The Value of Turneffe Atoll Blue Carbon

Prepared by:
Dr. Tony Fedler
Gainesville, FL

Prepared for:
Turneffe Atoll Trust
Belize City, Belize

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Executive Summary

Turneffe Atoll is a key component of the marine resources of Belize. Part of the Meso-American Reef System, Turneffe encompasses over 1,300 square miles of mangrove forests, seagrass beds, coral reefs and islands. Since 2012, when the Belize government formally designated Turneffe as a marine reserve, it has been co-managed by the Belize Department of Fisheries and the Turneffe Atoll Sustainability Association. The marine reserve designation was the culmination of more than 20 years work by several organizations and many individuals. The atoll's stakeholders established an extensive Management Plan (Belize Fisheries Department 2012) through countless consultations that encompassed more than 10,000 hours of effort.

The ecological resources of Turneffe, the largest coral atoll in the Caribbean, contains about 6,475 hectares (ha) of mangrove forests, 36,643 ha of seagrass beds, and 4,195 ha or coral reefs. These marine ecosystems provide a host of environmental and economic benefits to the country, and more broadly to the region and internationally. Turneffe Atoll plays a significant role in protecting the coastline of Belize in the shadow of the atoll, and particularly Belize City, from storms and extreme weather events. The value of Turneffe's shoreline protection was estimated to exceed $382 million (BZD) annually in damages avoided (Fedler 2018). The atoll also provides spawning and rearing habitat for many important commercial and recreational finfish and shellfish species. The tourism benefits derived from the atoll's recreational fishing, diving and eco-tour activity exceed $100 million (BZD) in 2011 with commercial fishing at Turneffe adding an additional $514,000 to the country's economy (Fedler 2011). In addition to these ecological and economic benefits, the atoll's mangrove forests and seagrass beds also play an important role in mitigating climate change by sequestering and storing organic carbon.

This study estimates the gross economic value of carbon sequestered in Turneffe Atoll's mangroves and seagrass beds through a Net Present Value analysis conducted without project establishment and management costs. The analysis was based on a discount rate of 10%, but rates of 1.5% and 5% were also used to show the value of Turneffe's blue carbon if valued at lower discount rates. A project life of 25 years was used to estimate the value of blue carbon payments over time. A 10% discount rate was used because it is commonly thought this rate better reflects the time preferences and risks associated with investments in developing countries.

The gross net present value of blue carbon contained in the biomass and soils of Turneffe's mangroves and seagrasses, based on a price of $15 per tCO_2e, would be $3,473,072 over the life of a 25-year period -- $694,548 for mangroves and $2,778,529 for seagrasses. These benefits would be reduced by any establishment and annual management costs. However, these costs should be relatively low given the extensive work in developing the marine reserve and its management plan, and recent regulations protecting mangroves.

Mangrove forests and seagrass beds are very important coastal blue carbon ecosystems, sequestering and storing carbon at a greater rate than terrestrial forests. Seagrass projects can be included in voluntary market or in future compliance market opportunities if the regulations for these markets are written broadly enough to include non-forested systems.

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Organic carbon captured and stored by mangroves, seagrasses and saltmarshes are collectively know as "Blue Carbon" because of their association with coastal margins and to distinguish it from carbon sequestered and stored in terrestrial ecosystems (Mcleod et al. 2011). The purpose of this study is to determine the value of Turneffe Atoll's blue carbon stock, so it can be used to encourage decision makers to protect mangrove and seagrass ecosystems and estimate the potential value of Turneffe Atoll blue carbon stocks in the carbon markets.

Background

Recognition of the growing effects of climate change throughout the international community has resulted in policymakers increasingly seeking creative ways to mitigate and reduce global carbon emissions. Much of this effort has focused on changing land-use practices, including development, deforestation and farming activities, that release organic carbon stored in trees, plants and soils back into the atmosphere. Annually, these changes in the environment comprise up to 20% of the total global carbon emissions (IPCC 2007). The United Nations Framework Convention on Climate Change (UNFCCC) has responded to this significant factor of anthropogenic climate change by adopting policies to allow countries to account for gained or lost carbon emissions in national assessments and by providing mechanisms to fund and incentivize conservation projects (Herr and Laffoley 2012), such as reforestation and afforestation, reducing erosion, and conserving existing forest resources.

A number of recent studies have pointed to the importance coastal ecosystems such as mangroves, seagrasses and salt marshes play in mitigating climate change by acting as carbon sinks (Donato et al. 2011: Pidgeon et al. 2011). Although these ecosystems comprise about two percent of the global area, studies have shown that these coastal ecosystems are both ten times more effective at sequestering carbon dioxide on an annual per area basis than boreal, temperate or tropical forests (McLeod et al. 2011), and about twice as effective at storing carbon in their soil and biomass (Pendleton et al. 2012). Blue carbon refers to mangrove forests, seagrass meadows, and tidal saltmarshes — vegetated coastal ecosystems that represent significant carbon stocks, and which are disappearing or becoming degraded as a result of continuing development pressures (Pendleton et al., 2012). The idea of blue carbon is attractive to many in the conservation and policy communities because it appears to be a cost effective strategy to achieve not only genuine reductions in greenhouse gas emissions but a host of 'co-benefits' as well: providing habitat for valuable food species, filtering and treating run-off and chemical pollution from industry and agriculture, and providing effective defense against storms and extreme weather events (Grimsditch et al. 2013; Nellemann et al. 2009; Barbier et al. 2011).

Marine and coastal ecosystems are increasingly losing their ability to provide fundamental services upon which human wellbeing depends. The high rate of loss of these ecosystems, estimated at one-third of the global total over the past several decades (Pendleton et al. 2012), is caused by direct and indirect anthropogenic factors such as such as deforestation, increasing coastal population size and development, agriculture and aquaculture, sedimentation, and the effects of climate change such as sea level rise and extreme weather events (Mcleod et al. 2011). When these systems become degraded, they fail to act as carbon sinks and begin releasing stored carbon into the atmosphere through resuspension from soils or clearing and burning from development.

In response to the significant negative effects of blue carbon ecosystem degradation, opportunities are developing for coastal ecosystem projects with the goal of mitigating climate change and increase the resilience of coastal communities (Crooks et al. 2014). Additionally, the international community has begun to evaluate how these ecosystems can be more effectively included within existing policy frameworks, including carbon financing methods such as Reducing Emissions from Deforestation and Degradation (REDD+) and other mechanisms (Herr and Laffoley 2012; Gordon et al. 2011; Murray et al. 2011; Lau 2013).

In 2009 the United Nations Environment Program published a landmark report titled, Blue Carbon: A Rapid Response Assessment (Nellemann et al., 2009). The publication was an important milestone for three reasons: (1) it completed the process of global carbon accounting begun by the International Protocol on Climate Change (IPCC) with the atmosphere, and then terrestrial biomes (most notably forests); (2) it raised the profile of vital marine and coastal zones by highlighting their significance in terms of carbon cycling and other ecosystem services, in contrast to the better understood terrestrial ecosystems; and (3) it made five key policy recommendations, the first of which was to establish a global blue carbon fund for protection and management of coastal and marine ecosystems and ocean carbon sequestration. In other words, the report proposed using climate finance – the basis of the international market-based approach to climate change mitigation – as the foundation of strategic efforts (biodiversity, communities, and livelihoods) that depend on the ocean.

The blue carbon discussion quickly gained momentum. A 'Blue Carbon Initiative' was established in 2010 by the United Nations and non-government partners, with the aim of promoting climate change mitigation through restoration and sustainable use of coastal and marine ecosystems. The Initiative comprises two working groups, one on scientific and technical issues, the other investigating policy matters. The policy group has made a number of recommendations, the first two of which are: (1) to integrate blue carbon activities fully into the international policy and financing processes of the United Nations Framework Convention on Climate Change (UNFCCC) as part of mechanisms for climate change mitigation; and (2) to integrate blue carbon activities fully into other carbon finance mechanisms such as the voluntary carbon market as a mechanism for climate change mitigation. At the Rio+20 United Nations Conference on Environment and Development in June 2012, the International Oceanographic Commission (IOC) released the Blueprint for Ocean Sustainability. Of the 10 proposed measures to achieve ocean sustainability, the first relates to mitigating and adapting to acidification, while the second, Objective 1b, advocates the creation of "a global blue carbon market as a means of creating direct economic gain through habitat protection" (IOC, 2011:33). As a result, nations have pledged substantial funds towards climate mitigation efforts and adaptation efforts, and private sector finance is expected to represent a substantial proportion of these contributions (O'Sullivan et al. 2011; Stadelmann et al. 2013). This high-level advocacy for market-based instruments (MBIs) to support blue carbon activities suggests that policy theorists and decision-makers recognize the importance of private sector commercial interests, as well as public agencies, to the blue carbon conversation.

Carbon Sequestration

Mangrove forests and seagrass beds are key marine biomes supplying valuable ecosystem goods and services such as water quality control, fisheries production, nursery habitats and storm protection. Like other forests, mangroves are efficient carbon dioxide sinks. As blue carbon represents 55% of the biological carbon on earth, the conservation and restoration of these 'blue carbon' habitats can play an important role in climate change mitigation. Globally, mangrove forests and seagrass beds are being lost at an alarming rate from pollution, land clearing, coastal development, natural disasters and climate change. In the Pacific, climate change is expected to have pronounced effects upon marine ecosystems and will exacerbate existing pressures. Unless global and regional declines are arrested, these important carbon sinks will continue to add to atmospheric CO_2 rather than reduce or mitigate impacts.

Possible mechanisms to reduce the decline of mangrove forests and seagrass beds include the use of payments for ecosystem services (PES) and carbon credit markets. In the terrestrial sector, the ability of tropical forests to sequester (remove and store carbon from the atmosphere) has led to quantification, and purchase and trade of this ecosystem service through carbon 'credits.' More recently, this has occurred within international and national programs to Reduce Emissions from Deforestation and Degradation (REDD+), whereby developing countries are compensated for maintaining carbon sequestration functions of their forests. This must be through quantifiable activities and includes conservation. Recent assessments indicate that tropical mangroves are among the most carbon-rich forests in the tropics, thus PES and carbon credit systems may offer the opportunity to achieve dual goals of local community enhancement and protection of marine carbon sinks. Globally, efforts to protect blue carbon stocks through PES and REDD+ initiatives are new and relatively untried.

Seagrass meadows are also globally significant carbon sinks (Duarte, Middelburg & Caraco 2005; McLeod et al. 2011) that endure over time (Fourqurean et al. 2012), but their value in the capture and storage of carbon is threatened by high global net loss rates of about 1% per year (Waycott et al. 2009). This has led to growing interest in the conservation of seagrass meadows as a pathway to mitigate CO_2 emissions and has resulted in blue carbon strategies to mitigate climate change (Nellemann et al. 2009; McLeod et al. 2011; Duarte et al. 2013a, 2013b). In the process of developing blue carbon strategies, two unresolved yet key uncertainties have been uncovered. First, whereas it is evident that the capacity for shallow coastal sediments to act as sinks for carbon is lost with seagrass loss, the fate of the carbon stocks in the resulting bare sediments is a matter of speculation (Fourqurean et al. 2012; Pendleton et al. 2012). Secondly, restoration projects have the potential to restore carbon sequestration capacity and protect sediment carbon stocks of seagrass meadows, but this premise is based on models (Duarte, Sintes & Marba 2013) supported to date by a single piece of evidence (Greiner et al. 2013). The consequences of habitat loss for the fate of sediment carbon stocks have been assessed for mangroves (Lovelock, Ruess & Feller 2011; Sidik & Lovelock 2013; Kauffman et al. 2014) but designing similarly robust tests for seagrass meadows have proved challenging (Duarte et al. 2013b).

Marba et al. (2005) demonstrate that loss of seagrass meadows causes erosion of the sediment carbon stock and that seagrass restoration projects preserve sediment carbon deposits and restore the carbon sink capacity of the seagrass ecosystem. This demonstration was based on detailed reconstructions of the decadal trajectory of carbon stocks, combining carbon chronosequences with ^{210}Pb dating of seagrass sediments in Oyster Harbor, SW Australia meadows that experienced losses until the end of 1980s but have had subsequent increases in seagrass cover through serial revegetation efforts. These results demonstrate that seagrass vegetation enhances carbon burial and preserves sediment carbon stocks and that revegetation projects effectively restore seagrass carbon sequestration within short, manageable time-scales.

In contrast, Greiner et al. (2013) provide the first quantitative evidence that the loss of seagrass vegetation leads to carbon stocks being removed through erosion following the loss of seagrasses as speculated by Fourqurean et al. (2012) and Pendleton et al. (2012). These results, therefore, dispel uncertainties on the fate of carbon stocks following seagrass losses, thereby reinforcing the merit of blue carbon strategies focused on seagrass conservation and restoration to mitigate climate change.

The results presented here substantiate the argument that accelerating losses of seagrass vegetation world-wide since the 1980s (Waycott et al. 2009) must have led to an important loss of carbon sink capacity and carbon stored in seagrass sediments (McLeod et al. 2011; Duarte et al. 2013b). However, these losses also imply that there are vast potential areas available for seagrass restoration programs, which can help rebuild the lost carbon sink and conserve the remaining stores. Indeed, seagrass restoration programs aiming to recover seagrass habitat have been conducted world-wide since the mid-20th century (Paling et al. 2009). Most of these projects have focused on restoring ecosystem services such as pollution abatement, sediment trapping, and storm protection rather than carbon sequestration.

Belowground carbon pools – inclusive of live and dead root biomass, accumulated litter and allochthonous organic matter – are by far the largest carbon store in coastal, intertidal wetlands. Higher sediment carbon densities have been reported in mangroves than seagrasses, globally, although density may be highly variable both within and between settings for both ecosystems (Chmura et al. 2003; Pendleton et al, 2012).

Mangroves are coastal forest ecosystems that occur in the sheltered intertidal zones of the tropical and subtropical regions of the world. They are globally recognized to be of extreme ecological, economic, social, and cultural importance because of the variety of goods and services they provide, reaching an estimated annual economic value of more than USD $900,000 per km^2. Some of the most important goods and services provided by mangroves include the protection of the coastline from the energy of the winds and waves and the conservation of fishing and biodiversity in the coastal and waters (Ewel et al. 1998; Mazda et al. 2005; Nagelkerken et al. 2008).

The increased emissions of greenhouse gases, in the recent decades, has enhanced society's perception of the social and economic damage that may be caused by climate changes, leading to an increasing interest in minimizing the potential impacts of these changes (Parry et al. 2007). In this sense, the large contribution of forest and wetland destruction to the global anthropogenic emissions of greenhouse gases (van der Werf et al. 2009) draws attention to the need for their conservation and understanding of their role in carbon sequestration. In the case of mangroves, although there is still considerable uncertainty in the estimates of the carbon balance in this ecosystem, recent studies have shown their potential for carbon storage (Donato et al. 2011; McLeod et al. 2011). Thus, the function of carbon storage and sequestration adds another reason in favor of the conservation of mangroves. This appeal is even greater since climate change is intensifying (Parry et al. 2007) and international agreements are being signed to reduce and offset the emissions of greenhouse gases.

Estimates of Blue Carbon in Belize Mangrove Forests

Belize is fortunate to have attracted several organizations and researchers interested in studying coastal ecosystems and the blue carbon associated with mangroves. In contrast, seagrass beds throughout the country have received relatively little attention, particularly regarding carbon sequestration. Chang et al. (2015) provide an excellent summary of research conducted on the size of Belize mangrove forests, an estimate of carbon stocks in biomass and associated sediments, and an estimate of the blue carbon offset value of those stocks. The remainder of this section summarizes the Chang et al. report for mangroves and extends its findings with a discussion of the extent, carbon and value of blue carbon associated with Turneffe Atoll seagrass beds.

Zisman (1998) conducted an initial study compiling the baseline data on the size of mangrove forests in Belize. Cherrington et al. (2010) updated Zisman's baseline data and completed a remote sensing-based change detection study using Landsat satellite imagery. In 2014, Cherrington again updated the Belize mangrove extent data and assessed changes from 2010. Analysis of these data showed an annual rate of deforestation of about 0.06% from 1980 to 2010. It increased to 0.7% per year from 2010 to 2014. While the deforestation rate since 2010 is close to the average worldwide decline, it has grown substantially over the preceding three-decade average. This annual loss rate equates to slightly more than 500 ha per year of Belizean mangroves.

Chang et al. (2015) used the mangrove extent data from Cherrington's 2014 estimate for Belize (72,622 ha) to estimate the carbon stocks contained in both above-ground biomass and soil components of the country's mangrove forests. They initially estimated total carbon stocks from average values from literature sources. This procedure resulted in an estimated 29.6 teragrams (Tg) of blue carbon stored in the mangrove forests of Belize. A second estimate was made using values from the Coastal Blue Carbon Guidebook (Howard et al. 2014). This value (386 Mg of carbon per hectare) estimated there was 23.3 Tg of blue carbon in Belize mangrove forests. Chang et al. (2015) also conducted a meta-analysis of studies to evaluate the pre-existing knowledge of below-ground carbon storage in mangrove ecosystems in the Caribbean and Gulf of Mexico regions. They identified six papers containing 23 study sites in Mexico and Florida. Using a linear relationship between total organic carbon and latitude they estimated that the below-ground carbon pool in Belize mangrove forests totaled about 9.4 Tg.

To obtain more accurate preliminary blue carbon stock estimates for Belize mangrove forests, Chang et al. (2015) conducted a field study on Turneffe Atoll. Turneffe Atoll is a marine reserve co-managed by the Turneffe Atoll Sustainability Association and Belize Fisheries Department. The investigation used five long-term monitoring study sites established by the University of Belize Environmental Research Institute (ERI). Each study site has three mangrove plots from which ERI annually collects biomass monitoring data (see Aheto et al. 2013 for methodology). Chang et al. supplemented the 2014 biomass data with a soil carbon pool sampling study also in 2014.

Analysis of the Turneffe above-ground and sediment carbon storage analysis was very interesting. Carbon from above-ground biomass estimates ranged from 27.7 to 62.1 Mg/ha across the five study sites. Sediment carbon storage estimates ranged from 147 to 187 Mg/ha. Using these data, Chang et al. (2015) estimated that there was approximately 13.0 Tg of blue carbon stored in Belize mangrove forests. About 20% of the carbon is stored in the above-ground biomass with the remainder in sediments.

Turneffe Atoll Mangrove Blue Carbon

Although Chang et al (2015) used both biomass and sediment blue carbon data from Turneffe Atoll to estimate blue carbon storage for the entirety of Belize's mangrove forests, they did not provide an equivalent estimate for Turneffe Atoll. However, using mangrove extent data from the 2016 Belize Integrated Coastal Zone Management Plan (CZMAI 2016) and the blue carbon values from the studies discussed above, it was possible to estimate mangrove blue carbon stocks on Turneffe Atoll.

An estimated 6,475 ha of mangrove forests were associated with Turneffe Atoll in 2016. Using the average of the biomass carbon estimates (40.77 Mg/ha) and average of the sediment carbon estimates (173.8 Mg/ha) from the five study sites resulted in approximately 1.4 Tg of blue carbon contained in Turneffe Atoll mangrove forests (Table 1).

Table 1: Calculation of carbon (C) and carbon dioxide (CO_2) in Turneffe Atoll mangrove forests and seagrass beds

Source	Ha	Mg C/Ha	Total Mg C	Mg CO2e	tCO2e
Mangrove					
Living	6,475	41	263,921	968,590	969
Soil	6,475	174	1,126,650	4,134,806	4,135
Total			1,390,571	5,103,396	5,104
Seagrass					
Living	36,643	1	31,147	114,308	114
Soil	36,643	151	5,529,429	20,293,003	20,293
Total			5,560,575	20,407,311	20,407
Total	43,118		6,951,146	25,510,707	25,511

Turneffe Atoll Seagrass Blue Carbon

As noted previously, seagrass beds have the capability to store carbon over long periods of time and at more concentrated levels than mangrove forests. However, compared to mangrove forests, relatively few studies of the blue carbon contained in seagrass beds have been undertaken and none in Belize have been identified. Thus, to estimate the blue carbon pool associated with Turneffe Atoll seagrass beds it is necessary to use averages from relevant regions to gain perspective.

The most comprehensive review of seagrass ecosystem carbon stocks was conducted by Forqurean et al. (2012). Their database on carbon in seagrass meadows contained 3,640 observations from 946 distinct sampling locations across the world. Within this database, 44 locations were from the Tropical Western Atlantic. From these locations, carbon in the mean living seagrass biomass was 0.85 Mg/ha. Further, mean soil organic carbon was 150.9 Mg/ha. Soil carbon measurements were standardized to the top one meter of soil. The top one meter of soil was considered because it is most vulnerable to being remineralized when seagrass meadows are lost (Forqurean et al. 2012). Their estimates are likely to underestimate total carbon stores because deposits can be several meters thick.

Table 1 shows estimates of aboveground biomass and soil carbon for Turneffe Atoll seagrass beds. These estimates were derived simply by multiplying the estimated 36,643 hectares of seagrass beds on Turneffe Atoll (CZMAI 2016) by the mean biomass and soil carbon rates for the Tropical Western Atlantic (Forqurean et al. 2012). The amount of biomass carbon in Turneffe Atoll seagrasses is a small fraction of that stored in soils. Not only does soil carbon benefit from that stored in the roots and rhizomes of seagrasses but also from detritus and organic matter precipitating from the water column above seagrass beds. For Turneffe Atoll, seagrass biomass contains an estimated 31,147 Mg of blue carbon and nearly 5.5 million Mg in the associated soils.

Altogether, the estimated blue carbon sequestered in Turneffe Atoll mangrove forests and seagrass beds totals 6.95 million Mg of carbon. This converts to 25.5 million Mg of carbon dioxide equivalents ($MgCO_2e$) or 25,511 tonnes of carbon dioxide equivalents (tCO_2e). This latter measurement is the basis for calculating carbon credits for the voluntary and compliance trading markets.

Economic Value of Turneffe Atoll Blue Carbon

The blue carbon captured and stored in Turneffe Atoll's mangroves and seagrasses presents an opportunity to use carbon sequestration and storage to Belize's benefit. Like payments for REDD+ projects, incentives to retain rather than release blue carbon would protect the country's biodiversity as well as other ecosystem services, such as shoreline protection and fisheries habitat, at local and regional scales. Thus, estimating the value of Turneffe Atoll's blue carbon provides a broad assessment of whether payments for blue carbon protection—money received for carbon emissions avoided by not altering coastal ecosystems—can provide economic incentives strong enough to curtail existing rates of habitat loss (Murray et al. 2011).

Having an estimate of the economic costs and benefits for a blue carbon offsets program helps show the net economic value of actions to conserve or enhance Turneffe Atoll's mangrove forests and seagrass beds and show how a carbon payments project might compete with alternative land uses. An initial assessment of Turneffe Atoll's mangrove blue carbon value was conducted by Chang et al. in 2015. This study used net present value analysis to determine the economic feasibility of a blue carbon offsets project for mangrove forests on Turneffe Atoll. NPV is the acronym for net present value. Net present value is a calculation that compares the amount invested today to the present value of the future cash receipts from the investment. In other words, the amount invested is compared to the future cash amounts after they are discounted by a specified rate of return.

Chang et al. (2015) used NPV to estimate the creditable carbon revenue for 25 years in which 25% (1,600 ha) of the mangroves on Turneffe are protected in perpetuity. In their analysis, they included carbon credit revenue, project establishment costs, annual project management costs, and land acquisition costs. Land acquisition costs of $46,700 per hectare were estimated from online searches of real estate prices for land on Turneffe Atoll. However, the Belize Lands Department recently assessed Turneffe lands at between $4,000 and $12,000 per hectare for tax purposes. Project establishment and management costs were estimated from literature (Murray et al. 2011). Chang et al. used a range of carbon credit prices and discount rates to assess the feasibility of establishing a carbon offset project.

Results of the study found that a carbon offset project would not be feasible at any carbon price up to and exceeding $45 /$tCO_2e$ if land costs were included in the analysis at any discount rate up to 10%. A break-even price greater than $10 /tCO2e would make the project feasible if land acquisition costs were excluded, even at a 10% discount rate. NPV of was estimated from $568,000 (USD) with a 1.5% discount rate and $85,000 with a 10% discount rate at $15 /tCO2e over the life of a 25-year project.

The study in this paper essentially replicates that of Chang et al. (2015) by estimating NPV for both mangrove forests and seagrass beds at Turneffe Atoll. The purpose was to estimate the potential benefits of protecting Turneffe's mangrove and seagrass carbon stocks over time when considering the presence and absence of establishment and annual management costs.

As noted earlier, Turneffe Atoll was officially designated as a Marine Reserve by the Belizean government in 2012. The Turneffe Atoll Trust spearheaded the development of a detailed management plan establishing goals and objectives for managing the atoll. Within this plan, specific guidelines set the baseline for protecting mangrove and seagrass resources. To further protect Belize's mangrove forests, The Forest (Protection of Mangroves) Regulations 2018 Act [34/1OP/1/18(36)] was implemented to further protect mangrove forests and regulate mangrove removals on public and private lands. The establishment of the Turneffe Atoll Marine Reserve and Act protecting and regulating mangroves have provided much of the necessary preparation for a blue carbon project. Further, the government of Belize has made progress on the implementation of a REDD+ framework (Neal and Cho 2014). This activity is important in that it will help reduce the costs of establishing future blue carbon projects.

From purely an economic value of the carbon sequestered in Turneffe Atoll's mangroves and seagrass beds, an NPV analysis was conducted without establishment and maintenance costs. The analysis was based on a range of discount rates (1.5%, 5% and 10%) and a project life of 25 years. A 10% discount rate is used in the discussion here because it is commonly thought this rate better reflects the time preferences and risks associated with investments in developing countries (Murray et al. 2011).

Based on above-ground mangrove carbon analyses by the University of Belize Environmental Research Institute (ERI) from five study sites on Turneffe Atoll, the average biomass carbon of mangroves is 41 Mg/ha. A mangrove soil carbon analysis was conducted by Chang et al. (2015) on Turneffe Atoll using the five ERI study sites. Analysis of the carbon contained in mangrove soils showed an average of 174 Mg/ha. Overall, Turneffe Atoll mangroves store approximately 215 Mg/ha of blue carbon. For this analysis, 5,103 tCO_2e would be stored when all Turneffe mangroves were protected from development or other disturbances (Table 1).

The gross net present value of the biomass and soil blue carbon stored in Turneffe Atoll's 6,475 ha of mangrove forests would be \$463,201 (USD) over 25 years if the price was \$10 per tCO_2e and \$694,545 at \$15 per tCO_2e (Table 2). Similarly, the gross value of blue carbon stored in the biomass and soils of Turneffe's 36,643 ha of seagrass beds would be \$1,852,352 (USD) if the price was \$10 per tCO_2e and \$2,778,527 at \$20 per tCO_2e (Table 3). The gross benefits of protecting all of Turneffe Atoll's mangrove forests and seagrass beds would be \$2,315,553 at a price of \$10 and \$3,473,072 at a price or \$15 per tCO_2e.

The value of Turneffe's mangrove and seagrass blue carbon was calculated without including establishment and maintenance costs throughout the life of the project. These costs are highly variable and can range from a few dollars to several hundred dollars per hectare (Murray et al. 2011). Including these costs in the analysis would reduce the net present value of the overall project and increase the price paid for carbon credits needed to break even or have positive benefits result from the project. Because Turneffe Atoll has already been designated as a Marine Reserve and a management plan is in place, establishment and maintenance cost would likely be minimal. The main costs would involve the scientific research needed to establish the carbon content of mangrove and seagrass biomass and soils for accurately establishing baselines for calculating carbon credits available.

Table 2: Net present value for protecting Turneffe Atoll mangrove forests over a 25-year time period

	Discount Rate		
	1.5%	5.0%	10.0%
$5	$528,661	$359,607	$231,601
$10	$1,057,332	$719,214	$463,201
$15	$1,585,983	$1,078,821	$694,545
$20	$2,114,644	$1,438,428	$962,403
$25	$2,634,304	$1,798,035	$1,158,003
$30	$3,171,965	$2,157,642	$1,389,604
$35	$3,700,626	$2,517,249	$1,621,205
$40	$4,229,287	$2,876,856	$1,852,805
$45	$4,757,948	$3,236,463	$2,084,406

Table 3: Net present value for protecting Turneffe Atoll seagrass beds over a 25-year time period

	Discount Rate		
Price	1.5%	5.0%	10.0%
$5	$2,114,126	$1,438,076	$926,176
$10	$4,288,251	$2,876,151	$1,852,352
$15	$6,342,377	$4,314,227	$2,778,527
$20	$8,456,502	$5,752,303	$3,704,703
$25	$10,570,628	$7,190,378	$4,630,879
$30	$12,684,753	$8,628,454	$5,557,055
$35	$14,798,879	$10,066,529	$6,483,230
$40	$16,913,004	$11,504,605	$7,409,406
$45	$19,027,130	$12,942,681	$8,335,582

Discussion

Turneffe Atoll sequesters and stores a significant portion of Belize's carbon stocks. Currently, about 9% of the country's mangroves and 19% of seagrass beds are located at Turneffe with a proportional amount of the country's carbon storage. Without protection, there is potential for significant reductions in carbon storage through land development, dredging, and water quality declines from increased development on Turneffe (CZMAI 2016).

The gross value of blue carbon contained in the biomass and soils of Turneffe's mangroves and seagrasses based on a price of $15 per tCO_2e would be $3,473,072 over the life of a 25-year period - $694,548 for mangroves and $2,778,529 for seagrasses. These benefits would be reduced by any establishment and annual management costs. However, these costs should be relatively low given the extensive work in developing the marine reserve and its management plan, and recent regulations protecting mangroves.

Several recent blue carbon projects have used mitigation (afforestation or reforestation) as one of their main objectives. However, none of these projects are currently being implemented using UNFCCC mechanisms (Wylie et al. 2016). These projects generate voluntary carbon credits because voluntary credits have so far proved to be more feasible for smaller projects than UNFCCC mechanisms such as REDD+. There are higher transaction costs and more stringent standards under UNFCCC mechanisms. Additionally, for UNFCCC mechanisms to be available to individual projects, national governments must implement compliant laws and regulations. In this regard, Belize may be moving toward participating in UNFCCC programs through establishing the Turneffe Atoll Marine Reserve, mangrove forest regulations and other actions. A few mangrove projects in other countries are in the planning stages for UNFCCC mechanisms with the hope of participating in the compliance market in the future. This demonstrates that blue carbon projects have the potential to be included within the UNFCCC system with proper planning and capacity-building. However, voluntary carbon markets will likely continue to be a better alternative in the short-term.

Based on a number of case studies (e.g., Thomas 2014), the voluntary market is more accessible for small projects. Participants in the voluntary market have a choice among standards and projects can be completed while potentially avoiding some of the high costs and administrative burdens associated with CDM standards or the detailed process needed to get a REDD+ project approved. For some projects, it will be more time efficient and cost-effective to utilize another standard, such as payments for ecosystem services, until the UNFCCC process becomes more streamlined. It is important to recognize that carbon credits on the voluntary market tend to worth less than in the compliance market by an order of magnitude.

One of the most important considerations when accounting for the maximum amount of carbon in coastal ecosystems is including the carbon stored in the soil, which is by far the largest carbon pool for both mangroves and seagrasses (Pendleton et al. 2012). This lack of information prevents projects from including all sources of blue carbon and keeps the project from reaching its full financial potential. An initial assessment of the soil carbon in Turneffe's mangrove soils by Chang et al. (2016) was an important start in this regard. However, additional assessments will need to be made for Turneffe's mangrove forests and initiated for biomass and soils if projects involving seagrass beds are planned. This may require capacity building to do these measurements locally or partnering with others who can provide the necessary technical expertise to enhance the value of blue carbon projects.

Most countries working to develop carbon offsets are in tropical areas where mangroves are abundant. As a result, some of the UNFCCC mechanisms, notably REDD+ and CDM, only include mangrove ecosystems. Nevertheless, seagrass beds are also effective coastal blue carbon ecosystems, sequestering and storing carbon at a greater rate than terrestrial forests. Seagrass projects can be included in voluntary market or in future compliance market opportunities if the regulations for these markets are written broadly enough to include non-forested systems.

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