish

Nutrient Enrichment (NUTR)	Mangrove forests, Tidal marshes, Seagrass meadows	
Hydrologic/Sediment Diversion (DIV)	Mangrove forests, Tidal marshes	Impoundments, barriers, oil and gas extraction - resulting in soil elevation loss
	Seagrass meadows	NA
Drainage (DR)	Mangrove forests, Tidal marshes	Agriculture, forestry, mosquito control
	Seagrass meadows	NA
Restoration (RES) and Creation (CRE)	Mangrove forests, Tidal marshes	Reestablishment of vegetation following hydrologic or sediment modifications
	Seagrass meadows	Reestablishment of vegetation following water quality improvements
Other Activities	Mangrove forests, Tidal marshes	Recreation (hunting), fire management
	Seagrass meadows	Recreation (anchoring, mooring, boating), salt production
CONVERSION FROM A LAND-USE CATEGORY THAT INCLUDES COASTAL WETLANDS Section 4.3 (This section covers the conversion of a Land-use category that includes coastal wetlands to another Land-use Category, primarily including (1) drainage in which the soil water table is lowered for conversion to Cropland or Grassland or (2) excavation of soil resulting in conversion to Settlement.		
CONVERSION TO A LAND-USE CATEGORY THAT INCLUDES COASTAL WETLANDS Section 4.4 (This section covers restoration and creation of coastal wetland ecosystems in which a Land-use conversion occurs.		
NA =not applicable; [1]no available Tier 1 guidance		

WHAT IS NOT COVERED IN THIS CHAPTER

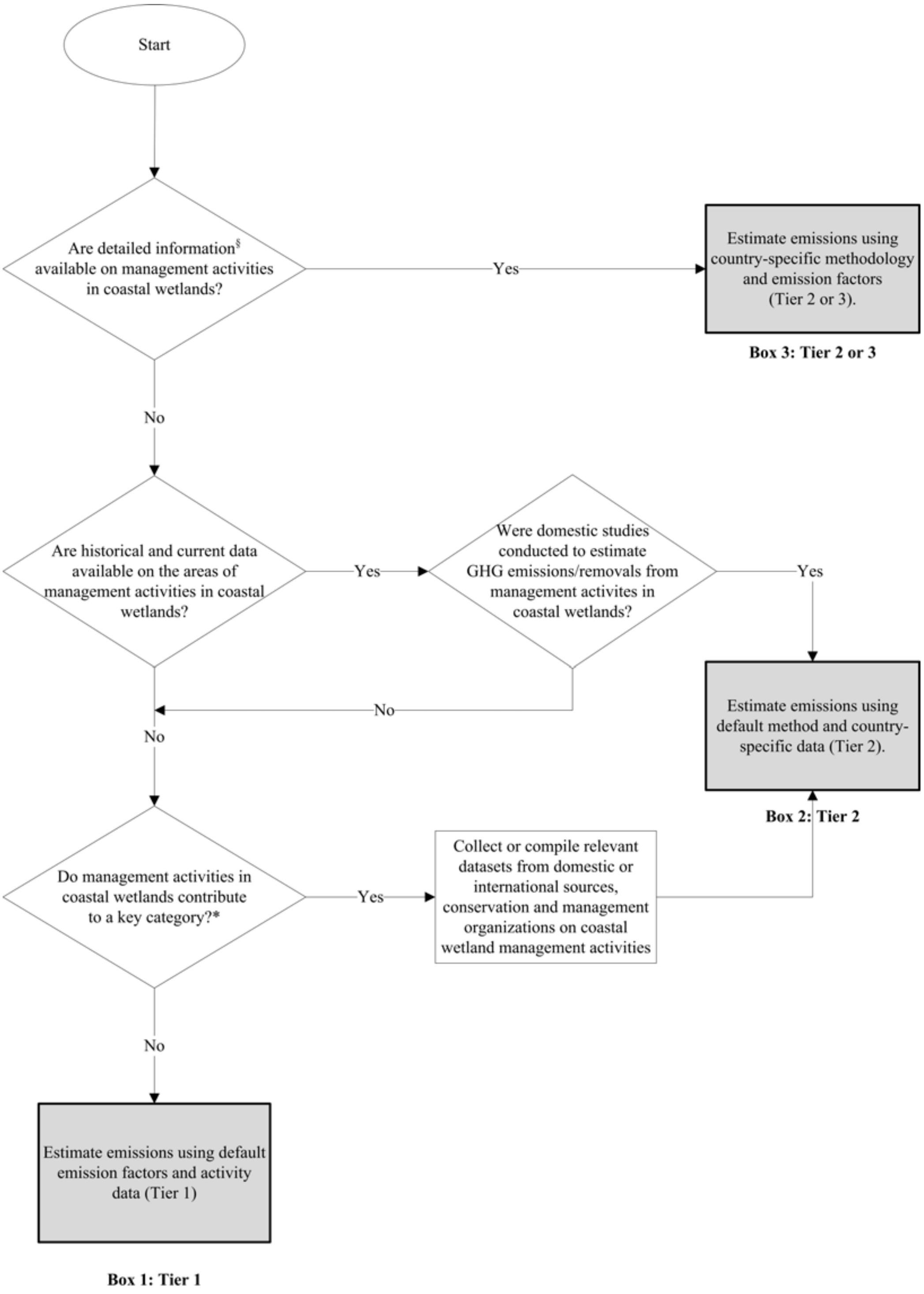
For constructed wetlands that occur in coastal zones that are modified to receive and treat waste water, refer to Chapter 6 (this Supplement). Chapter 6 also covers semi-natural treatment wetlands which are natural wetlands where wastewater has been directed for treatment but the wetland is otherwise unmodified. With reference to nutrient enrichment as an activity in coastal wetlands, this chapter on coastal wetlands covers CO_2, CH_4 and N_2O emissions from aquaculture and effluent derived from aquaculture as well as CH_4 emissions from untreated, uncollected agricultural runoff and leaching resulting from direct nutrient application to terrestrial soils. Nutrient enrichment effects on CO_2 emissions from this type of agricultural run-off affecting mangroves and tidal marshes is not covered as there is inadequate information to provide emission factors for all pools and risk of double-counting across pools. Direct and indirect N_2O emissions from soils associated with N applied to terrestrial soils (direct and indirect) are covered in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*. This Chapter only covers N_2O emissions during stocking of aquaculture and as a result of effluent from aquaculture in the coastal wetland. This chapter covers emissions from these lands, but excludes carbon losses or gains via tidal exchange (see Section 4.6).

SPECIAL CONSIDERATIONS FOR THE APPLICATION OF THE WETLANDS SUPPLEMENT GUIDANCE FOR COASTAL WETLANDS

Special considerations for the application of the Wetlands Supplement guidance for coastal wetlands include an understanding of: A) how to identify coastal wetlands, B) treatment of managed lands in coastal wetlands, C) identification of coastal ecosystems, D) soil type, and other generally applied assumption for soils.

A. Identification of coastal wetlands

Figure 4.1 Decision tree to estimate greenhouse gas emissions and removals due to management activities in coastal wetlands.



*A key source/sink category is defined in Chapter 4, Volume 1 of the *2006 IPCC Guidelines*, "as one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals". The *2006 IPCC Guidelines* recommend that the key category analysis is performed at the level of land remaining in or converted to a land-use category. If CO_2, CH_4 or N_2O emissions/removals from coastal wetlands are subcategories to a key category, these subcategories should be considered as significant if they individually accounts for 25-30% of emissions/removals for the overall key category (see Figures 1.2 and 1.3 in Chapter 1, Volume 4 of the 2006 IPCC Guidelines.

The first priority for inventory compilers is to determine if the managed wetlands under consideration conform to the definition and boundary of coastal wetlands that have been described. In many regions, these boundaries have been mapped using aerial photographs or remotely sensed data, and confirmed by field inspections, and in the form of freely available data (refer to respective sections on Activity Data and Annex 4.2). Wetlands are by definition lands with minimal slope and vegetated by species adapted to temporary, regular or permanent coverage by tidal freshwater or salt water (>0.5ppt) and saturated soil conditions. Many plant species are salt tolerant or salt resistant and may be adapted to grow fully submerged. Thus, wetlands can be identified by the presence of these specialized plant species or by soil characteristics that reflect flooded conditions (e.g., organic carbon content >12% or in mineral soils the presence of mottling).

B. Treatment of managed lands in coastal wetlands

The second priority for inventory compilers is to apply the concept of managed land in order to focus time and resources and report on management activities that impact anthropogenic emissions and removals of greenhouse gases at the national level. The activities that will result in the largest greenhouse gas emissions or removals are those that: 1) include removal and oxidation of soils (eg. aquaculture, salt production, extraction, drainage), 2) have both initial and sustained effects (eg. aquaculture, salt production, restoration) or 3) affect more than one pool. Additionally, for example, those activities which result in removal of forest biomass would have a larger impact than those that result in removal of tidal marsh biomass. So, the land area in which the activity occurs (coastal wetland ecosystem type) is also an important consideration in documentation and reporting of management activity impacts. Furthermore, IPCC *good practice* guidance requires documentation and reporting of all IPCC pools.

C. Identification of ecosystem types

A further consideration when applying the guidance in this chapter is the ecosystem type that is the subject of the management activity. Just as all management activities will not occur in all countries, not all management activities occur in all ecosystem types nor will all coastal wetland ecosystem types be considered managed. Coastal wetlands can occur in any IPCC land-use category regardless of how the land is classified (see examples Box 4.1). While countries should follow their own national definitions of coastal wetland ecosystem types, some general features that may help in consistent identification can be found throughout this guidance.

BOX 4.1. THE FOLLOWING REPRESENT EXAMPLES OF DIFFERENT MANAGEMENT PRACTICE THAT DO OR DO NOT RESULT IN A CHANGE OF A LAND-USE CATEGORY.

For Land remaining in a land-use category:

When areas of fish pens constructed within seagrass meadows are classified as Wetlands.

When tidal marshes or mangrove forests are classified as Wetlands and exploited for aquaculture or drained for agriculture that is also classified as Wetlands.

When selective harvesting or forest clearing occurs in mangrove forests that are classified as Wetlands to provide wood for fuel, charcoal or construction.

For Conversion from a land-use category that includes coastal wetlands:

When areas of fish pens constructed within seagrass meadows are classified as Settlements or Other Land.

When tidal marshes or mangrove forests are classified as Wetlands and exploited for aquaculture or drained for agriculture with that land area classified as Cropland. If the soils are organic and permanently drained for Cropland uses, refer to guidance in Chapter 2 of this Supplement. If the soils are mineral and permanently drained for Cropland uses, refer to guidance in Chapter 5 of the *2006 IPCC Guidelines*.

When mangrove forests classified as Forest Land are deforested, drained and maintained as grazing land and subsequently classified as Grassland.

D. Identification of soil types

A unique aspect of this chapter in the Supplement is that coastal wetland ecosystems can occur with either mineral or organic soils. For some management activities, soils may be aggregated and the same emission factor applied regardless of the soil type (i.e. drainage, restoration and nutrient enrichment). However, emission factors do vary based on ecosystem types and Tier 1 methods disaggregate ecosystem types on this basis. For other management activities, emission factors are disaggregated by soil type (i.e. aquaculture, salt production). This refinement results from the differing methodologies applied in these cases. Once management activities are identified, the inventory compiler should consider whether soil type must be determined. Thus, the fourth priority for inventory compilers is to distinguish organic from mineral soils in coastal wetlands once management activities and ecosystem types have been identified for Tier 1 estimation in the absence of soil map data. There are two assumptions that can be applied at Tier 1:

(i) Assumption 1: Soils which are or become colonised by seagrass meadows are assumed to be mineral.

(ii) Assumption 2: Soils in or at the mouth of estuaries or adjacent to any river characterised by a large and/or mountainous catchment and high flow are assumed to be mineral soils. For all other mangrove forests (sometimes termed oceanic mangroves) and tidal marshes the soils are assumed to be organic. See Durr et al. 2011for additional national level guidance.

4.1.1 Land remaining in a land-use category

The known management activities that occur in coastal wetlands and that may not result in their conversion to another IPCC land-use category depending on how those lands are classified are aquaculture, salt production, extraction, harvesting of aquatic resources, nutrient enrichment, hydrologic/sediment diversion, drainage, restoration/creation and other activities (Table 4.1). In the following sub-section, these activities and how they affect the coastal wetlands they primarily impact are described. All methodological guidance is found in section 4.2. When management activities do not result in a land-use category conversion, follow guidance in section 4.2. When a land-use category conversion is involved, refer to guidance in sections 4.3 and 4.4 which direct the inventory compiler to the appropriate methodological guidance.

Aquaculture (shrimp ponds, fish ponds, fish cages)

There exists a range of aquaculture practices, but the most important, and ones that commonly occur in coastal wetlands, are fish farming and shrimp ponds (World Bank 2006).

Mangrove Forests and Tidal Marshes. Shrimp and fish ponds in these settings are identified through three phases: construction, use and abandonment. In the first phase they are constructed by clearing vegetation, levelling, followed by excavation of surface soils to build containing berms within which water is held. During construction, carbon from the cleared biomass and excavated soils is lost from storage and subsequently oxidized (World Bank 2006). While in use (second phase), ponds are stocked with fish and shrimp, and soils underlying ponds receive excess organic matter leading to an enhancement of benthic CO_2 fluxes from the oxidation of the organic matter (Burford & Langton 2001), N_2O will be emitted from aquaculture systems primarily as a by-product of the conversion of ammonia (contained in fish urea) to nitrate through nitrification and nitrate to N_2 gas through denitrification (Hu et al., 2012). While CH_4 production may occur if bottom muds are anoxic, some of the CH_4 will be oxidized as it passes through the water column, which must be oxygenated for fish culturing (Bose et al., 1991). However, there is considerable uncertainty regarding N_2O and CH_4 fluxes associated with aquaculture and additional research is necessary. When stocking of the ponds is discontinued, the ponds are abandoned. On abandonment, the area utilized for aquaculture is often left with saturated soils. In this guidance, this Chapter covers CO_2 emissions and removals from all phases of aquaculture and N_2O emissions only during the period when the ponds are being stocked.

Seagrass Meadows. Fish farming is a rapidly expanding industry in Asia (FAO 2007a). The fish are retained in floating cages or pens made up of nets often fastened to bamboo sticks that are anchored in the sediment (Alongi et al., 2009). Fish farming generates organic waste that impacts the immediate environment resulting in nutrient enrichment of the water column and organic enrichment of sediments beneath the farm. Nutrient over-enrichment of seagrass meadows has led to water and sediment quality deterioration, algal overgrowth, and loss of seagrass (Apostolaki et al., 2010; Apostolaki et al., 2011). Increased organic matter accumulation increases benthic metabolism leading to anoxic conditions and high sediment sulfide concentrations have been associated with seagrass die-off events (Holmer & Heilskov 2000; Borum et al., 2005). Gas bubbles have been observed in the sediments underlying fish pens and the sulphate concentration were depleted in the surface layers, thus it is thus likely that methane production occurs in these settings but no measurements have been made to date (Holmer et al., 2002).

Salt production

Mangrove Forests and Tidal Marshes. The Ramsar convention recognizes salt exploitation sites or solar salterns as a type of wetland. These are sites where salt is produced by evaporating seawater. The area covered can be extensive and sites are found along tropical and subtropical coasts worldwide (Oren 2009). Many solar salterns have long histories, on the order of centuries (Thiery and Puente 2002). More recently, salt production has been shown to displace mangroves on the coast of Java (Sukardjo 1993). Some production sites, as in San Francisco Bay and on the Camargue, have been abandoned and restoration activities are underway. Establishment of the production system is similar to the construction phase of aquaculture and can include clearing vegetation, levelling, diking and constructing channels to develop a multi-pond production system (Oren 2002). Scientific evidence is not adequately developed to provide default emission factors for effects on CO_2 emissions while the salt production ponds are in use. The CO_2 emissions and removals of salt production are similar as those of aquaculture during construction and abandonment and so similar guidance in given in both instances.

Extraction (dredging; port, harbour and marina construction; filling)

Mangrove Forests and Tidal Marshes. Dredging excavates soil often leading to loss of coastal wetlands. In mangrove forests and tidal marshes this most often occurs by direct physical removal of biomass and soil. The CO_2 emissions and removals associated with this extraction are the same as those of aquaculture during construction and so the same guidance in given in both instances. The area that has had the soil removed is sometimes subsequently filled with other soil, whether extracted within or outside the coastal ecosystem. Filling of coastal wetlands is also considered a significant management activity affecting CO_2 emissions; if filling occurs, it is preceded by extraction. Similarly as for extraction, CO_2 emissions and removals must be reported. Once the extraction is complete, the area that has had the soil removed may become covered with water and CO_2 emissions are assumed to be negligible.

Seagrass Meadows. Extraction effects on seagrass meadows can take two forms: 1) direct via on-site physical removal of soil and biomass (Zainal et al. 1993. Ertlinmeyer et al 2012) or 2) indirect via sediment resuspension that causes high turbidity and reduces water quality impacting biomass stocks through inhibition of photosynthesis (Erftemeijer and Lewis, 2006) leading to major die back (Cyrus et al. 2008) and/or seagrass loss (Cabaço et al. 2008). The direct effects of extractionon seagrass meadows are when soil is removed todeepen and maintain navigation channels and harbour entrances or for extraction of fill materials from seagrass meadows (Larkum and West 1990; Da Silva et al. 2004). These activities have been reported to represent the greatest environmental threats to seagrass meadows, particularly in the Gulf region where more than 40% of the coastline has now been modified and developed (Sheppard and Price, 1991).The indirect effects of extraction can result from any significant dredging activity (i.e. beach renourishment, channel dredging or widening, changes in land catchments, etc) that occurs landward of seagrass meadows. The CO_2 emissions and removals associated with extraction (direct physical removal of biomass and soil) are similar to those of aquaculture during construction and so similar guidance is given).

Harvesting of aquatic resources

Mangrove Forests. Throughout the tropics, mangrove wood is harvested for fuel, charcoal, and construction (Ellison and Farnsworth 1996, Walters et al. 2008). Harvesting can range from extensive forest clearing, to more moderate, selective harvesting of individual trees to minimally invasive incidental bark removal. In wetlands dominated by woody vegetation change in biomass C stocks should be considered during both selective harvesting and forest clearance. CO_2 emissions from soils due to forest clearing should also be considered in C stock estimations (Alongi et al. 1998). To date, there have been no studies that suggest a change in N_2O emissions with harvests. Plant-mediated transport of methane has been documented (Kreuzwieser et al. 2003; Cheng et al. 2007), but few data are currently available.

Tidal Marshes. Harvesting of marsh vegetation is assumed to have negligible impacts on biomass and soil C stocks. However, in cases where extensive harvesting of vegetation or grazing is known to occur, it is good practice to document and report the CO_2 emissions and removals associated with this activity.

Seagrass Meadows. Physical disturbance is an issue with harvesting marine resources such as bivalves and other shellfish. On-ground shellfish culture and harvest methods can result in trampling and disturbance from boat wakes and propeller scars in shallow waters (Dumbauld et al. 2009). Intertidal seagrass beds can be particularly impacted by bait collection, through digging and trenching as well as pumping of sediment for prawns (Pillay et al. 2010) and associated trampling. Thus, harvesting of aquatic resources can have impacts on CO_2 emissions and removals primarily through changes in biomass C stocks where seagrass meadows have been lost.

Nutrient enrichment

Human activities can provide excess organic matter, nitrogen and phosphorus to coastal waters through agriculture runoff, discharge of sewage and industry effluent (Seitzinger and Harrison 2008). Nutrient enrichment stimulates algal production, adding to organic matter loads in coastal waters. Nitrate, ammonium and dissolved organic N are the major forms of N input (Dai et al. 2008, Seitzinger and Harrison 2008). Decomposition of organic matter and nutrients supplied through anthropogenic sources can result in enhanced emissions of greenhouse gases.

Mangrove Forests and Tidal Marshes. In mangrove forests and tidal marshes, the effects nutrient availability on plant community structure and aboveground and belowground biomass is not well understood. Numerous fertilization experiments indicate that aboveground production in saline wetlands is limited by availability of N, while tidal freshwater marshes may be limited by availability of P (Megonigal and Neubauer 2009). Fertilization with N in tidal salt marshes has resulted in an increase in plant height, photosynthetic rates, and aboveground biomass production (e.g. Valiela and Teal 1974; Leendertse et al., 1997; Pennings et al., 2002). However, belowground production decreases with increased nutrient supply (Valiela et al., 1976; Darby and Turner 2008; Deegan et al., 2012). Since belowground production is the major source of carbon sequestered in marsh and mangrove soils, fertilization may result in no, or perhaps decreased, rates of carbon sequestration (Deegan et al. 2012). However, scientific evidence is not adequately developed to provide default emission factors for nutrient enrichment effects on CO_2 emissions and removals associated with biomass or soils in mangrove forests and tidal marshes. For instance, most mangrove research has focused on short-term increases in foliage nutrient content (e.g., Simpson et al., 2013) than on actual measurement of increases in biomass over time and the rate of increase in biomass increases initially with rate of nutrient supply (Alongi 2011). Thus, for the management activity nutrient enrichment, this chapter covers only CH_4 emissions due to effluent from aquaculture and urbanisation of the coastal zone and agricultural run-off and N_2O due to effluent from aquaculture. For non-CO_2 gases associated with other types of nutrient enrichment, covers N_2O emissions from agricultural run-off (through N leaching from application of N to terrestrial soils) are covered in Chapter 11, Volume 4 of the *2006 IPCC Guidelines.* In this Supplement, N_2O and CH_4 emissions from waste water (including sewage) are covered in Chapter 6 on semi-natural treatment wetlands.

Seagrass Meadows. Decline of seagrass populations associated with anthropogenic nutrient loading including effluent from aquaculture (Yang and Yang, 2009) has been observed in many estuarine embayments (Waycott et al. 2009). Increased availability of nutrients may lead to blooms of macroalgae, phytoplankton, and epiphytes, all of which shade seagrass, reducing the light available for photosynthesis that can lead to seagrass loss (Waycott et al. 2009). Because the effects due to agricultural run-off and effluent discharge from aquaculture result in a decrease in both aboveground and belowground biomass stocks as well as increased CO_2 emissions from soils, with sufficient scientific evidence of both, CO_2 emissions and removals due to nutrient enrichment are covered in this Chapter.

Hydrologic/Sediment diversion (soil elevation loss)

Mangrove Forests and Tidal Marshes. The processes by which elevation in tidal wetlands is maintained against sea level rise and in some cases, coastal subsidence, rely upon the supply of mineral soils (Kirwan et al., 2011) derived from nearby rivers, cliffs, seabeds and oceanic import as well as growth of belowground biomass to maintain elevations against sea level rise. Therefore management practices that alter soil supply or cause subsidence will impact on coastal ecosystems. For example, many coastal wetlands are impacted by upstream diversions of water, such as from the construction of dams that is accompanied by diversion of sediment resulting in sediment starvation. Reduction of sediment delivery brought about by coastal structures can also result in sediment starvation, erosion of coastal wetland soils and release of stored carbon. Oil and gas extraction also affects coastal wetlands and results in soil subsidence and vegetation drowning in coastal areas (Craig et al. 1979; Dahl 2011). Thus hydrologic diversion from coastal areas with mangrove forests and tidal marshes, resulting in reduced elevation relative to sea-level rise or subsidence, can cause significant impacts to above and belowground C stocks if the soil becomes subtidal. As C in decayed vegetation is released to the water column and to the atmosphere, these C stock changes should be reported.

Drainage

Mangrove Forests and Tidal Marshes. Coastal wetlands have been diked and drained to create agricultural land (pasture and croplands) and settlement since before the 11th century (Gedan et al., 2009). The practice continues today on many coastlines. On some diked coasts, groundwater of reclaimed former wetlands is pumped out to maintain the water table at an optimum level below a dry soil surface while on other coasts drainage is achieved through a system of ditches and tidal gates. Drainage causes a reduction in the degree of soil saturation and ordinarily increases rates of organic matter decomposition, resulting in loss of soil carbon (Armentano and Menges 1986). This response will vary regionally with climate (Pozo and Colino 1992) and locally with soil salinity, soil texture, and the quantity of labile organic matter available in the drained soil (Heminga et al., 1998; Setia et al., 2011). Drainage can also lead to CO_2 emissions due to oxidation of dissolved organic and particulate organic carbon in the water carried by drainage channels (see Annex 4.2). Drainage could be accompanied by land clearing, resulting in changes in biomass and soil carbon pools. If burning accompanies drainage, emissions from changes in those C pools (e.g. DOM) should also be reported.

Restoration and Creation.

Mangrove Forests and Tidal Marshes. Rewetting as a component of restoration, results where hydrologic modifications reverse drainage or remove impoundments or other obstructions to hydrologic flow (i.e. levee breach). Rewetting of drained soils through reconnection of hydrology can reduce oxidation of soil C but may lead to CH_4 emissions depending on salinity of reintroduced water (Harris et al 2010). The reestablishment of vegetation can reinitiate soil carbon sequestration leading to wetland restoration. Improved estimates of soil carbon accumulation rates in mangroves and tidal marshes (Chmura et al. 2003, Breithaup et al., 2012) have recently been obtained making it possible to quantify C gains in restored systems. Also included in this activity are created mangrove forests and tidal marshes that are typically established by removing the upper layer of upland soil or dredge spoil and grading the site until the appropriate tidal elevation is reached. Hence, the initial soils at created wetland sites are typically upland soils and/or dredge spoil. A peat layer can eventually develop in the surface soils with soil properties equivalent to soil properties within the upper layer of natural wetlands (Osland et al. 2012). Mangrove forests can also be created through high riverine sediment load, leading to rapid sediment accumulation, so that previously sub-aqueous soils can be elevated above tidal influence. This naturally created land can be naturally or purposefully vegetated**.** Time lags for equivalence of C pools between created and natural mangrove sites also suggest a timescale of ~20 years for restoration of functionally equivalent soil C accumulation rates (Craft et al. 2003, Osland et al . 2012).

Seagrass Meadows. Water quality improvements can reverse seagrass loss due to increased light penetration. The re-establishment of seagrass vegetation can increase C gains, albeit slowly. For example, a 3-5 year time lag between nutrient load reduction and initiation of seagrass recolonization has been observed (Vaudrey et al. 2010), with a further 12-15 yr time lag before seagrass biomass attains a relatively stable distribution with potential for soil carbon accumulation rates equivalent to natural settings (McGlathery et al., 2012). Restoration of sites previously supporting seagrass meadows can be mediated by purposeful dispersal of seed or planting of seagrass modules (Orth et al., 2012). These same techniques can also be used to create new seagrass meadows (Jones et al., 2012)

Other Activities.

Mangrove Forests, Tidal Marshes and Seagrass Meadows. In order not to omit any potentially significant management activity that may now or in the future constitute significant CO_2 emissions or removals or emissions of non-CO_2 gases, a final subtype “other activities” is identified. For example, currently salt production is currently not considered a management activity that significantly impacts seagrass meadows and thus no Tier 1 guidance is provided However, as economic or social conditions change, so might management practices. Thus, the management activity termed, other activities, is provided to capture such potential changes in conditions.

4.1.2 Conversion from a land-use category that includes coastal wetlands

This section covers coastal wetland ecosystems that have been converted from the Wetlands land-use category to other land-use categories (see Section 4.3 for further guidance). Drainage or extraction are activities that are most likely to result in land-use category conversion from Wetlands to another IPCC land-use category, however, this is largely a function of how the land is classified (see Box 4.1). Excavation of soil may also result in conversion to Settlements. However, not all cases of land-use conversion result from drainage or extraction. For example, in the case of forested coastal wetland ecosystems, a land-use conversion can occur simply based on how the land is classified. For example, a mangrove forest that was cleared for timber harvest or otherwise deforested could undergo a change in land-use category if the mangrove forest had been classified as Forest land, but would not undergo a change in land-use category if the mangrove forest had been classified as Wetlands. Although the scale and resulting management activity may result in a land-use category change, the methodology to estimate CO_2 emissions is the same as given in section 4.1.1. There are cases in which a change in land-use category involves implementation of new methodologies and emission factors. For example, if a coastal wetland is drained to the extent that it is dry all year round, it does not meet the definition of wetlands as presented in this Chapter. Thus, a new land-use category would necessarily be applied. In the case that the coastal wetland has organic soils and is permanently drained wetland, refer to Chapter 2 of this Supplement (see

Box 4.1 for further examples). If conversion results in a land-use category with mineral soils, refer to the respective Chapter in the *2006 IPCC Guidelines*.

4.1.3 Conversion to a land-use category that includes coastal wetlands

This section considers rewetting and restoration or creation of coastal wetlands that occurs where hydrology, water quality or soils have been altered for establishment and survival of functioning vegetation (see Section 4.4 for further guidance). This includes restoration of coastal wetlands, where vegetation that was present prior to the current land use has been re-established, or creation, where actions have been taken to develop coastal wetlands in areas where they cannot be confirmed to have occurred previously.

4.2 LAND REMAINING IN A LAND-USE CATEGORY

This section details methodology necessary to estimate impacts of various human activities on greenhouse gas emissions from Land remaining in a land-use category. Sub-sections detail the methods for estimates as a result of change in biomass (subsection 4.2.1), DOM (subsection 4.2.2), soil (subsection 4.2.3), and for non-CO_2 gases (sub-section 4.2.4). Methods for biomass, DOM and non-CO_2 gases in large part reference the methodological guidance of the *2006 IPCC Guidelines* which should be read before and referred to in conjunction with, this guidance.

Guidance is provided here on estimating greenhouse gas emissions from management activities that do not result in a land-use conversion. These activities either take place without any changes of the water table over all land area (e.g. nutrient enrichment, harvesting of aquatic resources) or over part of the land area (e.g. salt production, extraction) within the managed coastal wetland. If these management activities can result in a change from the coastal wetland land-use category to another IPCC land-use category, then they will be considered in section 4.3.

The general approach that is applied combines the change in CO_2 emissions and removals for each activity summed for each pool with non-CO_2 gases treated separately. The following equation (Equation 4.1) is used for each of the carbon pools:

EQUATION 4.1

ANNUAL CHANGE IN CARBON POOLS IN LAND REMAINING IN A LAND USE CATEGORY

$$\sum \Delta C_{pool(1\ldots i)} = \Delta C_{AQ} + \Delta C_{SP} + \Delta C_{EXT} + \Delta C_{HARV} + \Delta C_{NUTR} + \Delta C_{DIV} + \Delta C_{DR} + \Delta C_{RES} + \Delta C_{CRE}$$

where:

$\sum \Delta C_{pool(1\ldots i)}$ = the sum of carbon stock changes for each pool with activities summed within each pool from 1 to i activities.

ΔC_{AQ} = Change in carbon stocks associated with aquaculture activity

ΔC_{SP} = Change in carbon stocks associated with salt production activity

ΔC_{EXT} = Change in carbon stocks associated with extraction activity

ΔC_{HARV} = Change in carbon stocks associated with harvesting activity

ΔC_{NUTR} = Change in carbon stocks associated with nutrient enrichment activity

ΔC_{DIV} = Change in carbon stocks associated with hydrologic/sediment diversion activity

ΔC_{DR}= Change in carbon stocks associated with drainage activity

ΔC_{RES}= Change in carbon stocks associated with restoration activity

ΔC_{CRE}= Change in carbon stocks associated with creation activity

4.2.1 Biomass

This section addresses estimation of changes in aboveground and belowground biomass carbon pools associated with management activities in coastal wetlands in all categories i.e. land remaining in a land-use category, conversion from a land-use category that includes coastal wetlands and conversion to a land-use category that includes coastal wetlands. It builds on the *2006 IPCC Guidelines* and the *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (*GPG-LULUCF*). For coastal wetlands with mangroves forest changes in biomass carbon stocks follow equations provided in Chapters 2 and 4, Volume 4, of the *2006 IPCC Guidelines*. For managed coastal wetlands with tidal marshes and seagrass meadows, changes in biomass carbon stocks follow largely follow equations in the Chapters 2 and 6, Volume 4, of the *2006 IPCC Guidelines*. However, there are some deviations from these general methods as applied to the Land Remaining in a land-use category guidance as presented in Volume 4 of the *2006 IPCC Guidelines*. Thus, Table 4.2 should be used to identify the appropriate Tier 1 approaches and equations that should be applied when following this guidance. The main Tier 1 approaches and equations for each activity are presented in Table 4.2 below.

TABLE 4.2 MANAGEMENT ACTIVITIES, TIER 1 EQUATIONS OR DEFAULT EF FOR BIOMASS POOL CHANGES

Activity	Ecosystem	Tier 1 Equation[1] and Default EF
Aquaculture ($\Delta C_{B\text{-}AQ}$), Salt Production ($\Delta C_{B\text{-}SP}$), Extraction ($\Delta C_{B\text{-}EXT}$)	Mangrove forest	**AQ, SP, EXT-D**[2]: at start of activity, apply Eq. 2.9 or 2.10 and Eq. 2.11 & 2.14; $\Delta C_G = 0$ and $\Delta C_L = L_{disturbance}$; Tabel 4.3 – 4.6 **AQ, SP**: for use phase, $\Delta C_G = \Delta C_L$; Table 4.3-4.6 **AQ, SP**: for abandonment phase, apply Eq. 2.9 or 2.10 and Eq. 2.11 - 2.14; Table 4.3-4.7
	Tidal marsh	**AQ, SP, EXT-D**[2]: at start of activity, apply Eq. 2.8a where $Ct_2=0$ and Ct_1=initial C stock[3]; Table 4.8 **AQ, SP**: for abandonment phase, apply Eq. 2.8a; Table 4.8 **AQ**: for use phase, $\Delta C_G = \Delta C_L$; Table 4.8
	Seagrass meadow	**AQ, EXT-D and EXT-I**[4]: at start of activity, apply Eq. 2.8a where $Ct_2=0$ and Ct_1=initial C stock[3]; Table 4.9-4.11
Harvesting of Aquatic Resources ($\Delta C_{B\text{-}HARV}$), Hydrologic/Sediment Diversion ($\Delta C_{B\text{-}DIV}$)	Mangrove	Apply Eq. 2.9 or 2.10 and Eq. 2.11 - 2.14[5]; Table 4.3-4.6
	Tidal Marsh	Apply Eq. 2.8a; Table 4.8
	Seagrass Meadow	NA
Nutrient Enrichment ($\Delta C_{B\text{-}NUTR}$)	Mangrove	NA
	Tidal Marsh	
	Seagrass Meadow	**EXT-I**[4]: at start of activity, apply Eq. 2.8a where $Ct_2=0$ and Ct_1=initial C stock[3]; Table 4.9-4.11
Drainage ($\Delta C_{B\text{-}DR}$), Restoration ($\Delta C_{B\text{-}RES}$) & Creation ($\Delta C_{B\text{-}CRE}$), Other Activities ($\Delta C_{B\text{-}OTHER}$)	Mangrove	**DR, RES, CR, OTHER**: apply Eq. 2.9 or 2.10 and Eq. 2.11 - 2.14; Table 4.3 – 4.7
	Tidal Marsh	**DR, RES, CR, OTHER**: apply Eq. 2.8a; Table 4.8
	Seagrass Meadow	**DR**: NA, **RES, CR, OTHER:** apply Eq. 2.8a; Table 4.9-4.11

Note -- [1]Equations in the section can be found in the 2006 IPCC Guidelines; [2] EXT-D = where biomassare is physically removed; [3]Ct_1=initial C stock can be found in Table 4.9-4.11; [4]EXT-I = biomass C stock change resulting from sediment deposition effects; [5]reporting $L_{disturbance}$ as loss due to harvest; NA = not applicable

4.2.1.1 CHOICE OF METHOD

Removal or loss of biomass resulting from management activities that occur during aquaculture, salt production, and extraction for mangrove forests, tidal marshes and seagrass meadows are estimated at Tier 1 level with the key assumption that carbon in biomass lost in the year of the start of the activity is oxidised to CO_2 (Table 4.2). For mangrove forests, this is estimated with the *Gain-Loss* method as $\Delta C_L = L_{disturbance}$. For tidal marshes and seagrass meadows, this is estimated with the *Stock-Difference* method with the biomass C stock at $t_2 = 0$. For harvesting of aquatic resources and hydrologic/sediment diversion, guidance follows equations provided in Chapter 2 as noted in Table 4.2. For nutrient enrichment, change in biomass C stocks are only estimated for seagrass meadows as EXT-I (indirect effect of extraction activity; see Section 4.1.1) and follows the *Stock-Difference* approach with the biomass C stock at $t_2 = 0$ (lost in the year that the activity starts). For drainage, restoration/creation and other activities, methodology follows guidance in *2006 IPCC Guidelines* as described in Table 4.2 with the exception of drainage for seagrass meadows, an activity for which there is no evidence of its occurrence.

TIER 1

Mangrove, Tidal Marsh and Seagrass Meadow

The method for estimating changes in mangrove biomass for Tier 1 follows Eq. 2.9 and Eq. 2.11-2.14 and for tidal marsh and seagrass biomass Eq. 2.8a is applied (see Volume 4 of the *2006 IPCC Guidelines* for details). Default values presented in Tables 4.3-4.11 are used in these equations, depending on whether the ecosystem is mangrove forest, tidal marsh, or seagrass meadow and their climate domain. For mangroves, Tables 4.3-4.7 contain default factors for average aboveground biomass, the ratio of belowground to aboveground biomass, and dry weight:carbon conversion factors, differentiated by humid and dry tropical regions and the subtropics. To estimate losses due to wood-removals and fuelwood, wood density (Table 4.7) and BEF values should be applied (Chapter 3 in 2003 *GPG-LULUCF*). For tidal marshes, Table 4.8 contains default factors for average aboveground and belowground biomass by climate and salinity. For seagrass meadows, methodology also generally follows the *Stock-Difference* approach with data provided for aboveground biomass, the ratio of belowground to aboveground biomass and C conversion factors (Tables 4.9-4.11). It should be noted that the loss of biomass C stock from seagrass meadows due to nutrient enrichment and indirect effects of extraction results in loss of water clarity and light available (as described in Section 4.1.1) and should be reported.

TIER 2

Tier 2 methods are used where countries have country-specific emission factors, and substantial national data or data that can be gathered based at reasonable cost. Country-defined methodology (e.g., high priority is empirical measurement of above-ground biomass which for mangroves involves use of allometric equations) may be based on detailed inventories of permanent sample plots for coastal wetlands. Tier 2 can include such other improvements as, in the case of mangroves, use of allometric relationships to accurately measure aboveground biomass; a priority in this case would be to measure diameter-at-breast height of trees in the permanent plots (see Annex 4.3). To estimate carbon gain using country-specific annual increment, wood density (Table 4.7) and BEF values should be applied (Chapter 3 in 2003 *GPG-LULUCF*). In the case of seagrasses, where extraction, nutrient enrichment, or aquaculture resulting in either reduced water quality or redeposition of sediments is significant leading to a land category or pool that is key, Tier 2 methods can involve data collected from permanent sample plots or other means of acquiring country-specific data as covered in standard texts. For seagrass meadows, the lag time between water clarity impacts and biomass C stock change could be employed where t_2 was estimated as a fraction of initial stock.

TIER 3

Tier 3 approach for biomass carbon stock change estimation allows for a variety of methods, including process based models. Implementation may differ from one country to another, due to differences in inventory methods, coastal wetland conditions and activity data. Tier 3 requires use of detailed national coastal wetland inventories. They may be supplemented by allometric equations and models calibrated to national circumstances that allow for direct estimation of biomass growth. Tier 3 could also involve inventory systems using statistically-based sampling of biomass over time and/or process models, to further stratify ecosystem type into subtype, ecological zone and salinity.

4.2.1.2 CHOICE OF EMISSION/REMOVAL FACTORS

TIER 1

Mangrove, Tidal Marsh and Seagrass Meadow

Countries using a Tier 1 method should utilize default data for mangrove forests, tidal marshes or seagrass meadows provided in this guidance. For mangrove forests, prior to when or where aquaculture, salt production, extraction or harvesting, or hydrologic/sediment diversion occurred, Tier 1 emission factors for biomass stocks can be calculated using a *Stock-Difference* approach or a *Gain-Loss* approach using biomass growth, primarily differentiated at the level of climate domain (and in the case of tidal marshes, also by salinity for the temperate climate domain). For mangrove forests, the use of Tables 4.3 – 4.7 including guidance on estimating BCEF based on woody density for losses of fuelwood and wood-removals found in the *2006 IPCC Guidelines* are needed. For tidal marshes, the default emissions factors to be used are in Tables 4.8. For seagrass, emission factors found in Tables 4.9-4.11.

TIER 2

The higher Tier methods described in Chapter 2 of the *2006 IPCC Guidelines* (Eq. 2.18-2.23) will permit better estimates when national data are applied. Estimate of loss of below-ground root biomass should also be empirically measured rather than using the ratio of aboveground to belowground biomass.

TIER 3

Tier 3 modelling would include country-specific emission factors derived or modelled from measurement data. The models should capture variation in emission rates driven by extent and depth of biomass extraction and in the case of water/sediment diversion, the rate of biomass decline. The incremental growth rates of the dominant species can be multiplied by the current biomass estimate to derive a figure of projected change over time, if required. For seagrass meadows, aerial photographs may be used in regions of high water clarity, good contrast between seagrass meadows and soil and low cover of other macrophytes. Field validations can be implemented to verify model output using field measurements by diving or underwater camera. Other examples of data improvements for aquaculture, salt production and extraction, for example, include ground-truth estimates of total area impacted, the depth at which removal of biomass has occurred or the completeness of biomass removal could also be verified. Furthermore, with indirect effects of extraction on seagrass meadows, because the time periods for biomass loss will vary based on national circumstances, some seagrass meadows will show more rapid decline than seagrass meadows in other areas. Total areas can be estimated with greatest certainty coupling aerial or remote sensing with field measurements.

4.2.1.3 CHOICE OF ACTIVITY DATA

All tiers require information on areas of managed coastal wetlands for ecosystem types, climate, and management activities which vary depending on national circumstances. The default methodology for all Tier 1 estimates requires data on the area of managed wetland, the type and dominant species present in the wetland, and soil type. The type of wetland present as well as soil type can be obtained from national wetland and soil type maps (if available or the International Soil Reference and Information Centre; www.isrig.org); wetland distributions for most countries can be obtained from the RAMSAR web site (www.ramsar.org). When information is gathered from multiple sources, cross-checks should be made to ensure complete and consistent representation and avoid omissions and double-counting. Please refer to the extended list of activity data sources in Annex 4.2 in this Chapter.

Aquaculture, Salt production

The ponds or structures used to create conditions conducive to aquaculture and salt production can be identified from aerial photographs or by inspection and measurement of the total area where biomass has been removed. Information on regional aquaculture projects worldwide can be obtained from the GISFish database of the FAO (www.fao.org) and similar project information for salt production projects can be obtained from the Salt Institute at www.saltinstitute.org.

Extraction or Harvesting

Information of current extraction/harvesting projects may be obtained from local, state or regional government department websites as many countries and regional government authorities require documentation of environmental impact assessments. For seagrass meadows, aerial photographs may be used in regions of high water clarity, good contrast between seagrass and soil and low cover of other macrophytes. If these conditions are not present, remote sensing imagery providing data on water clarity using intensity of chlorophyll or concentration of suspended particles other photoimagery can be used and readily available.

Nutrient enrichment

We can expect to find nutrient-affected systems downstream of major urban centers, municipal sewage treatment facilities, and watersheds where a large portion of the land is under intensive agricultural use. For seagrass meadows the N load per estuary that relates to complete loss of seagrass has been predicted to be at loading values between 100 and 175 kg N ha^{-1} yr^{-1} (Steward and Green 2007; Latimer and Rego 2010). Information about changes in seagrass biomass as a result of nutrient enrichment may be obtained from national government departments, marine conservation trusts and societies and global seagrass networks (http://seagrasswatch.org). Review papers in the scientific literature (e.g. Waycott et al., 2009) have collated information on localised seagrass loss. Historical records of seagrass cover including aerial photographs may be used in regions of high water clarity, good contrast between seagrass and soil and low cover of other macrophytes.

Hydrologic/Sediment Diversion, Drainage

Total areas impacted by upstream diversions of water and sediment result in soil elevation loss and coastal subsidence can be assessed using aerial or remotely sensed data as well as reports from Environmental ministries or other agencies reporting rates of coastal subsidence and at higher Tiers validated with field measurements. Drainage is recognized by presence of levees and rectilinear channel networks that stand out in comparison to the normally flat surface with curving, bifurcating channels. Restoration would be recognized by the removal of levees, tidal gates, enlargement of culverts, and possibly development of new hybrid channel networks that incorporate both constructed and natural channels (MacDonald et al., 2010). Channels may visibly widen. Immediately after rewetting, dead vegetation may be visible in tidal marshes, in both mangroves and tidal marshes fresh mud will be deposited over previous soil surface. These information can be easily detected on aerial images that are freely available. If following Approach 1 for land classification, information of drainage and diversion projects may be obtained from local, state or regional government department websites as many countries and regional government authorities require documentation of environmental impact assessments for these activities.

Restoration/Creation

Estimates of biomass change as a result of wetland restoration or creation requires knowledge of previous wetland coverage (in the case of restoration) and of biomass growth rates (in the case of restoration or creation). Historical photos may be used to most readily estimate the pre-restored wetland area. Information on regional wetland restoration and creation projects worldwide can be obtained from the Global Gateway to Geographic Information Systems of the FAO (www.fao.org) as well as from the websites, www.wetlands.org and www.globalrestorationnetwork.org.

Table 4.3 Carbon content of aboveground mangrove forest biomass ((gC/100gDW) or % DW)

Component	%C	95% CI	Range	References
Leaves	45.0 (n = 35)	42.8, 47.3	42.3-50.9	Spain and Holt, 1980; Saenger, 2002; Alongi et al., 2003; 2004; Kristensen et al., 2008
Wood (stems + branches)	45.4 (n = 12)	43.1, 47.7	41.6-47.2	Spain and Holt, 1980; Gong and Ong, 1990; Twilley et al., 1992; Bouillon et al., 2007; Alongi et al., 2003, 2004

Table 4.4 Aboveground Biomass in Mangrove forests (tonnes DW. ha^{-1})

Domain	Region	Aboveground biomass	95%CI	Range
Tropical	Tropical Wet	196 (n=53)[1]	186, 205	3.7-557
	Tropical Dry	92 (n = 13)[2]	88, 97	3.2-201
Subtropical		75 (n= 10)[3]	76, 84	3.9-129

[1] References: Golley et al., 1975; Christensen, 1978; Ong et al., 1982; Putz and Chan, 1986; Tamai et al., 1986; Komiyama et al., 1987, 1988, 2000, 2008; Lin et al., 1990; Mall et al., 1991; Amarasinghe and Balasubramaniam, 1992; Kusmana et al., 1992; Slim et al., 1996; Fromard et al., 1998; Norhayati and Latiff, 2001; Poungparn, 2003; Sherman et al., 2003; Juliana and Nizam, 2004; Kirui et al., 2006; Kairo et al., 2008; Fatoyinbo et al. 2008; Camacho et al., 2011; Kauffman et al., 2011;Thant and Kanzaki, 2011.

[2] References: Golley et al, 1962; Briggs, 1977; Suzuki and Tagawa, 1983; Steinke et al., 1995; Alongi et al., 2003; Medeiros and Sampoia, 2008; Khan et al., 2009.

[3] References: Lugo and Snedaker, 1974; Woofroffe, 1985; Lee, 1990; Mackey, 1993; Tam et al., 1995; Saintilan, 1997; Ross et al., 2001; Coronado-Molina et al., 2004; Simard et al., 2006; Fatoyinbo et al., 2008; Komiyama et al., 2008; Abohassan et al., 2012.

Table 4.5 Aboveground biomass growth in mangrove forests (tonnes DW ha^{-1} yr^{-1})

Domain	Region	Aboveground biomass growth	95%CI	Range
Tropical	Tropical Wet	9.9 (n=23)[1]	9.4, 10.4	0.1-27.4
	Tropical Dry	3.3 (n = 6)[1]	3.1, 3.5	0.1-7.5
Subtropical		18.1 (n= 4)[1]	17.1, 19.1	5.3-29.1

[1] References: Ajonina 2008; Kairo et al., 2008; Alongi 2010

Table 4.6 Ratio of belowground biomass to aboveground biomass (R) in mangroves forests

Domain	Region	R	95%CI	Range
Tropical	Tropical Humid	0.49 (n=18)[1]	0.47, 0.51	0.04-1.1
	Tropical Dry	0.29 (n = 9)[2]	0.28, 0.30	0.09-0.79
Subtropical		0.96 (n= 18)[3]	0.91, 1.0	0.22-267

[1] References: Golley et al., 1975; Tamai et al., 1986; Komiyama et al., 1987, 1988; Gong and Ong, 1990; Lin and Lu 1990; Tam et al., 1995; Poungparn, 2003

[2] References: Golley et al, 1962; Alongi et al., 2003; Hoque et al., 2010.

[3] References: Briggs, 1977; Lin, 1989; Saintilan, 1997.

Table 4.7. Wood Density (D) of Common Mangrove Tree Species

Bruguiera gymnorrhiza	0.74	*Heritiera littoralis*	0.8
Xylocarpus mekongensis	0.72	*Heritiera fomes*	1.1
Xylocarpus granatum	0.7	*Excoecaria agallocha*	0.45
Sonneratia apetala	0.56	*Ceriops tagal*	1.1
Sonneratia alba	0.08	*Ceriops decandra*	0.96
Rhizophora mucronata	1.1	*Bruguiera gymnorrhiza*	0.86
Rhizophora mangle	0.83	*Avicennia officinalis*	0.67
Rhizophora apiculata	1.1	*Avicennia marina*	0.9
Laguncularia racemosa	0.6	*Avicennia germinans*	0.66
Site average of above values	0.77		

Data sources: Kauffman and Donato, 2012; Bosire et al., 2012.

Table 4.8 Aboveground and Belowground biomass for Tidal Marshes (tonnes C ha^{-1})

Salinity	Domain	Region	Above-ground biomass	95% CI	n	Below-ground biomass	95% CI	n
Oligohaline to polyhaline	Subtropical	Warm temperate moist[1]	1.40	1.35, 1.44	3	9.2	8.58, 9.80	2
		Warm temperate dry[2]	5.64	5.57, 5.71	11	11.02	10.89, 11.15	4
	Temperate[3]		3.32	3.30, 3.34	91	23.9	23.37, 24.32	34
	Polar[4]		0.64	0.62, 0.66	3	ND[6]		
Tidal freshwater	Temperate[5]		4.03	4.00, 4.07	20	7.11	6.94, 7.18	8

Sources:

[1] AG: da Cunha Lana et al. 1991; Kirby and Gosselink 1976; Darby and Turner 2008; BG: da Cunha Lana et al. 1991; Darby and Turner 2008

[2] AG: Curco et al. 2002; Neves et al. 2007; Scarton et al . 2002; Linthust and Reimold 1978; Cartaxana and Catarina 1997; BG: Neves et al. 2007; Scarton et al. 2002; also referred to as Mediterranean

[3] AG: Benito and Onaindia 1991; Bouchard and Lefeuvre 2000; Boyer et al. 2000; Connor and Chmura 2000; Figueroa et al. 1988; Gallagher and Plumley 1979; Groenendijk 1984; Gross et al. 1986; Hopkinson et al. 1978; Hussey and Long 1982; Jeffrey and Hayes 2005; Jeffries et al. 1981; Jenssen 1980; Keefe and Boynton 1973; Ketner 1972; Kirby and Gosselink 1976; Kistritz et al 1983; Linthust and Reimold 1978; Mahall and Park 1976; Mendelsohn and Marcellus 1976; Morris and Haskin 1990; Pierce 1983; Schubauer and Hopkinson 1984; Smith et al. 1979; Squires and Good 1974; Whigham et al.1978; White et al. 1978; Williams and Murdoch 1972; BG: Boyer et al. 2000; Connor and Chmura 2000; Dame and Kenny 1986; Dunn 1981; Elsey-Quirk et al. 2011; Groenendijk and Vink-Lievaart 1987; Gross et al. 1991; Hussey and Long 1982; Kistritz et al. 1983; Livingstone and Patriquin 1981; Mahall and Park 1976; Roman and Daiber 1984; Smith et al. 1979; Whigham et al.1978

[4] AG: Curco et al. 2002; Neves et al. 2007; Scarton et al. 2002; Linthust and Reimold 1978; Cartaxana and Catarina 1997; BG: Neves et al. 2007; Scarton et al. 2002

[5] Birch and Cooley 1982; Doumlele 1981; Hopkinson et al. 1978; Whigham et al.1978

[6] No data available

TABLE 4.9 ABOVEGROUND BIOMASS FOR SEAGRASS MEADOW

Domain	Aboveground biomass for seagrass meadow (tonnes DW ha^{-1})	95%CI	Range	n
Tropical[1]	6.0	6.20, 7.89	0.1 – 75.4	137
Subtropical[2]	15.2	14.17, 16.26	1.2 - 810	260
Temperate[3]	19.9	18.16, 21.77	4.3 - 206	108

[1] Aioi & Pollard 1993, Brouns 1985, Brouns 1987b, Brouns & Heijs 1986, Daby 2003, de Iongh et al. 1995, Devereux et al. 2011, Fourqurean et al. 2012, Heijs 1984, Hertbert 1986, Holmer et al. 2001, Ismail 1993, Kaldy & Dunton 2000, Lee 1997, Lindeboom & Sandee 1989, Long et al. 1993, McDermid & Edward 1999, McKenzie 1994, Mellors et al. 2002, Moriarty et al. 1990, Nienhuis et al. 1989, Ogden & Ogden 1982, Paynter et al. 2001, Poovachiranon & Chansang 1994, Povidisa & Delefosse 2009, Rasheed 1999, Terrados et al. 1998, Uku & Bjork 2005, van Lent et al. 1991, van Tussenbroek 1998, Vermaat et al. 1993, Vermaat et al. 1995, Williams 1987.

[2] Aioi 1980, Aioi et al. 1981, Asmus et al. 2000, Bandeira 1997, Bandeira 2002, Boon 1986, Bulthuis & Woelkerling 1983, Burd & Dunton 2001, Cabaco et al 2012, Calleja et al. 2005, Cambridge & Hocking 1997, Carruthers 1994, Collier et al. 2009, de Boer 2000, Dillon 1971, Dixon & Leverone 1995, Dos Santos et al. 2012, Dunton 1990, Dunton 1994, Dunton 1996, Fourqurean et al. 2012, Goshima & Peterson 2012, Heck & Thoman 1984, Heijs 1984, Herbert & Fourqurean 2009, Herbert & Fourqurean 2008, Hillman et al. 1995, Holmer & Kendrick 2012, Holmer et al. 2004, Iverson & Bittaker 1986, James et al. 2009, Kaldy & Dunton 2000, Kenworthy & Thayer 1984, Kerr & Strother 1989, Kim et al. 2012, Kirkman & Cook 1987, Kirkman & Reid 1980, Kirkman & Reid 1979, Kirkman et al. 1982, Kowalski et al. 2009, Kraemer & Alberte 1993, Larkum et al. 1984, Lee & Dunton 1996, Lee et al. 2005, Lewis 1987, Longstaff et al 2000, Marba & Walker 1999, Masini et al. 2001, McGlathery et al. 2012, mcMahan 1968, McMahon & Lavery 2008, Meling-Lopez & Ibarra-Obando 1999, Moncreiff et al. 1992, Morgan & Kitting 1984, Mukai et al. 1979, Murray and Wetzel 1987, Nienhuis & Bree 1980, Odum 1963, Orth & Moore 1986, Paling & McComb 2000, Park et al. 2011, Perez-Llorens & Niell 1993, Perez-Ruzafa et al. 2012, Phillips et al. 1983, Powell 1989, Preen 1995, Reyes et al. 1995, Schwarz et al. 2006, Stevensen 1988, Terrados & Ros 1992, Thayer et al. 1977, Tomasko & Lapointe 1991, Townsend & Fonseca 1998, van Houte-Howes et al. 2004, van Lent et al. 1991, van Tussenbroek 1998, Walker 1985, Walker & McComb 1988, Walker et al. 1988, West & Larkum 1979, Yarbro & Carlson 2008, Zavodnik et al. 1998, Zieman et al. 1989.

[3] Auby & Labourg 1996, Bay 1984, Cebrian et al. 1997, Cebrián et al. 2000, Dennison & Alberte 1985, Duarte et al. 2002, Fourqurean et al. 2012, Guidetti et al. 2002, Gullstrom et al. 2012, Hebert et al. 2007, Jacobs 1979, Kaldy 2006, Kentula & McIntire 1986, Larned 2003, Laugier et al. 1999, Lillebo et al. 2006, Mann 1972, Marba & Duarte 2001, Martin et al. 2005, McRoy 1974, Nienhuis & Bree 1980, Nixon & Oviatt 1972, Olesen 1999, Olesen & Sand-Jensen 1993, Olesen & Sand-Jensen 1994, Ott 2008, Pedersen & Borum 1993, Perez & Romero 1994, Plus et al. 2003, Rismondo et al. 1997, Robertson & Mann 1984, Robertson & Mann 1974, Roman & Able 1988, Sand-Jensen & Borum 1983, Sfriso & Ghetti 1998, Terrados et al. 2006, Vermaat & Verhagen 1996, Vermaat et al. 1987, Zavodnik et al. 1998.

TABLE 4.10 RATIO OF BELOWGROUND BIOMASS TO ABOVEGROUND BIOMASS (R) FOR SEAGRASS MEADOW

Domain	R	95%CI	Range	n
Tropical[1]	1.7[1]	1.62, 1.78	0.05 – 25.62	396
Subtropical[2]	2.4[2]	2.33, 2.54	0.07 – 16.8	391
Temperate[3]	1.3[3]	1.18, 1.39	0.14 – 13.8	91

[1] Aioi & Pollard 1993, Brouns 1985, Brouns 1987, Coles et al. 1993, Daby 2003, Devereux et al. 2011, Fourqurean et al. 2012, Halun et al. 2002, Holmer et al. 2001, Ismail 1993, Lee 1997, Lindeboom & Sandee 1989, McKenzie 1994, Mellors et al. 2002, Moriarty et al. 1990, Nienhuis et al. 1989, Ogden & Ogden 1982, Paynter et al 2001, Poovachiranon & Chansang 1994, Povidisa et al. 2009, Rasheed 1999, Udy et al. 1999, van Lent et al. 1991, van Tussenbroek 1998, Vermaat et al. 1993, Vermaat et al. 1995, Williams 1987.

[2] Aioi 1980, Aioi et al. 1981, Asmus et al. 2000, Bandeira 2002, Boon 1986, Brun et al 2009, Collier et al. 2009, de Boer 2000, Devereux et al. 2011, Dixon & Leverone 1995, Dos Santos et al. 2012, Dunton 1996, Fourqurean et al. 2012, Hackney 2003, Herbert and Fourqurean 2009, Herbert & Fourqurean 2008, Holmer & Kendrick 2012, Jensen & Bell 2001, Kim et al. 2012, Kirkman & Reid 1979, Kowalski et al. 2009, Larkum et al. 1984, Lee et al. 2005, Lee et al. 2005b, Lipkin 1979, Longstaff et al. 1999, Masini et al. 2001, McGlathery et al. 2012, mcMahan 1968, Meling-Lopez & Ibarra-Obando 1999, Mukai et al. 1979, Paling & McComb 2000, Park et al. 2011, Powell 1989, Preen 1995, Schwarz et al. 2006, Stevensen 1988, Townsend & Fonseca 1998, Udy & Dennison 1997, van Houte-Howes et al. 2004, van Lent et al. 1991, van Tussenbroek 1998, Walker 1985, West & Larkum 1979, Yarbro & Carlson 2008.

[3] Agostini et al. 2003, Cebrian et al. 2000, Fourqurean et al. 2012, Hebert et al. 2007, Holmer & Kendrick 2012, Larned 2003, Lebreton et al. 2009, Lillebo et al. 2006, Marba & Duarte 2001, McRoy 1974, Olesen & Sand-Jensen 1994, Rismondo et al. 1997, Sand-Jensen & Borum 1983, Terrados et al. 2006

Table 4.11 Carbon content of aboveground and belowground seagrass biomass ((gC/100gDW) or % DW)

Component	CF	95% CI	Range	References
Above ground biomass	33.4 (n = 72)	32.9, 33.9	23.6 – 43.8	Augier et al. 1982; Erftemeijer 1994; Fourqurean & Zieman 1992; Fourqurean et al. 1997; Fourqurean et al. 2007; Kenworthy & Thayer 1984; Longstaff & Dennison 1999; Mascaro et al. 2009; Mateo & Romero 1997; Nienhuis et al. 1989; Pergent et al. 1994; Plus et al. 2001; Rublee & Roman 1982; van Lent et al. 1991; Vinther & Holmer 2008; Wahbeh 1988.
Below ground biomass	32.3 (n = 50)	31.8, 32.9	24.7 – 42.1	Erftemeijer 1994; Kenworthy & Thayer 1984; Mascaro et al. 2009; Mateo & Romero 1997; Nienhuis et al. 1989; Plus et al. 2001; van Lent et al. 1991; Vinther & Holmer 2008; Wahbeh 1988.

4.2.1.5 UNCERTAINTY ASSESSMENT

This section considers source-specific uncertainties relevant to inventory estimates. Estimating country-specific and/or disaggregated values requires more accurate information on uncertainties than given below. Chapter 3, Volume 1 of the *2006 IPCC Guidelines* provides information on uncertainties associated with sample-based studies. The literature available on uncertainty estimates on emission factors and activity data is limited. Seagrass aboveground biomass averages values from species that have very different leaf characteristics, resulting in a wide range of values. In the case of mangrove aboveground biomass, a comparatively large number of forest sites are extant, but the range of values is very large due to inherent differences in species composition, forest age, tidal height, and soil fertility. These uncertainties may be minimized as much as possible using Tier 2 or Tier 3 methods which can incorporate or classify forests by factors other than climate domain.

Variability in tidal marsh biomass will be due to differences in dominant species and competition between species, as well as salinity of flood waters, frequency of tidal flooding and climate. The high biomass in Mediterranean climates is due to the frequent dominance of perennial shrubs. For all vegetation there can be considerable yearly variability in production of biomass and seasonal variability in standing biomass. The empirical data available is biased by the prevalence of data from temperate regions and North America - the tidal fresh marsh data comes almost entirely from the Atlantic coast of the United States. Also lacking are data from boreal and subtropical marshes.

EMISSION AND REMOVAL FACTORS

The major sources of uncertainty for all wetland types are dominant species-specific differences in carbon content and differences as a function of ecosystem age, species composition, intertidal location, and community structure. As indicated in Tables 4.3 to 4.11, coefficients of variation range from about 24-200%. To reduce uncertainty, countries are encouraged to develop country- or region specific biomass expansion factors and BCEFs that fit their conditions. In case country- or regional-specific values are unavailable, the sources of default parameters should be checked and their correspondence with species present and specific conditions of a country should be examined.

The causes of variation of annual increment of mangrove growth include climate, site growth conditions, and soil fertility. Artificially regenerated and managed stands are less variable than natural forests. The major ways to improve accuracy of estimates of these wetlands are by application of country-specific or regional estimates of growth stratified by the dominant species present. If the default values of growth increments are used, the uncertainty of estimates should be clearly indicated and documented.

Tier 3 approaches can use growth curves stratified by species, ecological zones, site productivity and management intensity. For example, similar approaches are routinely used for mangroves in timber supply planning models and this information can be incorporated into carbon accounting models (e.g., Kurz et al., 2002).

For mangroves, data on commercial fellings are relatively accurate, although they may be incomplete or biased due to illegal fellings and underreporting due to tax regulations. Traditional wood that is gathered and used directly, without being sold, is not likely to be included in any statistics. Countries must carefully consider these issues. The amount of wood removed from forests after storm breaks and pest outbreaks varies both in time and volume. No default data can be provided on these types of losses. The uncertainties associated with these losses can be estimated from the amount of damaged wood directly withdrawn from the forest or using data on damaged wood subsequently used for commercial and other purposes. If fuelwood gathering is treated separately from fellings, the relevant uncertainties might be high, due to high uncertainty associated with traditional gathering.

4.2.2 Dead Organic Matter

The dead organic matter (DOM) pool in coastal wetlands includes coarse woody debris, fine litter, and dead roots. Fine litter and dead wood are differentiated as fractions <10 cm and >10 cm diameter, respectively (Table 1.1, Chapter 1, Volume 4 of the *2006 IPCC Guidelines*). The dead roots less than 2 cm diameter are included in the soil pool and not considered within the DOM pool. This fraction of dead roots turns over rapidly with the assumption approximating steady state. DOM C stocks can vary depending on tidal inundation and frequency, as well as soil oxidation and vegetation cover. Fine litter can be exported with tidal activity while a larger fraction of senesced woody biomass is buried or decomposes *in-situ*. In wetlands, decomposition of DOM, especially wood and coarse woody debris, is slow and accumulates as soil organic matter. In estimating inputs, outputs or changes of DOM C stocks, careful consideration of pools should be made to avoid double-counting. Consistency in how these fractions are determined and reported is good practice to avoid double-counting. DOM pools under conditions of low soil oxidation-reduction potential that occur under saturated conditions can be large and when exposed to oxidation constitute large CO_2 emissions. Thus, DOM C stock changes should be considered for the activities as described above with changes in mangrove forest cover. This is a notable deviation from Tier 1 assumptions for Land Remaining in a Land-Use Category as laid out in the *2006 IPCC Guidelines* and is necessary as certain types of management activities have large impacts on CO_2 emissions and removals without resulting in a conversion to another IPCC land-use category.

General assumptions for estimating changes in the DOM pool can be differentiated between mangrove forest and primarily non-woody coastal wetland types including tidal marsh and seagrass meadow. At Tier 1, tidal marsh and seagrass meadow ecosystems are assumed to have relatively fast turnover of DOM and a steady-state assumption applies. However, extensive management activities that result in vegetation or soil disturbance in tidal marsh with perennial biomass could have large impacts on C emissions and removals. In Land remaining in a land-use category, management activities where changes in the DOM pool are likely to be significant include aquaculture, salt production, extraction, where the start of the activity results in loss of the DOM pool. Methodologies for mangrove forests are supplied for Tier 1 estimation for management activities include aquaculture, salt production, and extraction (Table 4.1). In these cases, DOM inputs may cease as extant vegetation is cleared and DOM outputs are the extant stock of DOM. For drainage, DOM inputs may be unchanged if there is no disturbance to the biomass pool and DOM outputs are equivalent to the stock of DOM at the start of the activity where all C is assumed oxidized at Tier 1. For the harvesting activity and all other activities that affect mangrove forests, generic equations provided in *2006 IPCC Guidelines* are directly applicable. For all management activities that occur in tidal marsh and seagrass meadow, the change in C stocks of DOM is assumed to be zero at Tier 1 (Table 4.12). If mangrove forest clearing is a significant activity, Tier 2 or 3 approaches should be used and the assumption of instantaneous oxidation of the DOM pool is not valid. Both changes in dead wood and litter should be reported and summed to obtain changes in total dead organic matter due to each activity as detailed in Table 4.12 below.

TABLE 4.12 MANAGEMENT ACTIVITIES, TIER 1 EQUATIONS AND DEFAULT EF FOR DEAD ORGANIC MATTER C POOL CHANGES

Activity	Ecosystem	Tier 1 Equation[1] and Default EF

Aquaculture ($\Delta C_{DOM\text{-}AQ}$), Salt Production ($\Delta C_{DOM\text{-}SP}$), Extraction ($\Delta C_{DOM\text{-}EXT}$)	Mangrove forest	**AQ, SP, EXT-D**[2]: At start of activity, apply Eq. 2.18 or 2.19; $DOM_{in} = 0$ and DOM_{out} = DOM oxidized upon disturbance; Table 4.13 **AQ, SP**: for abandonment phase, apply Eq. 2.18 and 2.20 or 2.19; Table 4.13 **AQ**: for use phase, $\Delta C = 0$
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	
Drainage ($\Delta C_{B\text{-}DR}$)	Mangrove forest	At start of activity, apply Eq. 2.18 and 2.20-2.22 or 2.19; DOM_{out} = DOM oxidized upon disturbance ; Table 4.13
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	
Harvesting of Aquatic Resources ($\Delta C_{DOM\text{-}HARV}$), Nutrient Enrichment ($\Delta C_{DOM\text{-}NUTR}$), Hydrologic/Sediment Diversion ($\Delta C_{DOM\text{-}DIV}$),Restoration ($\Delta C_{DOM\text{-}RES}$) & Creation ($\Delta C_{DOM\text{-}CRE}$), Other Activities ($\Delta C_{DOM\text{-}OTHER}$)	Mangrove forest	Apply Eq. 2.18 and 2.20 or 2.19; Table 4.13
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	
Note – [1]Equations in this section can be found in the 2006 IPCC Guidelines; [2]EXT-D = physical removal of DOM pool associated with Extraction activity; EXT-I is not considered as it is only considered to have potentially significant impacts on seagrass meadows		

4.2.2.1 CHOICE OF METHOD

Changes in DOM resulting from management activities that occur in mangrove forests are estimated at the Tier 1 level because they represent potentially large CO_2 emissions to or removals from the atmosphere. Conversions that result in loss of mangrove forest biomass or oxidation of soils can have large implications for CO_2 emissions and removals. For tidal marsh and seagrass meadow, the default assumption is that no changes in C stocks occur at the Tier 1 level of estimation. For significant management activities in mangrove forests and extensive management activities that impact DOM pools in tidal marshes with perennial biomass, Tier 2 and higher estimation methods should be used and these values reported. In these cases, stock changes should be disaggregated relative to climate, vegetation type and salinity where applicable.

TIER 1

Mangrove forest

At Tier 1, for Aquaculture, Salt Production, and Extraction activities, it is assumed that C in DOM stocks is lost as CO_2 emissions in the year of conversion and that no change in DOM C stocks occurs afterward. For these activities, apply either *Gain-Loss* or *Stock-Difference* methods, following Chapter 2, Eq. 2.18 or 2.19 from Volume 4, *2006 IPCC Guidelines.* If applying *Gail-Loss*, apply Eq. 2.18. If applying *Stock-Difference*, apply Eq. 2.19. However, at the start of the activity (construction phase, including extraction), instead of applying Eq. 2.20 to estimate DOM_{in} of Eq. 2.18, $DOM_{in} = 0$. For *Stock-Difference*, $DOM_{t2} = 0$. In years subsequent to the start of the activity, the Tier 1 assumption is no change in DOM stock.

Tidal marsh and Seagrass meadow

For all management activities, the Tier 1 assumption is no change in DOM stock.

TIERS 2 AND 3

Tier 2 methodologies also employ Equations 2.18 or 2.19. However, country-specific data are encouraged, especially where management activities are expected to have significant impacts on CO_2 emissions and removals. For instance, after a management activity that results in a significant change in aboveground biomass stocks, conversion of aboveground biomass to DOM as litter can be significant. Countries should use in such cases national estimates for litter stocks for mangrove forests and tidal marshes disaggregated by tidal regime, where applicable. Loss estimates of dead wood and litter exports due to tidal advection should also be considered (see Annex 1 regarding C exports). Tier 3 methods may further employ stratification by ecological zone or disturbance regime to reduce uncertainties. Field measurements can further inform and be used to validate model output at Tier 3. For mangroves, Tier 3 methodologies should employ empirical measurements of canopy litter fall and census of downed wood lying on the forest floor. This methodology should involve the establishment of replicate forest plots of at least 5 X 5 m area with monthly census taking of changes in wood and measurement of litter lying within 1 X 1 m traps placed below the canopy but above highest astronomical tide (see Saenger and Snedakar, 1993, for full description of these methods).

4.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

TIER 1

Mangrove forest

Countries using a Tier 1 method require data on the default dead wood and litter carbon stocks as defined in Table 4.13. For coastal wetlands that are identified as mangrove forests prior to when the activity took place and activities including aquaculture, salt production, extraction or hydrologic/sediment diversion occur, Tier 1 emission factors for DOM stocks should be used (Table 4.13). The Tier 1 assumption is that carbon stocks in litter and dead wood pools in all non-forested coastal wetlands and in coastal wetlands where activities including nutrient enrichment and harvesting of aquatic resources occur are zero.

Tidal marsh and Seagrass meadow

For all management activities, the Tier 1 emission factor for DOM stock change is zero.

TIER 2

The higher Tier methods described in Chapter 4 for Forest Land and Chapters 5 and 6 on Cropland and Grassland of Volume 4 of the *2006 IPCC Guidelines* will permit better estimates when national data are applied. Additional requirements may arise if the assumption that carbon stocks in dead wood or litter pools of tidal marsh are zero cannot be justified, such as where intensive management activities have occurred.

TIER 3

Tier 3 emission factors include model output and validation and disaggregated data sources.

TABLE 4.13 TIER 1 DEFAULT VALUES FOR LITTER AND DEAD WOOD CARBON STOCKS

Domain	**Ecosystem type**	**Litter carbon stocks of mature forests (tonnes C ha^{-1}) with 95% CI**	**Dead wood carbon stocks of mature forests (tonnes C ha^{-1}) with 95% CI**
Tropical/Subtropical	Mangrove forest	0.7 (0-1.3)	10.7 (6.5-14.8)

Source:

Litter: Utrera-Lopez and Moreno-Casasola 2008, Liao et al 1990, Chen et al 2008, Richards et al 2011, Ramose-Silva et al 2007, Twilley et al 1986

Dead Wood: Kauffman et al 2011, Donato et al 2012, Allen et al 2000, Steinke et al 1995, Robertson et al 1989, Tam et al 1995, Krauss et al 2005

4.2.2.3 CHOICE OF ACTIVITY DATA

Choice of activity data follows from guidance provided in the *2006 IPCC Guidelines* in the Forest Land chapter (p. 4.38). Also, refer to Section 4.2.1.3 for guidance relative to specific management activities.

4.2.2.4 CALCULATION STEPS FOR TIER 1

Calculations steps for Tier 1is presented in the *2006 IPCC Guidelines* and follows from guidance provided in the Forest Land chapter (p. 4.38).

4.2.2.5 UNCERTAINTY ASSESSMENT

Guidance on uncertainty assessment for dead organic matter pools is unchanged from the *2006 IPCC Guidelines* in the Forest Land chapter (p. 4.38). With specific regard to coastal wetlands, uncertainties follow from Tier 1 assumptions about tidal export of C as well as assumptions of only non-woody biomass in tidal marshes.

4.2.3 Soil Carbon

Activities that occur within coastal wetlands can influence organic and mineral stocks of C in soils. The methodological approach follows equation 4.1 which combines the emissions from the activities listed in Table 4.14. Current data on inorganic soil C are not sufficient to provide generic methodologies and so the methodological approach provided here only takes into account the possible emissions and removals associated with changes in organic C of organic and mineral soils.

Management activities that include extraction of saturated soils that are then deposited above the existing water table, or that lead to drainage due to lowering of the water table, result in enhanced soil oxidation. The management activities Aquaculture, Salt Production, Extraction and Drainage result in the most significant effects on the soil carbon pool. These management activities however do not necessarily result in a land-use category change and this consideration needs to be applied when reporting CO_2 emissions. Conversely, restoration or creation of coastal wetlands can result in increased net C accumulation and subsequently net removals of CO_2 from the atmosphere. These activities can also be significant.

Activities associated with either localised or extensive lowering of the water table are often associated with the construction of drainage channels leading to CO_2 fluxes due to oxidation of dissolved organic and particulate organic carbon in the water carried by drainage channels. However, there is currently not enough information to provide emission factors for C exports (see Future Methodological Development).

Table 4.14 Management Activities, Tier 1 Approaches and Tier 1 Equations for Soil Carbon Pool Changes

Activity	Ecosystem	Tier 1 Equation and Default EF
Aquaculture (ΔC_{SO-AQ}), Salt Production (ΔC_{SO-SP})	Mangrove forest	**AQ, SP:** Apply Eq. 4.2. EF in Tables 4.15-4.18, this section **SP**: only *construction* and *abandonment* phases are considered
	Tidal marsh	
	Seagrass meadow	**AQ**: Only *use* phase is considered. Apply Eq. 2.6[1]; Table 4.17, this section,
Extraction (ΔC_{SO-EXT})	Mangrove forest	**EXT-D:** $\Delta C_{SO-EXT} = A_{,e} * EF_{CONST,e} * P$ from Eq. 4.2. EF in Tables 4.15 & 4.16, this section
	Tidal marsh	
	Seagrass meadow	If **EXT-D**, $\Delta C_{SO-EXT} = A_{c,e} * EF_{CONST,e} * P$, Eq. 4.2, Table 4.17, this section; if **EXT-I** $\Delta C = 0$
Harvesting of Aquatic Resources ($\Delta C_{SO-HARV}$)	Mangrove forest	Apply Eq. 2.6[1]; Table 4.18, this section
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	
Nutrient Enrichment ($\Delta C_{SO-NUTR}$)	Mangrove forest	NA[2]
	Tidal marsh	
	Seagrass meadow	Apply Eq. 2.6[1]; Table 4.19, this section
Hydrologic/Sediment Diversion (ΔC_{SO-DIV})	Mangrove forest	$\Delta C = 0$
	Tidal marsh	
	Seagrass meadow	NA
Drainage (ΔC_{SO-DR})	Mangrove forest	Apply Eq. 4.3; Table 4.20, this section
	Tidal marsh	
	Seagrass meadow	NA
Restoration (ΔC_{SO-RES}) & Creation (ΔC_{SO-CRE})	Mangrove forest	Apply Eq. 4.4; Table 4.21, this section
	Tidal marsh	
	Seagrass meadow	
Other Activities ($\Delta C_{SO-OTHER}$)	Mangrove forest	Apply Eq. 2.6[1]
	Tidal marsh	
	Seagrass meadow	

Note [1]Volume 4 of the *2006 IPCC Guidelines*

[2]no available Tier 1 guidance

4.2.3.1 AQUACULTURE, SALT PRODUCTION AND EXTRACTION

In aquaculture and salt production, the activity is broken down into three phases — *construction, use* and *abandonment* — and emission factors are provided for each of these phases. Extraction effects can take two forms: 1) direct via on-site physical removal of soil (EXT-D) or 2) specifically in seagrass meadows, indirectly via effects of soil deposition and loss of water clarity (EXT-I)

Construction phase and Extraction

In excavation there is only one phase, which is equivalent to the *construction* phase of aquaculture and salt production. During the *construction* phase of shrimp or fish ponds, or for salt production in mangrove forest and tidal marsh ecosystems, soil is excavated to build containing berms within which water is held. Depending on the type of aquaculture (intensive, extensive etc.) and the species stocked in the ponds (shrimp, fish) the soils can be excavated to make ponds of 50 cm to 2.5 m depth (Cruz, 1997; Kungvankij et al. 1986; Wang 1990; Robertson and Phillips 1995). In a similar manner the depth of solar salterns varies between depths of about 0.5 to 2.5m (e.g. Ortiz-Milan 2006, Madkour & Gaballah 2012). Therefore at Tier 1, it is assumed that soil is excavated to 1 m depth and that this is appropriate for aquaculture and salt production in the *construction* phase, as well as extraction. It is assumed that the soil excavated at the year in which these activities start is instantaneously oxidized. Differentiation between organic and mineral soils should also be made when reporting on the *construction* phase of aquaculture and salt production activities and extraction in mangrove forests and tidal marshes. Available data suggest that only direct extraction will impact the soil C pool of seagrass meadows through physical disturbance. Aquaculture in seagrass meadows using fish cages and pens is known to be a significant activity in some coastal areas but requires no soil excavation.

Use phase

In the second or *use* phase of aquaculture and salt production, ponds, pens or cages are stocked or ponds maintained for salt production. In aquaculture, the *use* phase results in CO_2 emissions from nutrient enrichment of the soils due to feeding and growing of stock (Holmer et al. 2003; 2004). For aquaculture, there is currently not enough information to provide emission factors for the *use* phase in tidal marshes and it is assumed that the emission factor is the same as that for, *use*, in mangrove forests. Once aquaculture begins, it is assumed that emissions persist until the ponds (constructed in mangrove forests and tidal marshes) or cages (established in seagrass meadows) are abandoned. The average lifetime of a shrimp pond is variable depending on various factors (management, water quality, and sediment characteristics) and a viability of 7–15 years has been estimated, considering improved management (Flaherty and Karnjakesom 1995, Pa´ez-Osuna 2001). Thus an average lifetime of 10 years is assumed before the activity ends. During the *use* phase, no differentiation is made between organic and mineral soils. For salt production, there is currently not enough information to provide emission factors for the *use* phase.

Abandonment phase

The final phase of aquaculture and salt production is the *abandonment* of the ponds, pens, or cage. In aquaculture the ponds are usually abandoned due to disease or declining water quality (Stevenson et al 1999). During this phase, the area utilized for aquaculture or salt production is assumed to leave the soils in a saturated condition. For abandoned ponds maintained as saturated soils in mangrove forests the emissions are assumed to be the same as for forest clearance until which time vegetation reestablishment begins. On abandonment, the area utilized for aquaculture is generally left unchanged and the ponds can remain unproductive for decades, but sometimes restoration of the local hydrology eventually leads to revegetation. In the *abandonment* phase, solar salterns established in tidal marshes or fish pens and cages constructed in seagrass meadows, there is currently not enough information to provide emission factors for these ecosystem types.

For aquaculture and salt production, the total change in C stocks in organic and mineral soils is estimated using Equation 4.2 below, which combines emissions from soil organic matter decomposition during all phases. Direct extraction of soil (EXT-D) is applied as for the construction term. In seagrass meadows there is the indirect impact of extraction (EXT-I), which affects the soil C pools differently.

EQUATION 4.2

ANNUAL CHANGE IN SOIL C IN COASTAL WETLANDS WITH AQUACULTURE, SALT PRODUCTION ACTIVITIES IN THREE PHASES OF SUB-ACTIVITIES AND EXTRACTION

$$CO_{2\text{-}SO}a,e = \Sigma\, e(A_{CONSTR},e * P * EF_{CONSTR},e) + (A_{USE},e * EF_{USE},e) + (A_{ABAN},e * EF_{ABAN},e)]$$

where:

CO_{2SOe} = CO_2 emissions from either organic or mineral soils that are used in Aquaculture or Salt Production occurring in the three phases of *construction*, *use* and *abandonment* or during Extraction and ecosystem type(e) (mangrove forest, tidal marsh and seagrass meadow), unit = tonnes C yr^{-1}

A_e = Total area under aquaculture and salt production activities during the *construction, use and abandonment* phases (for mangrove forests or tidal marshes), during *use* phase (for seagrass meadows) or during extraction (for mangrove forests, tidal marshes or seagrass meadows) by ecosystem type (e) as specified, unit = ha

$EF_{CONSTRe}$ = CO_2 emissions from either organic or mineral soils that are excavated for aquaculture or salt production during the *construction* phase (for mangrove forests or tidal marshes) or during extraction (for mangrove forests, tidal marshes or seagrass meadows) by ecosystem type (e) as specified, unit = tonnes C ha^{-1}

P = fraction of area excavated for aquaculture or salt production during the *construction* phase. The same value of P is used during the subsequent phases of *use* and *abandonment*. Tier 1 assumes P=1 for aquaculture or Salt Production, or during *use* phase (for seagrass meadows), dimensionless.

EF_{USEe} = CO_2 emissions from aquaculture or salt ponds in mangrove forests and tidal marshes or covered by aquaculture cages or pens in seagrass meadows by ecosystem type (e) as specified, unit = tonnes C ha^{-1} yr^{-1}

EF_{ABANDe} = CO_2 emissions from saturated soils after abandonment of aquaculture or salt production practices in mangrove forests as specified, unit = tonnes C ha^{-1} yr^{-1}

a = activity (aquaculture, salt production; extraction method is based on equation provided)

e = ecosystem type (specified ecosystem in which the activity has potentially significant impacts in mangrove forest, tidal marsh, or seagrass meadow)

CHOICE OF METHOD - ORGANIC AND MINERAL SOILS

Tier 1

Mangroves and Tidal Marsh

The method for estimating changes in soil carbon for Tier 1 uses Equation 4.2 for CO_2 emissions from organic and mineral soils. For Tier 1, extraction (EXT-D) is applied in the case of physical removal and CO_2 emissions are reported for either or both ecosystems where this activity occurs. For salt production, emissions are only reported for *construction* (mangrove forest and tidal marsh; Tables 4.15 & 4.16)) and *abandonment* (mangrove; Table 4.18). For aquaculture, CO_2 emissions in mangroves and tidal marshes are reported for all three phases, *construction*, *use* and *abandonment* following Equation 4.2. Data pertaining to CO_2 emissions from abandoned aquaculture ponds on tidal marshes were not found and so the Tier 1 CO_2 emissions are assumed to be zero. It is assumed that after 10 years the emissions associated with aquaculture *use* cease as the practise is abandoned.

At Tier 1, the area affected during use and abandonment must remain the same as that during the construction phase and it is assumed that the entire area is affected (P=1).

Seagrass Meadow

For Tier 1, if extraction (direct extraction, EXT-D) is an important management activity, CO_2 emissions are reported. For Tier 1 indirect effects of extraction (EXT-I), the default assumption is that no changes in C stocks occur. For significant aquaculture activities in seagrass meadows, emissions are only reported for the *use* phase. It is assumed that after 10 years the emissions associated with aquaculture *use* cease as the practise is abandoned (Holmer et al., 2003).

Tier 2

During the phases of *construction*, *use*, and *abandonment* of aquaculture and salt ponds or aquaculture cages and pens, the area in which the activities primarily occur may be better approximated as a proportion of the total area identified for Tier 1 estimation. That is, higher Tier methods may define the area of the activity as the area of soil actually excavated to construct the pond or covered by fish pens (i.e. P<1). For significant activities, Tier 2 and higher estimation methods should be used and these values reported. In these cases emissions should be separated relative to climate, ecological zone and salinity where applicable.

At Tier 2 countries should use national data on their particular aquaculture practices to include more specific information on, depth of pond excavated during the construction phase and determine how type of stock and feeding regime during the *use* phase affect CO_2 emissions and removals. Disaggregation of mineral and organic soils during *abandonment*, and consideration of more appropriate differentiation with respect to salinity and climate regime are some higher Tier improvements. For salt production, a Tier 2 level method requires more specific information on depth of pond excavated. For extraction the method countries should use national data to determine their particular extraction processes and the volume of soil removed as well as taking into account the fate of the excavated soil.

Tier 3

Tier 3 methods can employ models to estimate CO_2 emissions based on the whether the practise involves extensive or intensive farming techniques, the species farmed, stocking density and feeding regime, all of which affect CO_2 emissions during *use* and likely *abandonment* phases. The effect of temperature and salinity on benthic metabolism both seasonally and with climate and ecological zone should also be included. Tier 3 methods using models should be validated with field measurements. In salt production, the CO_2 emissions and removals associated with the use phase would be improved by providing data to quantify these fluxes and how the magnitude of the fluxes vary with the salt pond management practices.

CHOICE OF EMISSION FACTORS - ORGANIC AND MINERAL SOILS

Tier 1

Mangrove forest, Tidal Marsh and Seagrass Meadow

Default Tier 1 emission factors for aquaculture, salt production and extraction in organic and mineral soils are given in Tables 4.54-4.18 and where appropriate, for each phase of the activity, as well as ecosystems affected. These values should be used in conjunction with Equation 4.2 to estimate emissions. Land area must remain the same through all three processes.

TABLE 4.15 EMISSION FACTORS (EF) ASSOCIATED WITH CONSTRUCTION (EF_{CONSTR}) OF AQUACULTURE (AQ), SALT PRODUCTION (SP) AND EXTRACTION (EXT) ON ORGANIC SOILS (TONNES C HA^{-1}) AT START OF ACTIVITY

Ecosystem	EF_{CONSTR}	95% CI	range	n
Mangrove forests	471[1]	454, 490	216 – 727.1	43
Tidal marsh	340[2]	328, 352	221 – 579	35
Seagrass meadow	NA			

[1] Adame et al. (2012), Breithaupt et al. 2012, Chmura et al. 2003, Donato et al. 2011, Kauffman et al. 2011, Osborne et al. 2011, Vegas-Vilarrúbia et al. 2010 .

[2] Anisfeld et al. 1999, Callaway et al. 1996, Callaway et al. 2012, Chmura & Hung 2004, Craft et al. 1988, Craft 2007, Hussein et al. 2004, Kearney & Stevenson 1991, Orson et al. 1998, Markewich et al. 1998, McCaffrey & Thomson 1980.

TABLE 4.16 EMISSION FACTORS (EF) ASSOCIATED WITH CONSTRUCTION (EF_{CONSTR}) OF AQUACULTURE (AQ), SALT PRODUCTION (SP) AND EXTRACTION (EXT) ON MINERAL SOILS (TONNES C HA^{-1}) AT START OF ACTIVITY

Ecosystem	EF_{CONSTR}	95% CI	range	n
Mangrove forests	286[1]	266, 306	80 - 1376	77
Tidal marshes	226[2]	214, 239	15.6 – 623	82
Seagrass meadow[3]	140[4]		9.1 – 829	89

[1] Donato et al. 2011, Chmura et al. 2003, Breithaupt et al. 2012, Fujimoto et al. 1999, Adame et al. 2012, Perry & Mendelssohn 2009, Ren et al. 2010, Kauffman et al. 2011, Ray et al. 2011, Zhang et al. 2012, Khan et al. 2007, Matsui 1998.

[2] Cahoon et al. 1996, Callaway et al. 2012, Chmura & Hung 2004, Connor et al. 2001, Craft et al. 1988, Craft 2007, Hatton 1981, Kearney & Stevenson 1991, Livesley & Andrusiak 2012, Loomis & Craft 2010, Morris & Jensen 2003, Oenema & DeLaune 1988, Patrick & DeLaune 1990, Roman et al. 1997, Yu & Chmura 2009.

[3] For EXTRACTION (EXT) only; [4] Fourqurean et al 2012

TABLE 4.17 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH USE (EF_{USE}) OF AQUACULTURE (AQ) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1})

Ecosystem	EF_{USE}	95% CI	range	n
Mangrove forests and Tidal marshes	2.2[1,2]	1.7, 2.7	0.34-5.9	15
Seagrass meadow	9.5[3]	7.8, 11.6	1.4-28.8	22

[1] Alongi 1999b, Alongi et al. 2004, Blackburn et al. 1988, Lovelock et al. 2011;

[2] It is assumed that EF for tidal marsh is the same as that for mangrove forests.

[3] Holmer et al. 2003, Holmer et al. 2005, Heilskov & Holmer 2001

TABLE 4.18 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH ABANDONMENT AFTER AQUACULTURE (AQ) OR SALT PRODUCTION (SP) UNDER SATURATED CONDITIONS (EF_{ABAN-S}) ON ORGANIC AND MINERAL SOILS AND HARVESTING OF AQUATIC RESOURCES (EF_{HARV}) IN MANGROVE FORESTS (TONNES C HA^{-1} YR^{-1})

Ecosystem	EF_{ABAN-S}/EF_{HARV}	95% CI	Range	N
Mangrove forests	1.8[1]	0.9, 3.5	0.40 – 7.9	4

[1] Alongi et al. (1998), Lovelock et al. (2011), Cahoon et al. (2003). Data from forest clearance assumed to be the same as Aquaculture during the *abandonment* phase.

Tier 2

Tier 2 could include the use of country specific emission factors for each ecosystem that take into account local climatic factors. For fish and shrimp ponds, the actual area excavated ($P<1$) and depth to which soil is excavated, should be taken into account as this varies with aquaculture and salt production practices. During the phase, *use*, and the phase*, abandonment* in mangrove forests, the EF could be disaggregated to provide separate values for organic and mineral soils. Furthermore, country-specific data would include emission factors for tidal marshes and seagrass meadows in the *abandonment* phase.

Tier 3

A Tier 3 approach could use models that take into account the time-dependent nature of the CO_2 fluxes over a range of timescales. For example, during the construction phase a pulse of CO_2 efflux from soil directly after mangrove clearing and prior to excavation, followed by a logarithmic decline in CO_2 fluxes over time should be considered.

4.2.3.2 HARVESTING OF AQUATIC RESOURCES

Guidance on annual change in soil carbon stocks on coastal wetlands managed for resource harvest is provided only in the case of deforestation or complete clearing of aboveground biomass in mangrove forests. These emissions result in net CO_2 flux to the water or atmosphere as there are assumed to be no C inputs to soil once aboveground biomass has been removed. It is assumed that mangrove wood harvesting does not affect the height of the water table and that the soils remain saturated.

Selective logging in mangrove forests, harvesting of vegetation in tidal marshes or shellfish in seagrass meadows, are likely to have a low impact on carbon soil stocks and so the Tier 1 C stock change is assumed to be zero. If any of these activities contribute to emissions that represent a key category, then Tier 2 or Tier 3 estimation methodologies are recommended.

CHOICE OF METHOD & EMISSION/REMOVAL FACTORS

Tier 1

Mangrove forest

Default Tier 1 emission factor for harvesting of mangrove wood, resulting in forest clearance, is presented in Table 4.17. For harvesting of aquatic resources, the methodology follows Eq.4.2, however only the *abandonment* term is reported.

Tier 2

Tier 2 methods for wood harvesting may take into consideration the species of mangrove being felled and determination of country specific emission factors to disaggregate between organic and mineral soils. It may be possible to disaggregate emission factors for tree clearance and selective logging. At Tier 2, country and ecosystem specific emission factors may be also used to reflect the regional importance of harvesting specific resources.

Tier 3

A Tier 3 approach requires a comprehensive understanding of the processes that lead to CO_2 emissions and removals and the factors that drive these fluxes. The Tier 3 approach will involve country-specific models and/or measurement-based approaches along with disaggregated land-use data to incorporate information on the type of resources being harvested, the nature of the disruption to the soil, tidal regime, and local salinity. Tier 3 modelling would include country-specific emission factors derived or modelled from measurement data encompassing different resource harvesting and the physical methods deployed. The models should capture variation in emission rates driven by soil disruption, seasonal changes in precipitation and temperature and tidal influence.

4.2.3.3 NUTRIENT ENRICHMENT

Guidance on annual change in emissions associated with nutrient enrichment is provided only in the case of mangrove forests and seagrass meadows. Note that data for tidal marshes is insufficient to generate an emission factor for nutrient enrichment and so it is assumed that the emission factor is the same as reported for mangrove forests.

CHOICE OF METHOD AND EMISSION FACTOR

Tier 1

Mineral and organic soils have been aggregated for default Tier 1 emission factors for Nutrient Enrichment in seagrass meadows and are presented in Table 4.19. The emissions should be quantified by applying Eq. 2.6, Vol. 4 and be used in conjunction with equation 4.2.

TABLE 4.19 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH NUTRIENT ENRICHMENT (EF_{NUTR}) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1})

	EF_{NUTR}	95% CI	Range	N
Seagrass Meadow	3.5[1]	2.7, 4.5	1.9 - 7.2	5

[1] Holmer et al. 2005, Heilskov et al. 2008; No data available for tidal marshes.

Tier 2 and 3

A Tier 2 approach will involve country-specific emission factors and may take into consideration the source of the nutrient enrichment and their regional importance. Disaggregation of mineral and organic soils should be considered. A Tier 3 approach will use measurement-based approaches along with disaggregated land-use data to incorporate data on variable rates that will better capture variation in emission rates associated nutrient application or discharge rate as well as factors that include consideration of diel fluctuations in temperature, tidal regime, and salinity. If this activity contributes to emissions that contribute to a category that is key, then Tier 2 or Tier 3 estimation methodologies are recommended. If nutrient enrichment is a significant activity constituting managed coastal wetlands in tidal marshes and mangrove forests, Tier 2 or 3 estimation methodologies are also recommended.

4.2.3.4 HYDROLOGIC/SEDIMENT DIVERSION

Annual change in carbon stocks on coastal wetland managed for hydrologic and sediment diversion can occur in mangrove and tidal marsh. The Tier 1 emission factors for soils in all ecosystems as a result of coastal subsidence are also considered to be zero. If this activity contributes to emissions that contribute to a category that is key, then Tier 2 or Tier 3 estimation methodologies are recommended.

4.2.3.5 DRAINAGE

Emissions from drained coastal wetland soils are estimated at Tier 1 for mangrove forests and tidal marshes because they represent potentially large CO_2 emissions to the atmosphere. Annual C losses from both drained mineral and organic soils in mangrove forests and tidal marshes are aggregated at Tier 1 level of estimation using Equation 4.3.

EQUATION 4.3

ANNUAL CHANGE IN CARBON STOCKS IN DRAINED ORGANIC AND MINERAL SOILS

$$CO_{2DR} = \sum_{,e} (A_{,e} \bullet EF_e . F_{PD})$$

where:

CO_{2DR} = CO_2 emissions from organic or mineral soil C through drainage, units = tonnes C yr^{-1}

A = land area under drainage, units = ha

$EF_{DR,e}$ = CO_2 emissions from organic or mineral soil C through drainage ecosystem type (e), units = tonnes C ha^{-1} yr^{-1}

F_{PD} = fraction of area that is partially drained. Tier 1 assumes F_{PD}=1

TABLE 4.20 ANNUAL EMISSION FACTORS (EF) ASSOCIATED DRAINAGE (EF_{DR}) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1})

Ecosystem	**EF_{DR}**	**95% CI**	**Range**	**N**
Mangrove forests and tidal marshes	7.9[1,2]	6.5, 9.6	1.2 – 43.9	22

[1] Camporese et al. (2008), Deverel & Leighton (2010), Hatala et al. (2012), Howe et al. (2009), Rojstaczer & Deverel (1993).

[2] Based on aggregated data from tidal marshes and mangrove forests.

CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

Tier 1 – Organic and Mineral Soils

Mangrove forest and Tidal Marsh

The default Tier 1 assumption for drainage is that organic C is lost linearly over time until the stock is fully oxidised to CO_2, further drainage is initiated, or a new land use has started. Our default assumption is that the water table has been changed to 1 m below the soil surface for organic and mineral soils. If drainage does not result in a land-use change, the inventory compiler is referred to the aggregated emission factor for drained organic and mineral soils in tidal marshes and mangrove forests as reported in Table 4.20.

If drainage results in conversion to a new Land Use category, the inventory compiler is referred to Section 4.3 of this Chapter It is important under these reporting conditions to retain information about the conversion so that wetlands guidance can be applied if a reversal of drainage conditions occurs.

Tier 2 and Tier 3

The Tier 2 approach should incorporate country specific data on emission for soils disaggregated for mineral and organic soils. Higher Tier methods could take account of differences in the management of the drained coastal wetland, drainage and the fraction of area that is partially drained (F_{PD}) should be determined.

4.2.3.6 RESTORATION AND CREATION

Rewetting saturates the soil, which can lead to colonization by new wetland vegetation, that is, the subsequent natural re-establishment of original vegetation type in mangrove or tidal marsh ecosystems. Alternatively, rewetting of the soil can be followed by active replanting that restores the original vegetation type. In seagrass meadows, soils remain saturated and it is the water quality that must reach a satisfactory level before re-establishment of vegetation or its restoration. The original ecosystem can be either re-established naturally, or by manual replanting. Under these conditions, where vegetation becomes re-established, ecosystem restoration or creation is assumed to occur. Creation occurs where coastal wetlands cannot be verified to have previously occurred but likely occurred given the proximity of the land to the coastal margin. Rehabiliation, a form of creation where the re-establishment of any vegetation type results in soil C sequestration upon maturation (defined as 20 year since establishment).

Guidance for inventories of rewetting and restoration of coastal wetland ecosystems follows several general simplifying assumptions at Tier 1 level of estimation of CO_2 emissions from soil:

1. upon rewetting of previously drained soil, or re-establishment of water quality, creation of biomass by purposeful planting or restoration of biomass is initiated. During this 20 year transient period it is assumed that soil emissions and removals are insignificant, so that rewetting of coastal wetlands results in a Tier 1 EF = 0
2. after the 20 year transient period, restoration results in a change to a coastal wetland ecosystem supporting growth of mangrove, tidal marsh or seagrass biomass, which can then accumulate soil C whereby a Tier 1 soil EF_{RES} is applied. At this time it is assumed that soil C accumulation rates are functionally equivalent to the natural system net soil C accumulation (flux) and the Tier 1 EF_{RES} is applied (Table 4.20) with the same EF applied regardless of soil type (Craft et al 2003, McGlathery et al 2012, Osland et al 2012).

If the re-establishment of functioning vegetation is demonstrated to be unsuccessful during rewetting an, EF=0 is applied for a further 20 year period or until creation or restoration of biomass occurs. For creation it is assumed that once the site has been purposefully planted the EF=0 for soil for a 20 year transient period, by which time functionally equivalent soil C accumulation rates are assumed to occur and EF_{CRE} can be applied. Therefore EF_{RES} is the same as EF_{CRE}

EQUATION 4.4 ANNUAL CHANGE IN SOIL C IN RESTORED AND CREATED COASTAL WETLANDS

$$CO_{2SO\text{-}RESe} = (A_{RESe} * EF_{RESe}) \qquad CO_{2SO\text{-}CREe} = (A_{CREe} * EF_{CREe})$$

where,

$CO_{2SO\text{-}RESe}$ = CO_2 emissions associated with rewetted, improved water quality and restored coastal wetlands by ecosystem type (mangrove, tidal marsh and seagrass meadow), units = tonnes C yr^{-1}

$CO_{2SO\text{-}CREe}$ = CO_2 emissions associated with rewetted improved water quality and created coastal wetlands by ecosystem type (mangrove, tidal marsh and seagrass meadow), units = tonnes C yr^{-1}

A_{RESe} = Area of soil that has been modified by rewetting, improved water quality and/or restoration, by ecosystem type (e), units = ha

EF_{RESe} = CO_2 emissions from mineral and organic soils that have been modified by restoration, by ecosystem type (e), units = tonnes C ha^{-1} yr^{-1}

A_{CREe} = Area of soil that has been modified by rewetting and/or creation, by ecosystem type (e), units = ha

EF_{CREe} = CO_2 emissions from mineral and organic soils after creation by ecosystem type (e), units = tonnes C ha^{-1} yr^{-1}

This method can be applied for lands with either mineral or organic soils. At Tier 1, organic and mineral soils are not differentiated and land area estimates should be based on vegetation classification within the new land category to apply Tier 1 EFs.

CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

Tier 1

Mangrove, Tidal Marsh and Seagrass Meadow

Changes in soil carbon resulting from management activities that occur during rewetting and restoration or creation are estimated at Tier 1 level because they represent potentially large C removals from the atmosphere. During the transitional, rewetting period, the soil EF=0 regardless of the vegetation that is present. An EF=0 is applied until 20 years after vegetation re-establishment. The land can be assumed restored with functioning vegetation unless the definition of a classified vegetation type (as determined by country land classification system) is not met. Once the land enters the new land category, the EF in Table 4.21 can be applied. EF values should be used in conjunction with Equation 4.4 to estimate emissions.

TABLE 4.21 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH RESTORATION OR CREATION ($EF_{RES/CRE}$) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1}) AFTER 20 YEARS OF VEGETATION REESTABLISHMENT

Ecosystem	$EF_{RES/CRE}$	95% CI		range	n
Mangrove	1.62[1]	0.73	3.63	0.10 – 10.2	69
Tidal marsh	0.91[2]	0.82	1.02	0.05 – 4.65	66
Seagrass meadow	0.43[3]	0.28	0.67	0.09 – 1.12	6

[1] Breithaupt et al. 2012, Chmura et al. 2003, Fujimoto et al. 1999, Ren et al. 2010.

[2] Anisfeld et al 1999, Cahoon et al. 1996, Callaway et al 1996, Callaway et al 1997, Callaway et al 1998, Callaway et al 1999, Callaway et al. 2012, Chmura & Hung 2003, Hatton 1981, Craft 2007, Kearney & Stevenson 1991, Markewich et al. 1998, Oenema & DeLaune 1988, Orson et al 1998, Patrick & DeLaune 1990, Roman et al 1997.

[3] Mateo & Romero 1997, Serrano et al. 2012.

Tier 2 and 3

For key categories, Tier 2 and higher estimation methods should be used and these values reported. Soil types, organic and mineral, should be disaggregated in order to apply suitable country-specific factors. Country-specific emission factors applied during the rewetting of the lands and the transition period should be used under Tier 2 methods, and the inventory compilers are encouraged to estimate the transient time from rewetted to restored wetlands. Under the tier 3 method, the land use prior to rewetting, climate and vegetation type should be taken into account. A comprehensive understanding and representation of the dynamics CO_2 gas emission factors, based on field measurement is involved in Tier 3. A Tier 3 approach would also use models that take into account the time-dependent nature of the CO_2 fluxes over a range of timescales and the effects of sea-level rise on soil C sequestration rates (Morris et al., 2012) or other dynamics (Craft 2001).

4.2.3.7 OTHER ACTIVITIES

This category is retained to draw attention to the fact that all significant activities may not be covered in this guidance. It is good practice to consider other activities which may, based on national circumstances, have significant C emissions or removals associated with that management activity. A generic method is provided in Table 4.13.

4.2.3.8 CHOICE OF ACTIVITY DATA

See guidance provided in Section 4.2.1.3.

4.2.3.9 CALCULATION STEPS FOR TIER 1

The following summarizes steps for estimating change in carbon stocks in soils for Land Remaining in a Land-use Category where managed coastal wetlands occur.

Step 1: Organize data into inventory time periods based on the years in which activity data were collected (e.g., 1990 and 1995, 1995 and 2000, etc.).

Step 2: Determine the area of coastal wetland in the last year of the inventory time period.

Step 3: Determine the activities to be included in the assessment and their representative areas. Area data should be obtained using the methods described in Chapter 3 of the *2006 IPCC Guidelines*.

Step 4: Determine the activity categories by stratifying representative areas into soil type and previous coastal wetland vegetation type.

Step 5: For each activity category, assign the appropriate emission factor (EF) for annual losses of CO_2.

Step 6: Estimate total emissions by summing the product area (A) multiplied by the emission factor (EF) for all activity categories.

Step 7: Repeat for additional inventory periods.

Example: The following example shows the calculations for aggregate areas of soil carbon change in coastal wetlands. There is a 1Mha area of coastal wetlands. At the beginning of the inventory time period (1990 in this example) the total area of coastal wetlands was 500,000 ha. From this total 200,000 ha was identified as unmanaged and 300,000 ha was actively managed. The individual areas relevant to activities included in the inventory are; 50,000 ha of area under aquaculture with organic soils in previous mangrove forest (with 50%) under *construction* and 50% under *use*); 10,000 ha of area under aquaculture with mineral soils in previous tidal marsh (with 90% under *use* and 10% *abandoned*); 50,000 ha of area under fish cages in seagrass meadows (100% under *use*); 100,000 ha of area under salt production with mineral soils in previous tidal marsh (with 100% under *construction*); and 90,000 ha of area under hydrologic diversion. The CO2 emissions for the inventory time period are calculated as (50,000 ha • 0.5 • 471 tonnes C ha^{-1}) + (50,000 ha • 0.5 • 2.2 tonnes C ha^{-1}) + (10,000 ha • 0.9 • 2.2 tonnes C ha^{-1}) + (10,000 ha • 0.1 • 7.9 tonnes C ha^{-1}) + (50,000 ha • 9.5 tonnes C ha^{-1}) + (100,000 ha • 340 tonnes C ha^{-1}) + (90,000 ha • 0 tonnes C ha^{-1}) = 46,332,700 tonnes C for 1990. Repeat for additional inventory periods.

4.2.3.10 UNCERTAINTY ASSESSMENT

Few studies have addressed the questions of emission factors specifically and few reports are available to give specifics of activities which we expect to vary geographically. Thus, derivation of emission factors was based upon expert knowledge and application of data from reports of biomass and production of vegetation, the amount of carbon is living biomass and the amount of carbon held in soils, and how easily it is decomposed. There is uncertainty in the time, depth of soil affected, the rate of CO_2 loss from dead vegetation and soils and the C gained during wetland creation or restoration.

4.2.4 Non-CO_2 emissions

This section provides methods for estimating the emissions of N_2O and CH_4 from coastal wetlands under different management activities.

N_2O is an intermediate product of both nitrification (oxidation of ammonium by nitrifying microbes under oxic or aerobic conditions) and denitrification (reduction of nitrite and nitrate by denitrifying microbes under anoxic conditions). The flux of N_2O thus is controlled by oxygen availability and tidal influence, but also by the availability of N substrates (Purvaja and Ramesh, 2001; Kreuzwieser et al., 2003; van den Heuvel et al., 2009, Moseman-Valtierra et al. 2011). Therefore, management activities that change hydrology or N availability in sediment, e.g. N management or rewetting of wetlands, could lead to changes in N_2O emissions from coastal wetlands.

In reduced and anoxic environments microbial decomposition of the organic matter may produce CH_4. However, flooding seawater contains sulfate and microbial reduction of sulfate to sulfide will generally occur before methanogens produce CH_4. A strong inverse relationship between CH_4 emission and salinity of mangrove soils was reported by Purvaja and Ramesh (2001) and later work by Poffenbarger et al. (2011) showed that polyhaline tidal marshes (salinity >18) had significantly lower CH_4 emissions than oligohaline (salinity 0.5-5) and mesohaline (salinity 5-18) marshes. The depth distribution of methanogenesis in tidal marsh soils is closely related to the methanogenic substrate utilization (Parkes et al. 2012).

Aquaculture has been shown to lead to changes in N_2O emissions from coastal wetlands. Shrimp and fish cultivation increases nutrients loads in culture ponds. The body of research is growing, and sufficient for developing emission factors for non-CO_2 emissions from this activity but is relatively limited. Coastal wetlands subject to intensive carbon and nutrient loading may also be sources of CH_4 emissions, however, only when salinity <18 are present. In aquaculture, anaerobic conditions are not appropriate for maximized fish production and are therefore assumed negligible, however, they may increase over time.

If soil conditions prior to rewetting were aerobic, then it is likely that CH_4 emissions will increase where tidal water salinities are <18 ppt. If tidal waters rewetting coastal wetlands are carbon- or nutrient-enriched, then wetlands with salinities >18 ppt also are likely to be sources of CH_4 emissions. One of the main controlling factors in N_2O production is the availability of inorganic N in the soil. If, prior to rewetting, the area of coastal wetland was subject to increased N supply (e.g. in fertilized land) it may be a source of N_2O emissions during the rewetting. However, experimental studies have shown that the substrate N is rapidly depleted (Moseman-Valtierra et al. 2011), thus N_2O is likely to be negligible after the N is depleted and no continuous N is supplied.

N_2O emissions from managed terrestrial soils are covered in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*, which estimates N_2O emissions due to N additions to soils (e.g. synthetic or organic fertilizers, deposited manure, crop residues, sewage sludge), or of mineralization of N in soil organic matter following management of organic soils or cultivation on mineral soils (e.g., Forest Land/Grassland/Settlements converted to Cropland). For organic soils, these emission factors have been updated for these specific land uses and can be found in Chapter 2 of this Supplement Table 4.21 presents the equations and emission factors for managed coastal wetland. The most significant activities contributing to non-CO_2 emissions from managed coastal wetlands are Aquaculture and specific cases of nutrient enrichment, such as aquaculture effluent (indirect N_2O emissions from aquaculture use) for which there are available data Non-CO_2 emissions are assumed equal to zero except in the cases of Aquaculture effects on N_2O emissions and nutrient enrichment effects on CH_4 emissions caused by aquaculture and agricultural run-off in coastal wetlands.

TABLE 4.22 ACTIVITIES AND TIER 1 ASSUMPTIONS FOR NON-CO_2 EMISSIONS FOR THE ECOSYSTEMS AFFECTED

Activity	Ecosystem	Non-CO_2 gas/sub-activity	Tier 1 Equation
Aquaculture (EF_{AQ})[1]	Mangrove	CH_4: EF=0	NA
		N_2O: EF=based on fish production or N fed or nutrient-enriched EF	Apply Eq. 4.5; Table 4.23
	Tidal Marsh	CH_4: EF=0	NA
		N_2O: EF=based on fish production or N fed	Apply Eq. 4.5; Table 4.23
	Seagrass Meadow	CH_4: EF=0 N_2O: EF=0	NA
Salt Production (EF_{SP}), Extraction (EF_{EXT}), Hydrologic/Sediment Diversion (EF_{DIV}), Harvesting of Aquatic Resources (EF_{HARV}), Drainage (EF_{DR})	Mangrove	CH_4: EF=0 N_2O: EF=0	NA
	Tidal Marsh	CH_4: EF=0 N_2O: EF=0	
	Seagrass Meadow	NA	
Nutrient Enrichment (EF_{NUTR})	Mangrove	CH_4: EF=nutrient-enriched wetland (agricultural run-off including aquaculture effluent)	Apply Eq. 2.6[2]; table 4.24, this section
		N_2O: Run-off from terrestrial soil N application	Chapter 11[2]
		N_2O: Enrichment from aquaculture effluent	Apply Eq. 2.6[2]; table 4.25, this section

	Tidal Marsh	CH_4: EF=nutrient-enriched wetland (agricultural run-off including aquaculture effluent)	Apply Eq. 2.6[2]; table 4.24, this section
		N_2O: Run-off from terrestrial soil N application	Chapter 11[2]
		N_2O: Enrichment from aquaculture effluent	Apply Eq. 2.6[2]; table 4.25, this section
	Seagrass Meadow	CH_4: EF=0	NA
		N_2O: Run-off from terrestrial soil N application	Chapter 11[2]
		N_2O: Enrichment from aquaculture effluent	NA
Restoration (EF_{RES}) and Creation (EF_{CRE})	Mangrove	CH_4: EF=unmanaged wetland N_2O: EF=0	Apply Eq. 2.6[2]; table 4.26, this section
	Tidal Marsh	CH_4: EF=unmanaged wetland N_2O: EF=0	
	Seagrass Meadow	NA	NA
Other Activities (EF_{OTHER})	Mangrove	NA	NA
	Tidal Marsh		
	Seagrass Meadow		

Note

[1] for aquaculture, only the *use* phase is considered; EF for phases of *construction* and *abandonment* are assumed negligible

[2] Volume 4 of the *2006 IPCC Guidelines*

4.2.4.1 AQUACULTURE

CHOICE OF METHOD AND EMISSION FACTORS

Seitzinger et al. (2000) estimated that one-third of global anthropogenic N_2O emissions are from aquatic ecosystems, but there has been limited research aimed at quantifying the contribution of aquaculture to the global budget. N_2O is emitted from aquaculture systems as a by-product of the conversion of ammonia (contained in fish urea) to nitrate through nitrification and nitrate to N_2 gas through denitrification (Hu et al. 2012). Hu et al. (2012) estimates that 1.8% of the nitrogen fed to aquaculture systems is emitted as N_2O , and that 1.7 g N_2O-N is emitted per kg fish produced in an aquaculture system. These are applied only during the *use* phase of aquaculture. In the *construction* and *abandonment* phases, non-CO_2 emissions are assumed negligible and EF=0.

Tier 1

Methane

The Tier 1 method estimates the CH_4 emissions from aquaculture ponds are assumed negligible and reported as 0.

Nitrous Oxide

N_2O emissions from aquaculture ponds can be estimated based on fish production or the amount of N feed in the aquaculture activity. The default Emission Factors for these two methods are provided in Table 4.23. The emission estimation follows a modified form of Eq. 11.1 from Chapter 11, Volume 4 of the *2006 IPCC Guidelines* and is presented here in (Eq. 4.5).

EQUATION 4.5
DIRECT N_2O EMISSIONS FROM AQUACULTURE USE

$$N_2O\text{-}N_{AQ} = F_F * EF_F \text{ OR } F_I * EF_I$$

Where:

$N_2O\text{-}N_{AQ}$ = annual direct N_2O-N emissions from Aquaculture use, kg N_2O-N yr^{-1}

F_F = annual fish production, kg fish yr^{-1}

EF_F = emissions factor for N_2O emissions from fish produced, kg N_2O-N (kg fish produced)$^{-1}$

F_I = annual N amount of fish feed applied

EF_I = emission factor for N_2O emissions from N of fish feed applied, kg N_2O-N (kg N fed)$^{-1}$

Table 4.23 Emission factors for N_2O emission from aquaculture in coastal wetlands

Wetland	**Default EF**	**Uncertainty Range**	**Reference**
Aquaculture	0.003 kg N_2O per kg fish produced per yr		Hu et al. 2012
	0.028 kg N_2O per kg N fed per yr		

Tiers 2 and 3

Under Tier 2 method, country specific emission factors for these two gases need to be applied. N_2O emissions from aquaculture ponds could also be estimated using the country specific emission rate from the water if such data is available. In terms of CH_4, Tier 2 or 3 methods could include change in CH4 emissions with extended use, based on age of the pond and intensity of use. A comprehensive understanding and representation of the dynamics based on direct field measurements or models is involved under Tier 3 method, which estimates emission factors considering the category of aquaculture (fish species or feed stuff), aquaculture use intensity, and impact of environmental factors e.g. climate zone, season, and salinity.

4.2.4.2 SALT PRODUCTION, EXTRACTION, HYDROLOGIC/SEDIMENT DIVERSION, HARVESTING OF AQUATIC RESOURCES, DRAINAGE

As was noted in Table 4.22, CH_4 and N_2O emissions from the management activities of salt production, extraction, hydrologic/sediment diversion and harvesting of aquatic resources are assumed to be zero. However, under higher Tiers, emissions associated with these activities should be reported using country-specific data.

As was noted in Table 4.22, CH_4 and N_2O emissions from the management activities of drainage are assumed to be zero. However, if drainage is a significant activity within the Land Use category under which it is reported, it is good practice to apply Tier 2 and 3 estimation levels following generic methodologies (Eq. 2.6, *2006 IPCC Guidelines*) and using country-specific data.

4.2.4.3 NUTRIENT ENRICHMENT

CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

Methane and Nitrous Oxide - Mangrove and Tidal Marshes

Tier 1

For the Tier 1 method, the default emission factors are given in Tables 4.24 and 4.25. The default method to estimate non-CO_2 gas emissions from coastal wetlands is to multiply wetland area by the gas emission rates. For nutrient enrichment from agricultural run-off in the coastal zone, only CH_4 emissions are reported. N_2O emissions for this activity are covered in Chapter 11 of the *2006 IPCC Guidelines*. For nutrient enrichment from aquaculture effluent coming from aquaculture production both CH_4 and N_2O emissions are reported as there is currently no guidance in *2006 IPCC Guidelines* on non-CO_2 emissions from this impact of aquaculture activities. Data were not available on impact of aquaculture effluent on seagrass meadows.

Calculation of CH_4 emissions follows the same method applied in the case of agricultural run-off to the coastal zone and aquaculture effluent within the coastal zone (Table 4.24). For calculation of N_2O emissions associated with agricultural run-off from terrestrial sources that comes from either direct or indirect N application to terrestrial soils the inventory compiler is referred to Chapter 11 of the *2006 IPCC Guidelines*. The following assumption is applied under Tier 1 estimation: vegetation of coastal wetlands is not a source of non-CO_2 gases and the emission factor represents only fluxes directly from the soil to atmosphere.

A second method for estimating indirect N_2O emissions from nutrient enrichment resulting from aquaculture effluent uses a modified form of Eq. 11.9 and 11.10 for effluent effects from aquaculture. The leaching factor can be applied and the EF from estuaries following this method. This method is recommended when absence of data on land area impacted by aquaculture effluent prevents use of that approach (see Chapter 11, Volume 4 of the *2006 IPCC Guidelines*).

TABLE 4.24 EMISSION FACTORS FOR CH_4 EMISSIONS FROM NUTRIENT ENRICHMENT (AGRICULTURAL RUN-OFF AND AQUACULTURE EFFLUENT) (TONNES CH_4 HA^{-1} YR^{-1})

Ecosystem	EF	95% CI	range	n
Mangrove forest and Tidal marsh (oligohaline - polyhaline)	1.13[1]	0.68, 1.18	0.015 – 27.83	18

[1] Mukhopadhyay et al. 2002, Kreuzwieser et al., 2003, Alongi et al., 2005, Biswas et al., 2007, Chauhan et al., 2008, Krithika et al., 2008, Liikanen et al., 2009, Allen et al., 2010, Chen et al., 2010, Tong et al., 2010, Adams et al., 2011.

TABLE 4.25 EMISSIONS FACTORS FOR N_2O EMISSIONS FROM NUTRIENT ENRICHMENT (AQUACULTURE EFFLUENT) (KG N_2O HA^{-1} YR^{-1})

Ecosystem	EF	95% CI	range	n
Mangrove forest and Tidal marsh (oligohaline - polyhaline)	3.7[1]	0.19, 5.4	-4.6 – 66.3	17

[1] Corredor et al., 1999, Bauza et al., 2002, Kreuzwieser et al., 2003, Alongi et al., 2005,, Krithika et al., 2008, Liikanen et al., 2009, Chen et al., 2010, Adams et al., 2011, Allen et al., 2011, Chen et al., 2012.

Tier 2 and 3

Tier 2 methods are used where countries have their country-specific emission factors and substantial national data. The Tier 2 method allows the inventory complier to adjust the assumptions applied to the Tier 1 method. It is a good practice to use the representative data of climate zones and vegetation type from published literature, e.g. papers, reports and books, and estimate the non-CO_2 gases emissions from wetland plants, where applicable.

Tier 3 methods involve a comprehensive understanding and representation of the dynamics of non-CO_2 gas emission factors, taking account parameters such as salinity, season, N load, tidal elevation and tidal cycle (high tide vs. low tide). Field research should be carefully carried out at representative sites for empirical gas fluxes. Countries are encouraged to setup their own methodology or modelling exercises based on the N input rates for estimation of emission factors.

4.2.4.4 RESTORATION AND CREATION

The degree of water saturation is a key factor controlling CH_4 and N_2O emissions. Rewetting of coastal wetland soils shifts microbial decomposition from aerobic to anaerobic conditions, increasing the potential for CH_4

emissions. If water used to rewet coastal wetlands increases N supplies through ground water or tidal water, a new source of N_2O emissions is possible.

Guidance for inventories of rewetting and restoration or creation of coastal wetlands follows several general simplifying assumptions at Tier 1 level of estimation.

(i) The default assumption is that water introduced for rewetting, by whatever means, is ambient water free of excess nutrients.

(ii) Once rewetting occurs, the EF equals 0 for N_2O during a 20 year transition period is the default transition period unless the re-establishment of functioning vegetation is demonstrated to be unsuccessful.

(iii) Once rewetting occurs, the EF for CH_4 in Table 4.27 should be applied during a 20 year transition period.

(iv) After the 20 year transition period which begins with the reestablishment of vegetation, the EF remains the same for both N_2O and CH_4 while the land continues to be subject to the management activity of restored or created, regardless of the land-use category that is applied.

In the case of rewetting of lands that had been previously been in agricultural (or any other drained) land-use or category, for example, the prior land use is not considered at Tier 1 as any increase in emissions from rewetting has not only been shown to be a transient effect and data are insufficient to assign an EF to capture this effect. The water quality should be reevaluated to determine whether the EF for nutrient-enriched wetlands should continue to be applied. If water applied in the rewetting activity is enriched in nutrients and the restoration activity contributes to a land-use category or pool that is key, Tier 2 and 3 methods should be applied.

CHOICE OF METHOD AND EMISSION FACTORS

Tier 1

Mangrove and Tidal Marsh

The Tier 1 method in this section estimates the non-CO_2 emissions without considering the land use prior to rewetting. The Tier 1 default assumption is that the lands are rewetted with uncontaminated water. Thus, the emission factor for $N_2O = 0$ and for CH_4, emission factors are found in Table 4.26. For mangrove forests, the EF for CH_4 is zero. Default Tier 1 emission factors for rewetting and restoration or creation of coastal wetlands with organic and mineral soils are given in Table 4.21. These values should be used in conjunction with equation 4.2 to estimate emissions and take into account the ambient soil salinity and vegetation type. For tidal marshes, the CH_4 EF is based on salinity (which is controlled by factors such as proximity to ocean water, the supply of freshwater through precipitation and fluvial inputs, and evapotranspiration).

TABLE 4.26 EMISSION FACTORS FOR CH_4 FROM UNMANAGED COASTAL WETLANDS FOR TIER 1 ESTIMATION OF REWETTING AND RESTORATION

Wetland Type	Salinity type	Salinity (ppt)	Default EF (tonnes CH_4-C ha^{-1} y^{-1})	EF Range (tonnes CH_4-C ha^{-1} y^{-1})	Error (95%CI)	Reference
Tidal Marsh	Tidal fresh	0.5-5	1.12	0.03-4.04	±80%	Poffenbarger et al. 2011[1]
	Oligohaline/ Mesohaline	5-18	0.28	0.02-0.24		Poffenbarger et al. 2011[1]
	Polyhaline (>18ppt)	>18	0	0-0.04	±90%	Poffenbarger et al 2011[1]
Mangrove	Saline	>18	0		±90%	Page and Dal 2010

Note [1]Review paper

Tier 2 and Tier 3

Country-specific emission factors applied during the rewetting of the lands and the transition period should be used under Tier 2 methods, and the inventory compilers are encouraged to estimate the EF for the land during the transition to the new land category for the rewetted lands. Under the tier 3 method, the land use prior to rewetting, climate and vegetation type should be taken into account. A comprehensive understanding and representation of the dynamics of non-CO_2 gas emission factors, based on field measurement, is involved in Tier 3. Tier 2 could include the use of country specific emission factors for each ecosystem that take into account local climatic factors, salinity, and species composition of the vegetation. The quality of the water should also be considered in the case of seagrass restoration.

In the case of rewetting of lands that had been previously been in agricultural (or any other drained) land-use or category, for example, the prior land use is not considered at Tier 1 because data are insufficient to assign an EF to capture this transient effect. The emissions of N_2O and CH_4 are considered to also depend on the nutrient/organic matter available in the tidal water. The water quality should be reevaluated to determine whether the EF for nutrient-enriched wetlands should continue to be applied. If water applied in the rewetting activity is enriched in nutrients and the restoration activity contributes to a land-use category or pool that is key, Tier 2 and 3 methods should be applied.

Tier 2 and 3 should also consider the effect of vegetation as plants can act as conduit for gas exchange between the soil and atmosphere.

4.2.4.5 CHOICE OF ACTIVITY DATA

Aquaculture ponds

For aquaculture, this is the fish production, the amount of feed, and amount of N in feed. These data can be obtained from FAO (http://www.fao.org/fishery/statistics/global-aquaculture-production/en). To estimate non-CO_2 gas emissions from aquaculture activities, the area under cultivation must be determined either by on-site measurement or from aerial photographs. Also required is the rate of nitrogen input as feed, which can usually be obtained from the pond operator, and the sediment type beneath the cages or at the bottom of the pond. For additional guidance, see Section 4.2.1.3

Nutrient enrichment

To estimate CH_4 emissions, the area receiving agricultural runoff must be determined by visual inspection of the maximum ingress of tidal waters within the wetland. For Tier 2 and 3 methods, the rate of N input should be determined although this may be very difficult and may involve knowledge of the tidal prism and N concentrations in the waters in question. For nutrient enrichment, this is the area of nutrient--affected land. We can expect to find nutrient-affected systems downstream of major urban centers, municipal sewage treatment facilities, and watersheds where a large portion of the land is under intensive agricultural use. For additional guidance, see Section 4.2.1.3.

Restoration/Creation

To estimate non-CO_2 gas emissions, the area restored, created and/or rewetted must be determined by visual inspection of pre- and post-impact stages. The type of wetland and the salinity regime must be measured. For additional guidance, see Section 4.2.1.3.

4.2.4.6 UNCERTAINTY ASSESSMENT

There have been few empirical measurements upon which to base emission factors and the factors identified for incorporation in Tier 2 and 3 will reflect variability. Uncertainties in non-CO_2 emissions associated with aquaculture can be reduced greatly by better estimation of fish production, quality of N in feed, area of ponds relative to total area under aquaculture use. For additional guidance, see Section 4.2.1.3.

4.3 CONVERSION FROM A LAND USE CATEGORY THAT INCLUDES COASTAL WETLANDS

This section references methodology provided in Section 4.2 to estimate impacts of soil drainage, extraction or other activity when lands are classified under a land-use category other than Wetland. Examples of when classification of land into a different land-use category may occur are given in Box 4.1. In these cases, the inventory compiler is directed to the guidance in those chapters of Volume 4 of the *2006 IPCC Guidelines* (Chapter 5-Croplands, Chapter 8-Settlements) but applying the assumptions and default EFs provided here.

4.3.1 CO_2 emissions and removals

4.3.1.1 BIOMASS, DOM AND SOIL CARBON

Permanent drainage under agriculture use or conversion to Settlements are cases in which a land-use conversion may be considered to have occurred. For biomass and DOM, see sections 4.2.1 and 4.2.2 unless land is converted to lands with dry soils in which case follow guidance in *2006 IPCC Guidelines* (following flow chart provided in Chapter 1). For soil carbon, refer to Chapter 2, this supplement for drained organic soils and the respective Chapters in the *2006 IPCC Guidelines* for land use conversion to lands with mineral soil. Regardless of how the land is classified, supplementary guidance provided in this Chapter should be followed where management activities where coastal wetlands are involved.

4.3.2 Non-CO_2 emissions

This section provides guidelines for estimating non-CO_2 gas emissions from coastal wetlands, especially mangroves and tidal marshes being drained for conversion to other dry land uses. The land use following coastal wetland drainage (e.g., agriculture, settlement, forestry), will have a major impact on emissions of non-CO_2 greenhouse gases from soils. Refer to the respective chapter depending on end Land Use in the *2006 IPCC Guidelines*. For guidance on drainage of organic soils and conversion to another IPCC Land-use category, refer to the guidance provided in Chapter 2, this supplement.

4.4 CONVERSION TO A LAND USE CATEGORY THAT INCLUDES COASTAL WETLANDS

4.4.1 CO_2 emissions and removals

This section includes management activities that result in rewetting and restoration or creation of coastal wetland ecosystems and subsequent classification as Wetland. Land that is exposed to rewetting can previously have sustained mangroves or tidal marshes, but the previous land-use is characterised by (A) unsaturated soils due to sediment infill to a height above the water table, (B) drainage of the original ecosystem, (C) construction of dikes or levees that prevent tidal flooding, or (D) emplacement of culverts that restrict flow of tidal waters.

Methods for biomass and DOM pools follow guidance provided in Sections 4.2.1 and 4.2.2. Non-CO_2 emissions are covered in section 4.4.4 and follow a similar approach with EFs for rewetting applied during the transitional land-use and EFs for restoration or creation applied when functioning vegetation has become re-established. For example, an aquaculture facility that is classified as Settlement or Cropland and restored to Wetlands would involve a change in IPCC land use category.

Guidance for inventories of rewetting and restoration of coastal wetland ecosystems follows similar general simplifying assumptions at Tier 1 level of estimation of C emissions from soil (as presented in Section 4.2.3): 1) upon rewetting, EF=0 for a 20 year *transition* period (as opposed to *transient* period in the case of Land Remaining in a Land-use Category). The default transition period is 20 years unless the re-establishment of functioning vegetation is demonstrated to be unsuccessful, 2) after conversion to the new (restored or created coastal) land use category, a new EF is applied. The new EF is equivalent to the natural system net soil C accumulation (flux). Regardless of the land category, reestablishment of functioning vegetation is assumed to occur after a 20 year transition period (in the case of a land-use change to Wetlands) and a new EF is applied for soils (Table 4.21) following general guidance in Section 4.2.3.

4.4.2 Non-CO_2 emissions

This section provides guidelines for estimating non-CO_2 gas emissions from coastal wetlands, especially mangroves and tidal marshes, undergoing management activities that result in rewetting and restoration or creation of coastal wetland ecosystems. These activities will have a major impact on emissions of non-CO_2 greenhouse gases from soils. Apply methods and default EF provided in section 4.2.4.5.

4.5 COMPLETENESS, TIMES SERIES CONSISTENCY, QUALITY ASSURANCE AND QUALITY CONTROL

4.5.1 Completeness

Completeness is a requirement for greenhouse gas inventories, and it is *good practice* to address all wetland carbon gain and losses. For completeness, it is *good practice* to include all carbon pools and non-CO_2 gases. The wetland area used for calculation for different carbon pools must be the same, and emissions from organic and mineral soils on mineral soils should be estimated. Country-specific information should be incorporated into higher tier methodologies. A complete accounting of emissions and removals of CO_2 associated with for Land Remaining in a Land-use category, Land Converted to another Land-use category in which the land that is converted is a coastal wetland, and Conversion to a Land-Use category that includes coastal wetlands regardless of how it is classified. It is *good practice* that all losses from biomass carbon pools that result in transfers to dead organic matter pools are first accounted for as changes to biomass carbon stocks.

4.5.2 Developing a consistent time series

It is good practice to develop a consistent time series of inventories of anthropogenic emissions and removals of greenhouse gases using the guidance in Chapter 7 in this volume. Achieving time series data may require extrapolation or interpolation from longer time series data or from long term trends, as few long-term data are available for most coastal wetlands.

Consistent accounting over time of wetland areas included in biomass and soil C emissions and removals inventory requires that activity data be stratified by the common definitions of wetland type/ soil type. Wetlands subject to land-use change must not be lost or double-counted due to accounting errors resulting from inconsistent stratification of wetland types/ soil types. Ideally, the same protocol should be applied consistently every year in the time series, at the same level of disaggregation and where country-specific data are used, it is *good practice* to use the same values and methods for equivalent calculations throughout the time series.

New values should be included if the inventory capacity and information and data sources improve over time. It is *good practice* in these circumstances to consistently recalculate the earlier emissions and removals. Other changes during the time series need to be consistent to take account of new data or methods and their consistency with the earlier data. It is *good practice* to recalculate the entire time series of data if the default values are changed; changes in wetland types need to be tracked for long periods of time.

It is *good practice* to use the same model parameter values for the entire time series and to recalculate the entire dataset if one of more of the parameters has changed. Failure to do so may result in either under-or over-estimates of the true changes in carbon and non-CO_2 gas emissions or removals.

4.5.3 Quality assurance and quality control

Different levels of precision and accuracy, and as a result, bias will invariably apply to a number of the values used to assess greenhouse gas inventories. Estimates are influenced by the quality and consistency of data and information available as well as knowledge gaps, all of which will vary among countries. Depending on the tier level used, estimates will be affected by different sources and degrees of error, such as sampling error.

It is *good practice* to execute quality control checks through Quality Assurance (QA) and Quality Control (QC) procedures as detailed in Chapter 7, and review the emission estimation procedures by experts. Additional quality control checks as outlined in Chapter 7 and quality assurance procedures may also be applicable. This is especially so if higher tier methods are used. It is *good practice* to supplement the general QA/QC related to data processing, handling, and reporting and documenting, with source-specific procedures. QA/QC procedures should be documented separately for Land Remaining in a Land-use category, Land Converted to another Land-use category in which the land that is converted is a coastal wetland, and Conversion to a Land-Use category that includes coastal wetlands regardless of how it is classified.

Organizations and institutions which collect the data are responsible for reviewing data collection methods and all aspects of the data handling and analysis procedures, and ensure that they are done correctly, and are complete and consistent over time. It is important to document all procedures and processes as it enables reviewers to identify inaccuracy, gaps and to suggest improvements. Transparency is most important in other to ensure consistency and clarity of the processes and procedures over time.

All data should be checked against other reliable sources of information that are independent. Any differences or discrepancies must be documented, and consistency must be applied to total areas involved in the inventory to ensure that wetland area are neither 'created' or 'lost' overtime. When using country-specific data, the inventory compiler should compare these data to the IPCC default values or the Emissions Factor Database (EFDB) and detail any differences. These country-specific data must be of high quality, adequately described, and documented.

If factors are based on direct measurements (i.e., soil C content) the inventory agency should review the measurements to ensure that they are representative of the actual range of environmental conditions. It is *good practice* to review and, if necessary, revise the default assumptions and to compare model estimates with field measurements and other data sources.

4.5.4 Reporting and documentation

General requirements for reporting and documentation are set out in Chapter 7. It is *good practice* to archive and document all data and information applied to produce the national emissions/removals inventory. Definitions of all carbon pools should be included in the inventory, including evidence that these definitions have been applied consistently over time.

Documentation is necessary for demonstrating transparency, completeness, consistency of all data and methods for interpolating between samples, methods and years, and for recalculating and avoidance of possible double accounting or 'loss' of C inventory. Regardless of Tier methodology used, explanations are required for decisions regarding choice of methodology, approaches and use of default or other data. This is necessary to facilitate examination by independent third parties; inventories should include summaries of approaches and methods used and references to data sources so that the reported emissions estimates are transparent and can be retraced or recalculated.

All data sources, including default values, must be quoted. The scientific basis for any country-specific data and methods must be completely described and justified, as well as describing sources and magnitudes of uncertainty. This is especially so for any large-scale estimates as in these cases the statistical procedures should be described and well as the level of uncertainty.

Differences between years in emissions should be explained and the possible reasons for these differences documented as much as possible.

4.6 FUTURE METHODOLOGICAL DEVELOPMENT

4.6.1 C export

The amount of dissolved and particulate carbon potentially available for export is highly variable among coastal wetlands, depending on a large number of factors such as: net primary productivity, tidal range, the ratio of wetland to watershed area, lateral trapping of tidal water, the presence of high salinity plugs in the tropical dry season, total wetland area, frequency of storms, amount of precipitation, and volume of water exchange Each ecosystem is unique; some wetlands export DOC but import POC, others import DOC and POC but export DIC, while other systems import or export all forms of dissolved and particulate carbon. The direction of net exchange also usually varies within the same estuary with change in season.

Accurate estimation of tidal exchange in a particular wetland is not a straightforward process. Many workers have provided rough estimates by multiplying carbon concentrations suspended in wetland creeks and waterways by the tidal range multiplied by the creek/waterway cross-sectional area. Estimates derived from such simple calculations are invalid and misleading for a number of reasons, including the inherent assumption that there are differences in carbon concentrations between ebb and flood tide stages and that the tidal prism is symmetrical. In fact, carbon concentrations in many wetland waters do not show significant differences between tides. Further, tides in most wetlands are asymmetrical, characterized by a pronounced asymmetry between ebb and flood tides with the ebb most often being of shorter duration but with stronger current velocity than the flood tide. Also, tidal velocities vary across a waterway with faster surface current velocities mid-stream than those just above the creekbed or proximal to the wetland.

For these reasons, it is not possible to make simple generalizations regarding total carbon export from mangroves, seagrasses or tidal marshes and, in fact, comparatively few such measurements have been made properly. The correct method would be to measure water volume and velocity over entire tidal cycles over several seasons in relation to position in the water-column to derive an overall annual estimate of average water flow by volume. This involves fairly complex instrument measurements and sophisticated mathematical modelling as well as extensive and expensive repetitive measurements of dissolved and particulate carbon concentrations. For mangroves, net exchange of carbon has been properly measured in only twelve systems, with no clear exchange patterns among locations, although it does appear that most mangroves export POC as litter but with rates ranging widely from 0.1-27.7mol C $m^{-2}yr^{-1}$(Alongi, 2009). This export equates globally to only about 10% of total carbon fixed by trees; respiration to the atmosphere is by far the largest loss of C to the atmosphere. Such appears to be the case for tidal marshes (Chmura et al., 1993) and subtidal seagrass beds (Fourqurean et al., 2012)

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ANNEX 4.1 PERCENT REFRACTORY CARBON

Percent refractory carbon in organic/mineral soils were estimated for mangrove soils based on either the amount of phenolic compounds/lignins in soils or % TOC in mangrove soils deeper than 1 m if there was no further decline in TOC concentration (Table 4.3).

PERCENT REFRACTORY CARBON APPLIED TO ESTIMATE % C OXIDATION FOR MANGROVE SOILS (% BY SOIL DRY WEIGHT)	
Mean	3.98
Median	3.4
N	16
Prasad & Ramanathan 2009; Marchand et al. 2003;Dittmar & Lara 2001; Koch et al.2011; Ranjan et al.,2010; Marchand et al. 2005), which is similar to that in tidal marshes (Filipet al. 1988; Alberts et al., 1988; Ramesh et al. 2008)	

ANNEX 4.2 ADDITIONAL SOURCES FOR ACTIVITY DATA

The following web sources provide links to domestic and international data sources pertaining to coastal wetland areas and other activity data for management activities contained in this chapter. Other web sources are provided in the text of the chapter in the respective activity data sections. Resources providing recent trends in coastal wetland area can help countries understand circumstances of those trends and what management activities contribute to them (FAO 2007; Green and Short 2003 http://archive.org/stream/worldatlasofseag03gree#page/n5/mode/2up; Sifleet et al. 2011, http://nicholasinstitute.duke.edu/publications/; Fatoyinbo & Simard 2013)

Mangroves

Mangrove.org: http://mangrove.org/

Mangrove Action Project: http://www.mangroveactionproject.org/

Mangrove, National Geographic Magazine: http://ngm.nationalgeographic.com/2007/02/mangroves/warne-text

FAO Mangrove Management: http://www.fao.org/forestry/mangrove/en/

USGS National Wetlands Research Center: http://www.nwrc.usgs.gov/index.html

World Atlas of Mangrove: http://www.fao.org/forestry/20067/en/

World Distribution of Coral Reefs and Mangroves: http://www.unep-wcmc.org/marine/data/coral_mangrove/marine.maps.main.html

International Society for Mangrove Ecosystems: http://www.mangrove.or.jp/

Global Mangrove Database & Information System: http://www.glomis.com/

The UNESCO Mangrove Programme: http://www.unesco.org/csi/intro/mangrove.htm

Mangrove and the Ramsar Convention: http://www.ramsar.org/types_mangroves.htm

USGS Global Mangrove Project http://lca.usgs.gov/lca/globalmangrove/index.php

Mangroves, tidal marshes and seagrass meadows

http://data.unep-wcmc.org/

Global distribution of seagrasses (V2.0, 2005) prepared by UNEP World Conservation Monitoring Centre (UNEP-WCMC) in collaboration with Dr. Frederick T. Short.

Global distribution of Mangroves (V3.0, 1997) compiled by UNEP World Conservation Monitoring Centre (UNEP-WCMC) in collaboration with the International Society for Mangrove Ecosystems (ISME).

ANNEX 4.3 ACCURATE ESTIMATION OF ABOVEGROUND MANGROVE BIOMASS: HIGHER TIER METHODOLOGY

Because of field conditions and heavy weight of wood, an accurate survey of a mangrove forest is difficult and time-consuming. Allometric methods (Soares and Schaeffer-Novelli, 2005; Komiyama et al., 2008) estimate the whole or partial weight of a tree from measurable tree dimensions, notably trunk diameter and height, using allometric relations developed from empirical measurement of weight of individual tree components (leaves, branches, stem). Use of allometric equations is favored because it is non-destructive and is therefore useful for estimating temporal changes in forest biomass by means of subsequent stem diameter measurements over subsequent years.

Up until recently, the major drawback of this method has been the site- and species-specific differences in allometric relations, necessitating the use of different allometric equations for different sites (e.g., Smith and Whelan, 2005) and, at a minimum, different species. However, a number of workers, using global datasets, have developed a common allometric equation applicable for all tropical tree species, with the most applicable equations for aboveground biomass being those developed for all tropical trees by Chave et al. (2005) and for all mangrove species by Komiyama et al. (2005):

$$W_{top} = 0.168 p \mathrm{DBH}^{2.47} \text{ (Chave et al. 2005)}$$

$$W_{\mathrm{top}} = 0.251 p \mathrm{D}^{2.46} \text{ (Komiyama et al. 2005)}$$

where W_{top} = aboveground tree weight in kg DW; D = tree diameter; DBH = diameter-at-breast height. The relative error of each equation varies among species, but is typically within the range of -10% to +10%. There are, of course, arguments to be made that empirical measurements should be made in all mangrove forests, considering the significant allometric differences between species and for the same species at different locations (Smith and Whelan, 2005; Soares and Schaeffler-Novelli, 2005). However, this idea is impractical for inventory compliers; a relative error of ± 10% is acceptable being within the range of error for allometric relations within a forest where biomass has been weighted.

Comparing the two equations, the Chave estimation gives lower aboveground weight estimates than that of the Komiyama equation. Presuming that a complete census of all trees, with species identified, and their diameter have been undertaken from replicate plots within a given forest, these numbers can then be used in either equation to derive individual tree weight.