Abu Dhabi Global Environmental Data Initiative (AGEDI)

Abu Dhabi Blue Carbon Demonstration Project

Ecosystem Services Assessment Report

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Executive Summary

The Ecosystem Services Assessment component of the Abu Dhabi Blue Carbon Demonstration Project provides information about co-benefits being delivered from Abu Dhabi's Blue Carbon ecosystems. These benefits, comprising both provisioning and regulating ecosystem services, make the mangrove, seagrass, salt marsh, sabkha, and algal mat ecosystems that can be found along the coast, around the islands, and offshore in the Emirate particularly valuable. These services are only beginning to be understood and quantified; some values are already recognized as significant, but all can be considered potentially important, to be further defined in future studies. These will prove to be noteworthy considerations when weighing trade-offs and in development of future policies.

The Blue Carbon ecosystems that were assessed in this study contribute to the beauty of the Abu Dhabi environment, and enhance human well-being at the local, regional, and global scale. Locally, Blue Carbon ecosystems contribute to maintaining livelihoods, providing food and materials, promoting economic growth, and reducing vulnerabilities to sea level rise, storm events, and spread of disease. At the regional level, Abu Dhabi's Blue Carbon areas maintain the web of life in both the Gulf and the coastal areas in countries bordering it – an increasingly critical contribution given the rapid acceleration of loss of these ecosystems in other locales. On a global scale, understanding these ecosystems in terms of the benefits they offer and the ways they are threatened provides valuable knowledge and ground-truthing for the rest of the world. This is especially true since the environmental conditions in the Gulf region may be a harbinger of things to come in certain regions across the globe in a future of climate change, given that seawater temperatures and salinity are among the highest in the world. How these mangroves, seagrasses, salt marshes, sabkhas, and algal mats fare, and what can be done to make them as resilient as possible in the face of global change, allows a glimpse into the future, and prepares the world to safeguard these important ecosystem services as best it can.

All of the aforementioned Blue Carbon areas have a role in supporting the overall biodiversity, natural productivity, and environmental health of Abu Dhabi. Many perform pivotal roles, and their loss could create irreversible degradation and lost opportunities to take advantage of natural capital and its benefits. In particular, mangrove, seagrass, salt marsh, and to some extent algal mats play a role in maintaining coastal water quality. This in turn allows for recreational and tourism use, reduces costs of desalination, diminishes the chance for public health problems relating to exposure to toxins (via bathing or seafood), and prevents reductions in commercial fisheries. Similarly, mangroves, seagrass, salt marsh, and associated coral reefs offshore maintain shorelines and navigation channels, reduce chronic erosion, and buffer land and property from storm surges. Mangrove and seagrass are particularly critical in supporting fisheries production, valued by commercial, traditional, and recreational fishers alike. Collectively, Blue Carbon ecosystems play a key role in contributing to a healthy, aesthetically pleasing, and resilient coastal environment.

By rapidly assessing the condition of a subsample of habitats within Blue Carbon ecosystems, focusing specifically on seagrass ecosystems, and analysing this information alongside the findings of the carbon assessment team, it was possible to identify areas of highest potential value (in terms of carbon being sequestered and other valuable benefits being provided as well).

The Blue Carbon Ecosystem Services Assessment has identified what these vital areas are providing in terms of overall value, based on studies identifying market and non-market values of some of these ecosystems (in particular, mangrove, seagrass, and salt marsh). Taking the highest figures for Blue Carbon ecosystem value and multiplying it by coverage (i.e. extent of the ecosystem), the high end of the economic value range can, in very rough terms, be estimated. Based on economic studies undertaken on these ecosystems in other parts of the world, the existing Blue Carbon ecosystems in Abu Dhabi likely provide hundreds of millions of US dollars of shoreline stabilization, support to fisheries, direct recreational use, and water quality maintenance. From net benefits transfer based on valuations from other parts of the world, estimates of economic value for quantified ecosystem services are as follows: mangroves can be seen as likely contributing a minimum of US$ 188 million per annum; salt marshes are likely contributing at least US$ 70 million per year; and seagrasses, for only a few services quantified, are likely contributing a minimum of US$ 400 million per annum. The sum total for only these three Blue Carbon ecosystems is estimated as over US$ 658 million or 2.4 billion AED, per annum. Benefit transfer cannot be done for sabkha and algal flats, as these ecosystems have not been assessed for their services anywhere in the world. Other non-market values of Blue Carbon ecosystems such as support to a wide array of biodiversity, regulating services that maintain planetary and regional balances, and cultural, spiritual, and aesthetic values must also be considered. While the true economic values of these Blue Carbon ecosystems are still being determined (and will need to be verified by future ecological and economic studies), the opportunity costs of losing these ecosystems to degradation or development are undeniably significant. This is especially true since most Blue Carbon ecosystems are difficult if not impossible to restore, with full restoration resulting in high costs over long time frames.

There are important caveats that must be kept in mind, however. Using proxy values from other parts of the world where economic studies have been conducted to frame the range of possible values in Abu Dhabi via benefits transfer may be misleading. Due to the extreme environmental conditions and anthropogenic impacts in the Gulf region, both biodiversity and productivity is relatively low in these ecosystems compared to other marine systems elsewhere in the world. Market values are not directly comparable to other parts of the world where fisheries are more productive, where eco-tourism is a greater factor in economic development, or where coastal communities and properties are at greatest risk from flood-related inundation, storm surges caused by cyclones or hurricanes, and/or tsunamis. It is recommended that these ecosystems need to be further assessed to determine whether the ecosystem services they are hypothesized as delivering are in fact being delivered. Since value fundamentally relates to perception, it will be important to undertake social science research to ascertain how these services are viewed and the level of commitment there is (in government, among the private sector, and in the general populace) to maintaining or enhancing them.

Particularly valuable Blue Carbon ecosystems in Abu Dhabi occur where their benefits, across a wide range of services, are already being realized. Such ecosystem services values are being delivered from high quality mangroves (mature and dense forests of ample size and little degradation), extensive seagrass beds, intact salt marsh areas, and coastal sabkha in combination with algal mats that occur in close proximity to rich fishing grounds (commercial and recreational), areas of high biodiversity and spectacular scenic value, sites of cultural and archaeological importance, and carefully developed areas of high asset value. Such high asset value properties include, *inter alia*, luxury beach and island resorts, civil engineering infrastructure that are particularly influenced by the sea (corniches, ports, marinas), private residences, desalination plants, and aquaculture operations. For the purposes of this assessment, analysis is concentrated on the current land and marine use. However, planned development must also be considered when determining where valuable Blue Carbon Ecosystem Services are being delivered and/or where these services are especially threatened.

Given that each Blue Carbon ecosystem and the ecological community it supports provides different services, the most valuable areas will be those that have a combination or mosaic of these ecosystems, especially those in relatively close proximity to assets of value. Five areas within Abu Dhabi stand out in this regard:

1) A large portion of the western region, centred on the area between Yasat Island and Dalma, and extending south to the mainland coast;
2) The area around Marawah Island, particularly off its southern and western coast;
3) The west and north/northeast portions of Abu al-Abyad;
4) The marine and peninsular areas east of Bul Syayeef Marine Protected Area; and
5) The eastern mangroves and environs of Saadiyat Island.

One additional, however critically important consideration is that these ecosystems and the services they generate cannot be viewed in isolation. The delivery of goods and services from natural systems is dependent not only on the condition of the ecosystem but also its functional linkages to associated ecosystems. For mangrove forests to continue to provide nursery grounds for commercially and recreationally important fish populations, the two-way linkages between mangrove and offshore ecosystems such as seagrass beds, coral reefs, and offshore landform features must be maintained. Similarly, offshore systems such as coral reefs create the sheltered conditions necessary for inshore systems such as seagrasses to thrive; while mangroves and saltmarsh act to trap sediments and nutrients that might smother or degrade seagrasses. When marine and coastal spatial planning is undertaken or updated in Abu Dhabi, it will therefore be important to consider the full suite of services, their values, and the impacts that human activities in any sector will have on continued delivery of these services. This is especially true as climate change adds to the spectre of cumulative impacts, and threatens to undermine the resilience of all marine and coastal ecosystems, in the Emirate and in the Arabian Gulf region.

Five general conclusions can be drawn about Blue Carbon co-benefits:

1) Ecosystem services have both market and non-market values in Abu Dhabi, and for the region; total economic values are likely to exceed US$ 650,000,000 per annum;
2) Certain areas that have a mosaic of Blue Carbon ecosystems in close proximity, or have extensive and productive Blue Carbon habitats, or both, can be flagged as delivering a concentration of ecosystem services beyond carbon; the potentially most valuable areas with maximum ecosystem services have been tentatively mapped (see Figure 22);
3) The costs of losing the valuable ecosystem services being generated from Blue Carbon ecosystems will be high and felt for many generations to come, and while some restoration may be possible, full ecosystem function is rarely achieved even despite significant investment of time and resources;
4) Blue Carbon ecosystems can be considered to provide risk minimization for existing and prospective investments, as Abu Dhabi continues to grow and as it diversifies its economic base, through Plan Maritime 2030 and other strategic planning initiatives which have been developed and are being implemented; and
5) Maintaining connections between Blue Carbon ecosystems (and with associated ecosystems like coral reefs or the pelagic zones) will allow maximum service delivery, maintenance of values, and maximum resilience in the face of climate change.
6) The potentially most valuable areas should be confirmed as a priority, and should be the focus of planning and conservation efforts, and the sites in which immediate targeted research is conducted in order to determine locally relevant economic values.

1 Introduction

1.1 Project Context

"Blue Carbon" refers to the functional attributes of coastal and marine ecosystems to sequester and store carbon. Blue Carbon ecosystems of the United Arab Emirates (UAE) include mangrove forests, salt marshes and seagrass beds. Another potential Blue Carbon ecosystem identified as a result of this project is cyanobacterial "blue-green algal" mats (hereafter called algal mats). When these ecosystems are destroyed, buried carbon can be released into the atmosphere, contributing to global warming. In addition to their climate related benefits, Blue Carbon ecosystems provide highly valuable *Ecosystem Services* to coastal communities. They protect shorelines, provide nursery grounds for fish and habitats for a wide range of terrestrial and aquatic species, and support coastal tourism. They also have significant cultural and social values.

The Abu Dhabi Blue Carbon Demonstration Project aims to improve our understanding of carbon sequestration and the other services that coastal and marine Blue Carbon ecosystems provide in the Emirate and in addition, contribute to the improved understanding of this relatively new concept on a regional and international level. The project will enhance local capacity to measure and monitor carbon in coastal ecosystems and to manage associated data. The project also identifies options for the incorporation of these values into policy and management, which can lead to sustainable ecosystem use and the preservation of their services for future generations.

1.2. International Context

The Blue Carbon concept has strengthened interest in the management and conservation of coastal marine ecosystems, supporting climate change mitigation efforts. However, there are still gaps in the understanding of Blue Carbon, and incentives and policies are needed to ensure more sustainable environmental management practices.

The experience and knowledge gained from the project will help guide other Blue Carbon projects and international efforts, such as the International Blue Carbon Initiative[1] and the Global Environment Facility's (GEF) Blue Forests Project, of which Environment Agency – Abu Dhabi (EAD) are a partner. This project provides a carbon stock inventory for intertidal and subtidal natural Blue Carbon ecosystems, as well as planted mangroves, in an arid region, reducing gaps in the global database. Recognition of algal flats as a Blue Carbon ecosystem emphasis the importance of understanding coastal carbon cycling in arid regions of the world. The project has also helped develop Blue Carbon science and data management through the production of tools and the testing of methodologies that can be utilised and up-scaled to the international arena to enhance International Blue Carbon cooperation and training.

[1] http://thebluecarboninitiative.org/

1.3. Project Setting

In just over 40 years, Abu Dhabi has evolved from a small fishing community to the largest of the seven Emirates of the UAE. With the vision and direction from His Highness the late Sheikh Zayed Bin Sultan Al Nahyan, the environment has become an intrinsic part of the heritage and traditions of the people of the UAE. This national affinity to the sea has led to the initiation of the Abu Dhabi Blue Carbon Demonstration project in order to explore the values which coastal ecosystems provide the UAE, and to help preserve our environmental and cultural heritage. The project, commissioned by the Abu Dhabi Global Environmental Data Initiative (AGEDI) will run until the end of 2013.

1.4. Project Structure

The project is comprised of five components:

1) A **carbon baseline assessment** that has quantified the stocks of carbon for coastal ecosystems, and the rate of carbon sequestration associated with mangrove afforestation in particular;
2) A **geographic assessment** that has mapped Abu Dhabi's Blue Carbon ecosystems and provides a carbon analysis tool to support informed decision making;
3) An **ecosystem services assessment** that investigated the goods and services beyond carbon sequestration that Blue Carbon ecosystems provide Abu Dhabi (subject of this report);
4) A **policy component** that identifies the most suitable options for incorporating Blue Carbon and Ecosystem Services in Abu Dhabi's policy and governance frameworks; and
5) A **Blue Carbon and ecosystem services finance feasibility assessment** that recommends the most feasible policy and market options for implementing Blue Carbon projects in Abu Dhabi.

1.5. The Ecosystem Services Assessment Team

The Ecosystem Services Assessment component was lead by Dr. Tundi Agardy of Forest Trends, n internationally renowned senior expert on marine and coastal ecosystem management. Dr. Ameer Abdullah of IUCN provided his expertise, both global and regional, and created a rapid assessment protocol specifically designed to quickly assess Blue Carbon sites as to their condition and their ability to generate services (Appendix B). See Section for further details. Dr. Robert Irving, owner of Sea-Scope Consultants (and also a member of the WCMC team delivering the Geographic component) applied the protocol in the field. For more details, please see Appendix E.

1.6. Report Organisation

This report summarizes findings of the field surveys, literature reviews and stakeholder consultation in terms of the Ecosystem Services of Blue Carbon ecosystems in Abu Dhabi. Additionally, it provides a summary of the local, regional and global context of Ecosystem Services Assessment and the importance of this for Blue Carbon ecosystems locally.

1.7. Acknowledgements

In undertaking Ecosystem Services Assessment Dr. Agardy worked closely with her colleague from Forest Trends, Frank Hicks, who is leading the Carbon Financing component, as well as the rest of the Project team. Collective acknowledgement is extended to the enormous assistance provided by AGEDI (in particular Jane Claire Glavan and Huda Petra Shamayleh), and many of the staff of EAD.

2 Background: Marine and Coastal Ecosystem Services in Abu Dhabi

2.1 Marine and Coastal Ecosystem Services Overview

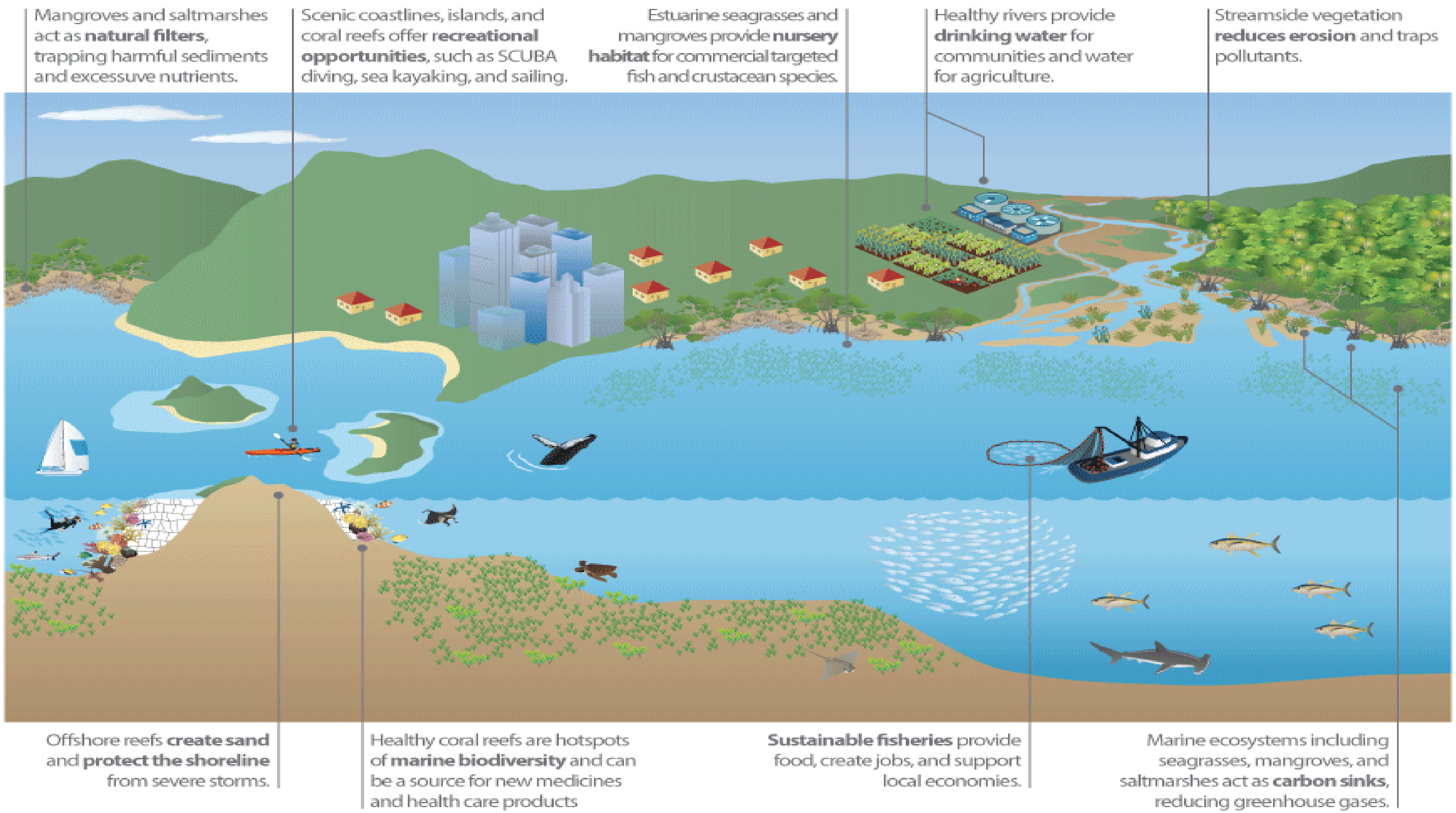
Ecosystem services are the natural by-products of healthy, well-functioning environments. Such services include provisioning for food and water resources, as well as regulating and supporting functions such as flood control, waste management, water balance, climate regulation, and other processes. Human reliance on these ecosystem services is significant, although we rarely recognize the value of ecosystem services until they are lost. The oceans and coasts provide a great many of these critical yet undervalued services, supporting not only coastal inhabitants but all life on the planet.

We derive many benefits from marine ecosystem services. Coastal wetlands maintain hydrological balances, recharge freshwater aquifers, prevent erosion, regulate flooding and buffer land from storms. Marine ecosystems supply us with food, recreational opportunity, pathways for transport, places to do research and learn, and spiritual values. Both coastal and marine ecosystems provide food, shelter, and living space for a broad array of life, in some cases providing essential and unsubstitutable support to wide food webs and biodiversity. Some of these many ecosystem services are illustrated in Figure 1.

With the vast majority of the world's coastal population living in close proximity to wetlands, reefs, and other coastal ecosystems, it is apparent that the services they provide present many of the "pull" factors that resulted in initial settlement along coasts as well as subsequent migration to them (Agardy and Alder 2005). Nearly 50% of the global population now lives within the thin band of coastal area that is only 5% of the total land mass, and dependence on these coastal systems is increasing.

2.2 Blue Carbon Ecosystems Services in Abu Dhabi

In Abu Dhabi, valuable ecosystem services are being provided by the Blue Carbon ecosystems that are the focus of the Abu Dhabi Blue Carbon Demonstration Project (Figure 2). These ecosystems include mangrove forests and fringe, seagrasses, salt marsh, sabkha, and algal mats, as well as associated ecosystems not considered Blue Carbon areas *per se* but that act in concert with these to provide additional valuable services, such as oyster beds and coral reefs. The services provided by this mosaic of ecosystems in Abu Dhabi include support to biodiversity and the wider environment; fisheries production, water quality maintenance, shoreline and channel stabilization and erosion control, buffering land from catastrophic storm events and intense shamal winds, and opportunities for recreational use, spiritual recharge, as well as culturally important activities. Regulating services arising from these and other coastal ecosystems in Abu Dhabi also include disease regulation (prevention of spread of water borne pathogens, for instance) and contributions to overall ecological resilience in the face of climate change.

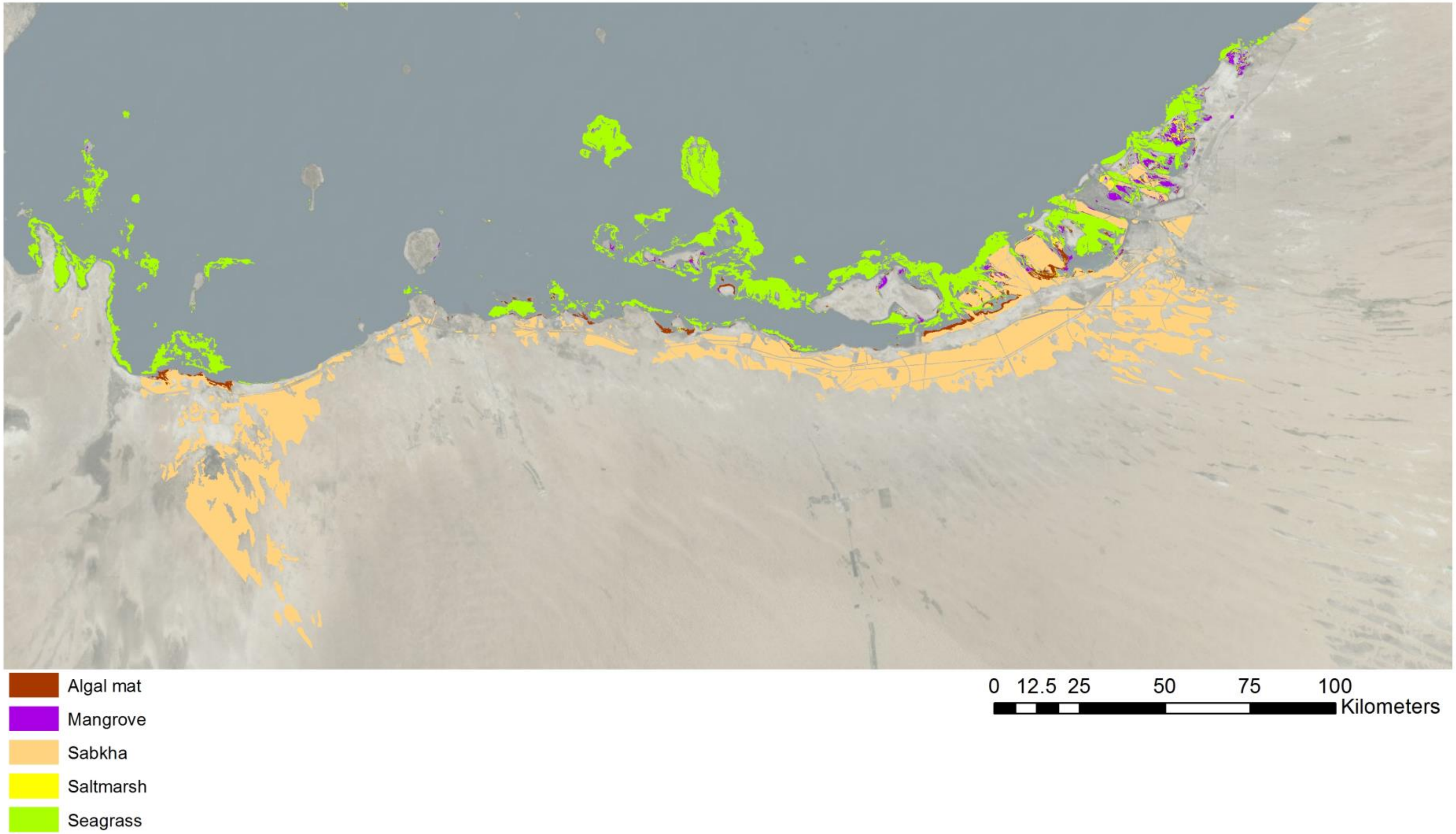


SOURCE: Agardy et al. 2011 UNEP EBM Manual

Abu Dhabi Blue Carbon Demonstration Project

Figure 1

Scheme showing coastal and marine ecosystem services



SOURCE: RapidEye (2012), Habitat data “UAE_Habitat_Layers”, “Mangrove_Update_2012”. Provided by Environment Agency – Abu Dhabi

Abu Dhabi Blue Carbon Demonstration Project

Figure 2

Composite map showing Blue Carbon Ecosystem distribution in Abu Dhabi

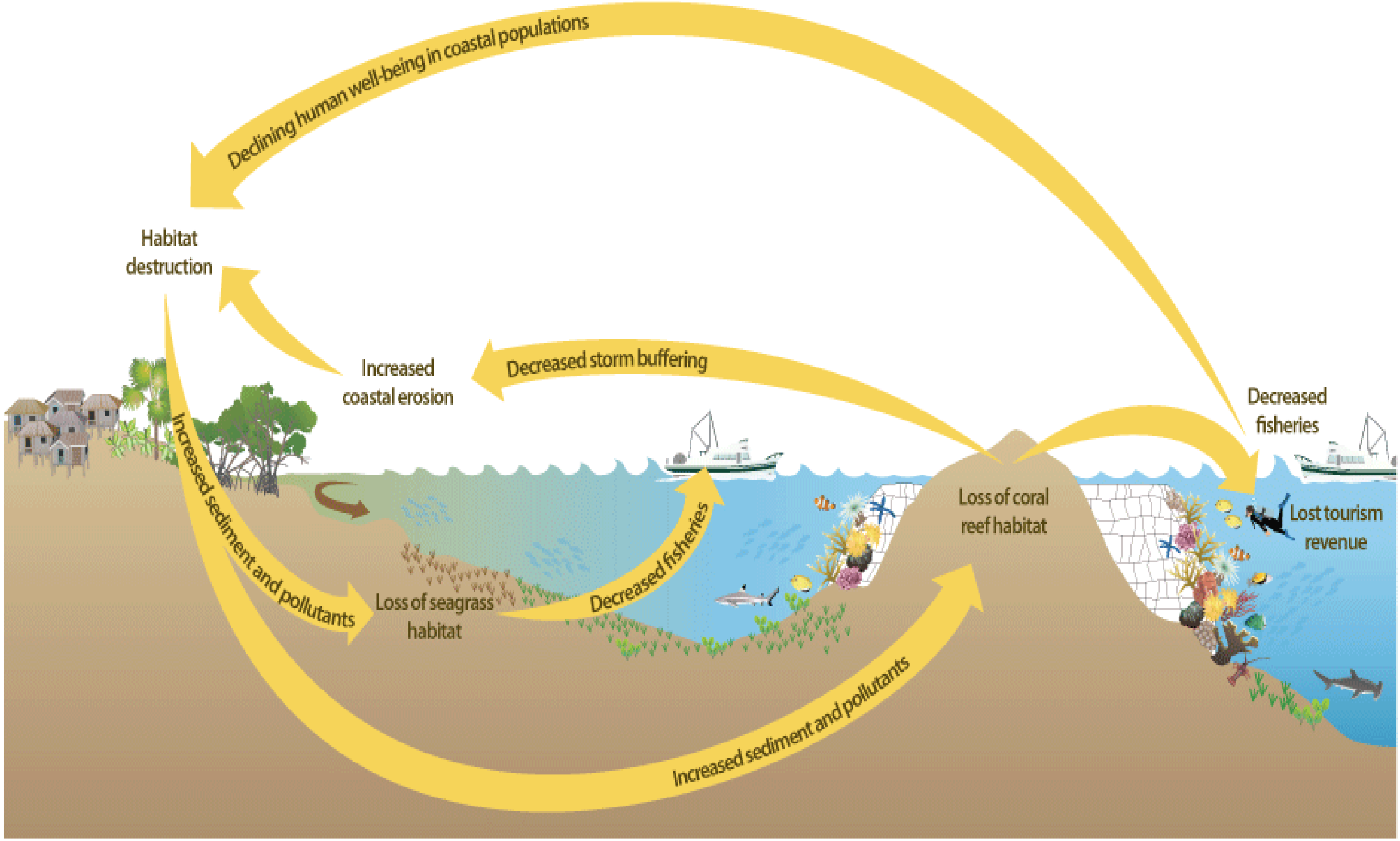
Abu Dhabi has the oldest known mangrove restoration/afforestation initiatives anywhere in the world, with some stands being nearly 50 years old. Natural and planted mangroves are fringe forests of only one species, *Avicennia marina*, a mangrove species able to tolerate the environmental conditions of high salinity, limited freshwater inflow, and high temperatures which are present in this part of the Gulf. The mapping component of the Abu Dhabi Blue Carbon Demonstration Project presents data on Blue Carbon ecosystem coverage and suggests Abu Dhabi currently has approximately 14,117 hectares of viable mangrove (AGEDI, 2013). Most of the mangroves are small (1-3 meters in height) however mangroves in the north-eastern part of the Emirate are slightly taller (and may be tapping into extra nutrients or freshwater sources). These more developed natural ecosystems, as well as the older plantations, are assumed to be delivering a number of other ecosystem services beyond carbon sequestration.

Seagrass meadows are extensive in Abu Dhabi and represent one of the largest expanses in the world. The geographic component of the Project indicates approximately 158,262 hectares of natural seagrass meadow exist in Abu Dhabi (AGEDI, 2013). As this extent is based upon the amalgamation of remote sensing imagery to 3.5m and local expert knowledge, this is considered to an underestimate of the actual extent of seagrass, particularly as this was found to be widespread below 10 metres. Seagrass is an important feeding, breeding, and nursery ground for many marine species (it is estimated that over 75% of the myriad fishery species in Abu Dhabi may rely on mangrove or seagrass or both for production (see Aburto-Oropeza et al. 2008). Abu Dhabi seagrass meadows, particularly those in the western region, support the world's second largest population of dugong and feeding habitat for other sea turtle species as well). In addition, seagrass supports other ecosystems of recognized value, such as the coral reefs that are the focus of Abu Dhabi's growing dive industry. Seagrass meadows can also act as a buffer to help regulate storm surges caused by shamal winds or other meteorological events. Finally, along with mangrove and salt marsh, seagrass acts to trap sediment and stabilize the sea floor, removes any overabundance of nutrients in the water, and secures heavy metals and other pollutants in the plants tissue, thereby reducing the amount of pollutants that might otherwise taint seafood.

Salt marshes and coastal sabkha are relatively less frequent than seagrass meadows. The xeric (ecosystem adapted to extremely dry conditions) salt marshes cover an estimated 4,770 hectares of coastline, and coastal sabkha accounts for a small proportion of overall sabkha (estimated to be in excess of 300,000 hectares across the whole of Abu Dhabi (AGEDI, 2013). These coastal ecosystems provide shoreline stabilization and maintain water quality, in addition to sequestering carbon, in the case of the salt marshes. More surprising is the role that algal mats (comprised of cyanobacteria, or blue-green algae, in association with other macroalgae such as *Cladophora*, along with bacteria) play in maintaining coastal and marine ecosystems. In the absence of detailed research it is possible to only surmise that these ecosystems are providing other services, including providing nutrients to support food webs, in addition to sequestering carbon. Cyanobacteria are undoubtedly fixing nitrogen in extreme environments where nitrogen fixation is not being performed by other plants or bacterial symbionts, and cyanobacterial mats can also utilize sulphur to provide base nutrients for marine food chains.

This fixation is driven in part by high-iron or other mineral inputs, as is characteristic of the Arabian Peninsula's shorelines. Cyanobacterial mats are likely to be providing other ecosystem services not provided by other Blue Carbon ecosystems, including (possibly) disease regulation and biodiversity support in the most extreme environments of Abu Dhabi. Carbon fixation by these algal mats is quite high, and algal mats are estimated to cover 3,800 hectares of Abu Dhabi's coast (AGEDI, 2013).

These Blue Carbon ecosystems are functionally or physiologically linked to each other and other marine and coastal ecosystems not considered herein. In addition, they are immutably linked to economic activity and human well-being. Figure 2 illustrates these feedback loops and benefits flows. For mangrove forests continue to provide nursery grounds for commercially and recreationally important fish populations, the two-way linkages between mangrove and offshore ecosystems such as seagrass beds and coral reefs must be maintained. Similarly, offshore systems like coral reefs create the conditions necessary for inshore systems like seagrasses to thrive; while mangroves and saltmarsh act to trap sediments and nutrients that might smother or degrade seagrasses. The delivery of goods and services from natural systems is dependent not only on the condition of the ecosystem but also its functional linkages to associated ecosystems.



SOURCE: Agardy et al. 2011 UNEP EBM Manual

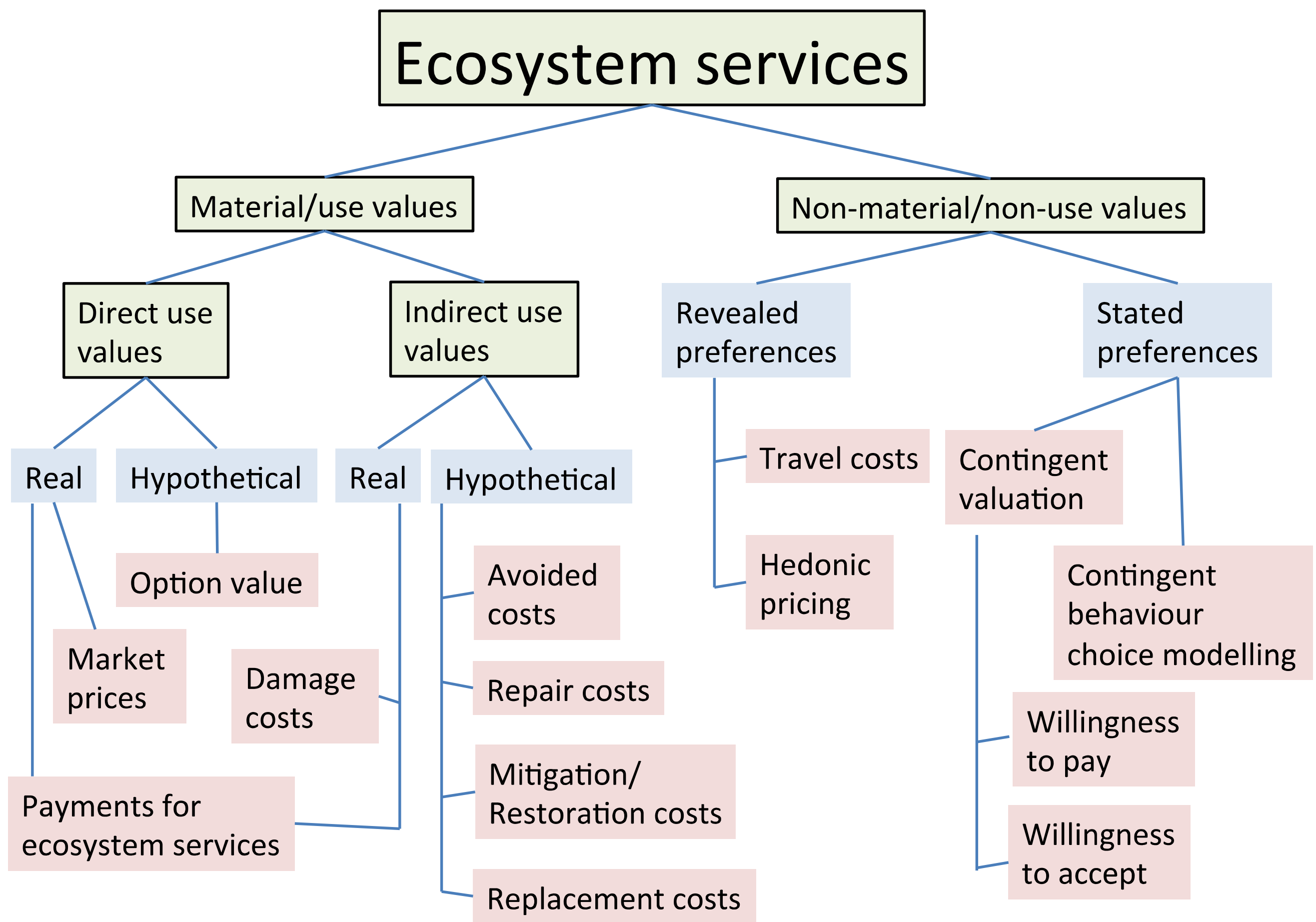
Figure 3

Assessing ecosystem services arising from Blue Carbon habitats necessitates recognising connections

2.3 Valuation of Blue Carbon Ecosystems Services in Abu Dhabi

Although neither a full assessment of all ecosystem services, nor valuation exercises to determine the true economic values of the services identified, were within the scope of this Demonstration Project, this assessment does recognise that the ecosystem services provided as co-benefits to Blue Carbon do have both market and non-market value. As "value" essentially relates to the realization of these benefits, valuation is however somewhat subjective and highly case-specific. As such, important benefits may be being provided by Blue Carbon ecosystems in Abu Dhabi (as elsewhere), which have little apparent value because those benefits are not captured on the market or assessed by non-market valuation. As illustrated in Figure 4, values can be derived that reflect either real or hypothetical value. In Abu Dhabi, as the number of valuation studies undertaken to date is limited, discussion of the value of Blue Carbon co-benefits is largely, at present, hypothetical.

Figure 4: Valuation framework (taken from Spalding 2013)



Adapted from: Spangenberg and Settele, 2010

A robust valuation framework captures all values (market and non-market). The most common, and most appropriate framework for aggregating the value of ecosystem services is Total Economic Value (TEV). According to Philcox (2007), TEV divides the value of ecosystem-based goods and services into two categories:

1) Use values: direct use value (e.g. provisioning services such as food, water); indirect use value (e.g. regulating services such as climate control, waste assimilation, water quality), and; option value (i.e. the value derived from the option to make use of a resource in the future);
2) Non-use values (including existence value, bequest value, and altruism value).

For the purposes of this assessment in its support to the overall Abu Dhabi Blue Carbon Demonstration Project, hypothetical use values based on studies from other regions have been utilised, and are discussed in relation to the case in Abu Dhabi from three different perspectives:

1) As per the hypothesized values of coastal ecosystem services to Abu Dhabi itself;
2) As per the values from a regional perspective (the Gulf region), and;
3) As per the values of these services on the global stage.

This approach allows a range of values, based on economic analyses undertaken for these ecosystem types elsewhere in the world, to be presented. With this potential range of values, and knowing the areal extent of mangrove, seagrass, salt marsh, sabkha, and algal mats as well as having some indication of their relative condition around Abu Dhabi, an estimate of total potential ecosystem services values has been generated by ecosystem type. To ensure robustness it is recommended that additional studies be undertaken to: confirm these values; understand how they are being realized in Abu Dhabi, and; use this information to inform investment in ecosystem protection.

2.4 Pressures on Blue Carbon Ecosystems Services in Abu Dhabi

In addition to assessing ecosystem services that provide co-benefits to Blue Carbon, pressures affecting continued ecosystem service delivery and the potential drivers behind some of those pressures have also been considered in outline. The aim is to assist Abu Dhabi make informed decisions in relation to costal development and Blue Carbon policies. Additional studies to consider this information in detail would additionally facilitate coastal space and resource use decisions, as well as an enhanced predictive capability as these ecosystems encounter accelerated climate change.

Wherever they occur, coastal and marine ecosystems are naturally dynamic, but recent changes affecting coastal systems worldwide are unparalleled. Services are lost or degraded when waterways are dredged, wetlands are filled or drained, ports are constructed, coastal areas are developed for tourism, industry, or housing, and when overfishing and destructive fishing occurs. At the same time, sediment transport and changes in hydrology are dramatically altered by land and freshwater use in watersheds and aquifers. In many parts of the world, too many nutrients are entering the sea, resulting in eutrophication and reduced biodiversity and ecosystem health. Toxins from land-based sources of pollution, from shipping and ports, from mining and other industries, from desalination brines, are all adding to cumulative impacts that impede the delivery of ecosystem services upon which we all depend. Coastal waters across the globe are now considered the most highly chemically altered environments anywhere. Additionally, coasts are vulnerable to major impacts from sea level rise, erosion and storm events, and are near thresholds for healthy functioning, putting coastal populations ever more in danger.

The situation in Abu Dhabi is effectively a microcosm of what is happening elsewhere at larger scales. Given the arid environment and the lack of surface water, both the positive ecological attributes of brackish water surface environments such as estuarine areas, and the negative aspects of freshwater-mediated land—sea connection (such as land-based sources of pollution, sediment starvation, etc.), are largely absent. This suggests that the coastal environment of Abu Dhabi, and the Blue Carbon ecosystems it supports, are even more critical as they are the key links in a chain that supports biodiversity, enhances ecosystem and environmental health, and in large part drives the well-being of Abu Dhabi’s inhabitants.

3 Information gathering and analysis methodologies

3.1 Overview

Extensive information on Blue Carbon ecosystems was compiled through: literature search; EAD database examination, and: interviews with stakeholders (list provided in Appendix A), largely undertaken by Ecosystem Services Assessment component lead Dr. Tundi Agardy, in conjunction with other component leads and with the support of AGEDI. A Rapid Assessment Protocol was specifically designed to quickly assess Blue Carbon sites as to their condition and their ability to generate services, and applied on seagrass ecosystems as a test case. This Protocol is provided in Appendix B.

3.2 Field Sampling

To field test the condition protocol and ensure its utility as a way to rapidly assess sites within Blue Carbon ecosystems for their potential to deliver valuable ecosystem services, the Ecosystem Services Assessment Team liaised with the science teams. While component leader Tundi Agardy was able to visit some of the Eastern Mangrove areas, field researcher Robert Irving was able to apply the protocol to a number of different Blue Carbon ecosystems. By joining the seagrass survey team in late April/ early May of 2013, he was able to fully apply the protocol in 16 seagrass sites, 2 mangrove sites, a coastal sabkha and a saltmarsh site, and several algal mat areas. For ecosystems other than seagrass, this application was intended as a test of this portion of the Demonstration Project, and not as a data collection endeavour.

3.3 Literature review of ecosystem services and value

In addition to rapid assessment using the protocol, the Ecosystem Services Assessment component team worked closely with EAD to gather published and grey literature, and examine EAD databases. Additional data and information was provided by stakeholders outside EAD. A full stakeholder consultation list is provided in Appendix A.

3.4 Data availability

Ample data are available on Abu Dhabi's coastal ecosystems, but much of them are not currently in a format to create robust valuations that can serve as the foundation for planning, for determining compensation damages, or for guiding Blue Carbon policy. In general, more information is needed on the condition of ecosystems vis a vis their delivery of ecosystem services. Such condition and trends data could be collected using the Ecosystem Services Assessment protocol. Additionally, information that is currently being collected by EAD could be made more applicable to Ecosystem Services Assessment by georeferencing. For instance, data on fish spawning and movements, data on dugong and sea turtle home range, foraging areas, and breeding/nesting areas, data on resident and migratory bird abundance and distribution, etc. could all be mapped in such a way as to allow the geographic identification of priority areas (at an even finer scale than what was performed in this Ecosystem Services Assessment). Data on human uses of the coasts and seas should also be georeferenced, to the maximum extent possible: number of boats using particular marinas or boat landing facilities, number of recreational fishers and popular fishing spots, number of divers and popular diving destinations, boat traffic patterns, etc. Finally, it would be useful to get additional data on property values and usage, as in occupancy rates for coastal hotels and resorts, visitation rates at beaches, capital and operating investments in coastal infrastructure, etc. All this data collection can and should occur independent of any specific economic valuations that might explore actual willingness-to-pay or contingent valuation.

4 Results: Blue Carbon Ecosystem Services in Abu Dhabi

4.1 Ecosystem Services Assessed

Four major classes of ecosystem services being generated from Blue Carbon ecosystems were investigated: each grouping a combination of provisioning and regulating services. The four classes comprise:

1) Shoreline stabilization, erosion control, and buffering land and property from storm surges;
2) Maintenance of water quality;
3) Enhancement of fisheries production;
4) Support to biodiversity and ecological communities; and, in turn, maintenance of cultural, aesthetic, and recreational values.

These ecosystem services, and their potential and/or realized values at the local, regional, and global scale, are discussed separately for each Blue Carbon ecosystem.

4.1.1 Mangroves

Mangrove forest occurs as natural ecosystem and as plantation forest across much of Abu Dhabi's coastal strip. Afforestation of mangrove stands (i.e. purposeful planting of saplings) has been on-going in Abu Dhabi since the mid 1960's, and some of the older plantations are now mature forests that likely provide many of the same ecosystem services as natural mangrove. Mangrove acts to stabilize navigation channels and shorelines, prevent inundation from sea level rise and from shamal-induced flooding of coastal property by the sea (Ellison 2010). Mangrove is also one of the most important buffers against catastrophic flooding brought about by cyclones or tidal waves (Arkema et al, 2013).

Like saltmarsh, mangrove trees can export nutrients to the nearshore environment, and they most certainly trap sediments (in Abu Dhabi entering the sea mainly through atmospheric deposition in natural conditions, and by sediment release during in-filling, dredging, and coastal constructions). They also act to trap heavy metals and other toxins, and to some extent they can maintain salt balances (though this service is likely overcome by the high salinity of Gulf waters, exacerbated by the addition of brines from a multitude of desalination plants across the region). Thus mangrove plays a critical role in maintaining water quality, even as groundwater, freshwater, and seawater become increasingly degraded.

Mangrove channels and tide-inundated mangrove support a variety of fisheries species through provision of nursery habitat. Recent studies have quantified this contribution to fisheries production, by gauging estimated losses in terms of fisheries yield and profitability once mangrove is deforested. At the same time, mangrove supports broader avian, fish, crustacean, mollusc, and sponge diversity, and may be one of the most important supporting service-providing ecosystems across the globe as well as at a local level.

4.1.2 Seagrass

Seagrass provides feeding and breeding grounds for most neritic species that live in tropical and subtropical environments. It has been estimated that some 80% of coastal fisheries species rely on seagrass during some part of their life histories. The nitrogen-fixing ability of the seagrass rhizomes allows these aquatic flowering plants to thrive even in the low-nutrient conditions typical of tropical seas. Therefore while the biodiversity of a seagrass meadow at any point in time may be relatively low (especially when compared with coral reefs, or with transitional ecosystems like estuaries and mangroves), the cumulative biodiversity can be high, with support to extensive food chains (van Lavieren et al 2012). Component species of seagrass meadows, such as tunicates, exert controlling effects on phytoplankton production and thus support wider food webs (Agardy and Alder, 2005; Tampa Bay Study Group 1998).

Abu Dhabi's dugong population is thought to be the world's second largest (currently about 3000 individuals), but with apparent losses of 20-25 individuals a year this could lead to population levels below minimum viable population size and thus collapse if trends continue. Both dugong and sea turtles (green and hawksbill sea turtles) are flagship and umbrella species, indicating ecosystem condition, and both rely on intact and productive seagrass for feeding. Seagrass is especially important for the herbivorous green sea turtle, for which the main source of food in the region appears to be Abu Dhabi's seagrass meadows. Sea turtles are also used traditionally. In such cases seagrass has added value of supporting a culturally important traditional use, though whether this is sustainable is open to debate, given the population dynamics of sea turtles in the Gulf region.

Seagrass, like mangrove, acts as a buffer against storm surge, tsunamis, and other catastrophic events, including significant shamals. Plants retain the sediment on the soil, keeping it from being deposited along the shoreline in severe weather events. Similarly, seagrasses stabilize the sea floor, providing a stable environment for infauna (meiofauna and burrowing clams, worms, etc.) as well as demersal marine species. These functions are commonly lost when seagrass is physically damaged. Seagrass meadows can be directly damaged during dredging or infilling, and indirectly affected by pollution (particularly sediments and excessive nutrients), over-fishing, species invasions, and losses of key component species through collection or displacement by invasives. When these factors act in concert, as they do in most stressed coastal and marine ecosystems worldwide, the results can be catastrophic for seagrass. Damaged or degraded seagrass can be restored (Ganassin and Gibbs 2008), but restoration takes time, is highly expensive, and is only successful under optimal conditions.

4.1.3 Salt marsh

Abu Dhabi's salt marshes differ from those in temperate environments with major watersheds as they exist in highly saline environments, have sparse vegetation (for the most part) and are typically bordered by xeric vegetation or coastal sabkha. Nonetheless, the salt tolerant plants of the salt marshes do provide services such as the filtration of water, and the stabilization of the shoreline. This shoreline stabilization acts by reducing wind erosion and erosion from tidal inundation or storm surges, including shamal events. Dune plants have an added aesthetic value which is difficult to quantify monetarily, however in Abu Dhabi astute developers and resort owners such as the Monte Carlo Beach Club on Saadiyat Island have recognized their value and have not only avoided destroying dune vegetation but actively engage their clients in minimizing impacts on this ecosystem. Through signage at the Club, guests are informed that the dune vegetation provides a specific ecosystem service of value: stabilizing the beach for the use by nesting sea turtles, a much-admired iconic species.

4.1.4 Coastal Sabkha

Abu Dhabi is recognised as hosting the world's largest coastal sabkha, 300km long and extending in places more than 20km inland (Evans and Kirkham, 2002). Coastal sabkha comprises the seaward part of the sabkha, and mostly is not flooded by normal astronomical tides but is flooded several times a year when exceptionally strong Shamal winds which drive seawater inland. The Carbon Baseline Assessment determined that although there was no evidence of active carbon sequestration within this ecosystem, there was evidence that in places, coastal sabkha does cap buried former Blue Carbon ecosystems and is therefore considered an associated Blue Carbon ecosystem. In addition to its relationship with Blue Carbon, sabkha provides a unique ecosystem for species and a unique landscape for those interested in Abu Dhabi's varied environments.

Coastal sabkha provides important terrestrial ecosystem services unlike any other when found above the high tide mark; below it and in the coastal sabkha provides valuable habitat for migratory, transient, and resident fish species, as well as birds and other taxa. Both forms contribute to Abu Dhabi's unique landscapes, and likely act to safeguard archaeological and paleontological sites from erosion (Barth and Boer 2002; Beech and Hellyer 2005).

4.1.5 Algal Mats

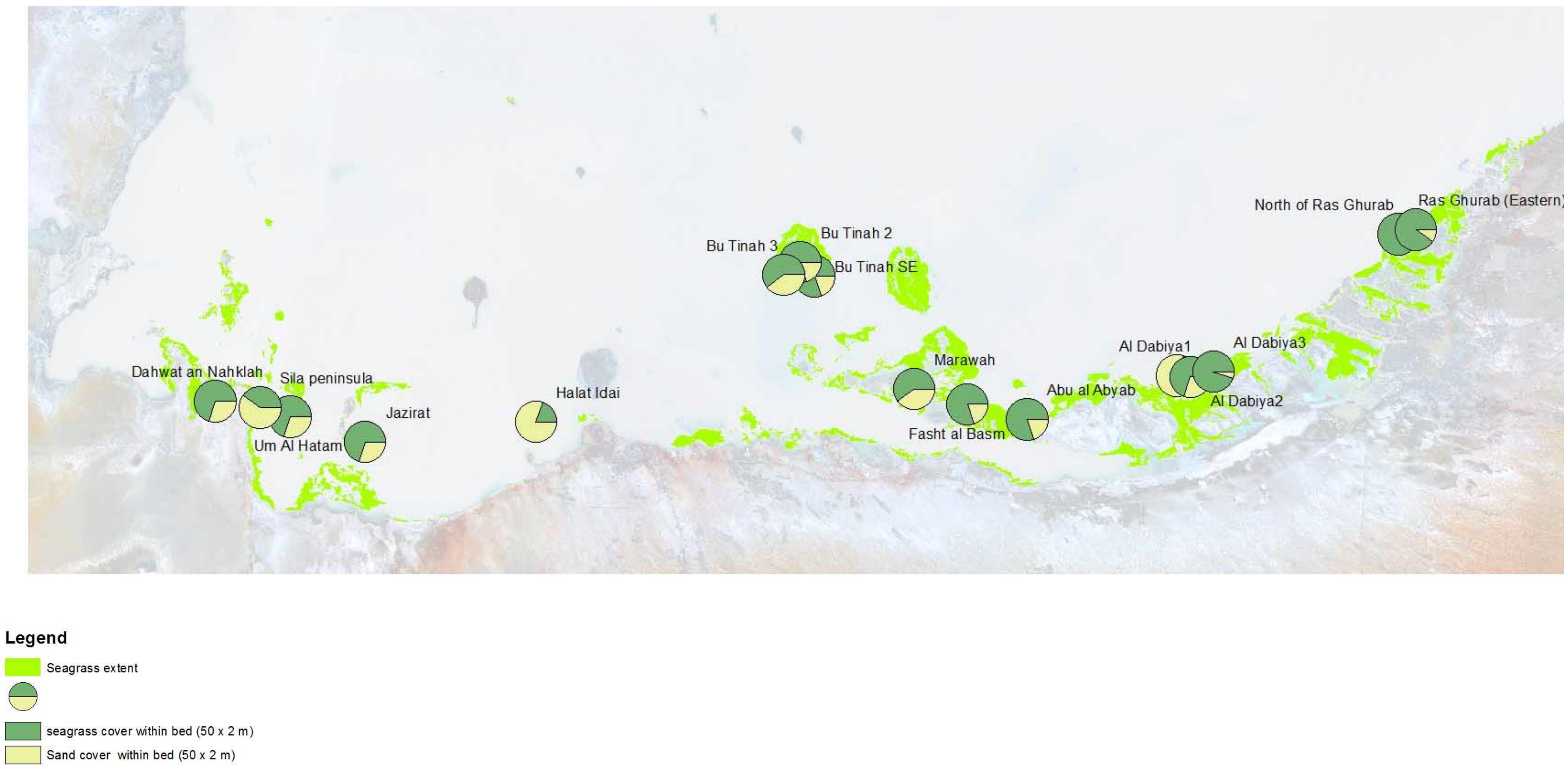
Cyanobacteria are critically important in nitrogen fixation, especially in environments where other nitrogen-fixing plants are absent or rare. Cyanobacterial mats are diazotrophic, in that they use atmospheric dinitrogen (N_2) as the source of nitrogen (Stal *et al., 2010)*. These mats sequester large amounts of carbon and likely export that carbon to adjacent ecosystems. But the intrinsic life of the algal mat is also noteworthy: cyanobacteria live in close association with sulphur-fixing and other bacteria, other algae, and even viruses. Paradoxically, these bacteria and viruses may play a role in suppressing the spread of pathogens into other environments, much like the sea surface microlayer achieves this for the open ocean (Colwell, as cited in Agardy and Alder 2005).

4.2 The Condition of Blue Carbon Ecosystems

To determine the condition of Blue Carbon ecosystems, vis a vis their ability to maintain resilience in the face of environmental change, support ecological processes, and deliver ecosystem services of value, a protocol was devised to rapidly assess a sample of habitats.

The Blue Carbon Ecosystem Condition Assessment Protocol was developed to be applied as a rapid assessment technique to determine the condition of these habitats as it relates to ecosystem services delivery (primarily use values, though existence values are corollary considerations). The protocol can be applied to Abu Dhabi's (or other) main Blue Carbon ecosystems, including mangrove, seagrass, salt marsh, sabkha, and algal mat. In addition, it can be applied to associated ecosystems such as oyster beds and coral reefs. During the study period, the protocol's application was tested on a number of different Blue Carbon ecosystems, mainly seagrass (16 sites) but also including 2 mangrove sites, a coastal sabkha and a saltmarsh site, and several algal mat areas. Again, for ecosystems other than seagrass, this application was intended as a test of this portion of the Demonstration Project, and not as a data collection endeavour. For future studies it is recommended that the protocol be applied to a wide sample of Blue Carbon ecosystems for baseline assessment and confirmation of modelled findings; in addition, the protocol can and should be used as a monitoring tool to determine the trends in condition of Blue Carbon ecosystems and their provisioning of valuable services.

The results of the protocol application suggest that the Abu Dhabi seagrasses sampled are in relatively good condition. Although not pristine, it is functionally healthy. As Figure 5 illustrates, the overall condition of seagrass did vary and sites exhibiting the best condition attain high scores for different reasons. One cluster of sites (A28.1, M02.1, M05.1, M06.3, M07.1, and M07.2) positively correlate with optimal water depth, the presence of dugong feeding trails, and sea urchin abundance. Another cluster of sites (A28.2, A29.2, A30.1, M02.2, M05.3, and M07.3) ranks high because of low erosion and low seagrass epiphyte cover. A third cluster of sites (A29.1, M06.1, M06.2) positively correlates with high seagrass cover (in quadrate and transect), along with the presence of macroherbivores, and animal burrows. Per cent cover of seagrass, an indication of overall productivity, varied from 20 to 90%. A detailed analysis of seagrass condition is included within Appendix C and Appendix D.



SOURCE: (AGEDI, 2013). Note that the percentage cover of seagrass is indicated by the dark green portion of the accompanying pie charts.

Abu Dhabi Blue Carbon Demonstration Project

Figure 5

Distribution of Seagrass and Seagrass sample sites (16 in total)

For future studies it is recommended that the protocol be applied to a wide sample of Blue Carbon ecosystems for baseline assessment and confirmation of modelled findings. For example, if applied to a variety of sites of varying condition, it can be expected to be more discriminating. In the case of the sites sampled for the seagrass, these were the sites where carbon stock was also being assessed and therefore consisted of relatively large and intact habitats. In addition, the protocol can and should be used as a monitoring tool to determine the trends in condition of Blue Carbon ecosystems and their provisioning of valuable services.

For Blue Carbon ecosystems other than seagrass, the Ecosystem Services Assessment has relied on relative carbon values as an indicator of ecosystem age or maturity, health, and productivity. Presumably more mature mangrove, salt marsh, and sabkha will be support more ecological functions than early stages of these ecosystems, all other things being equal. For this reason, relative carbon values were considered as an approximation of relative condition, and relative ability to deliver a full suite of services. This proxy assessment was then refined according to location of the Blue Carbon ecosystem: its proximity to threats, as well as its concurrence or proximity to assets of value (natural and manmade).

4.3 Relation of Condition to Delivery of Services

Applying the rapid assessment protocol facilitated the ranking of ecosystems in relation to their health and service delivery. In the case of seagrass, the areas most likely to be delivering high levels of ecosystem services, including feeding and breading grounds for most neritic species as well as feeding grounds for some of Abu Dhabi's marine protected species (section 4.1.2), were found at Al Dabiyah

As the sites sampled for the seagrass were relatively large and intact and these were the sites assessed for carbon stock, it is hypothesized that in terms of mangroves, that the areas sequestering the most carbon, especially in habitat tracts of relatively large size, are those most likely to be delivering more services than other, less productive or smaller tracts. In addition, in the case of sabkha and salt marsh, systems ecology studies (e.g. Lavieren et al 2011) support this claim that the greater the carbon sequestration, the more ecological functions are being performed, and the greater the delivery of services. Although there is limited information on algal flats, the same has been assumed for this ecosystem.

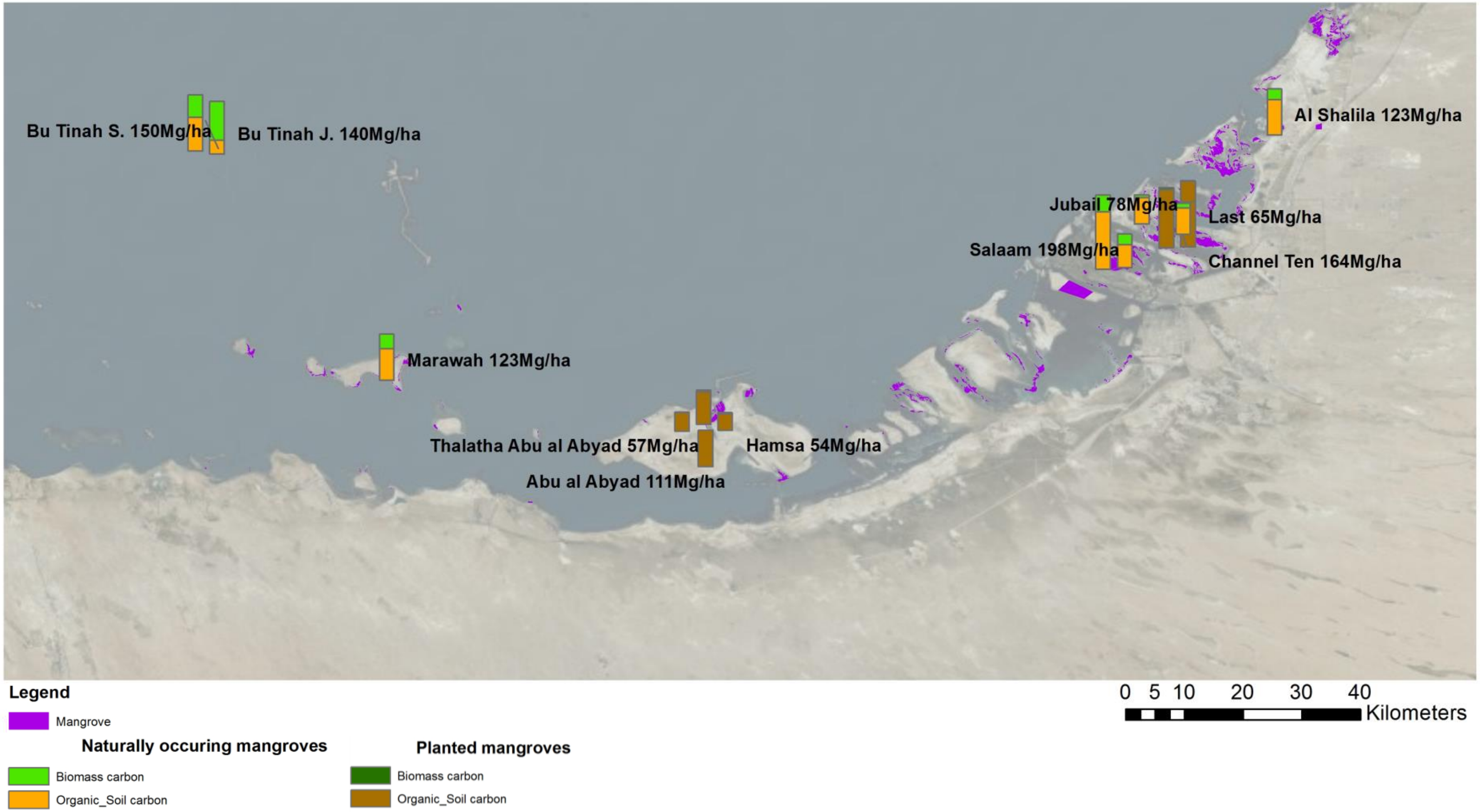
Table 1 provides information obtained by the Abu Dhabi Blue Carbon Baseline Assessment surveys, showing median, mean and standard deviation for carbon stocks in the five Blue Carbon ecosystems assessed. Coastal sabkha is not included in the Blue Carbon maps, however the sabkha ecosystems are included in consideration of algal mats, since these occur in association with sabkha. Figures 6-9 illustrate the location of these sampled Blue Carbon sites along with carbon values derived.

Table 1: Carbon stock data and assumed greatest ranges in condition (in descending order, with greatest variability in condition presented first, least variability last (sabkha not included)

Ecosystem	Median	Mean	StDev	S.E.	± 95% C.I.	n
Salt marsh	69.15	81.07	50.12	9.15	17.93	5
Mangrove	98.29	115.49	64.16	7.04	13.80	15
Seagrass	51.62	49.56	29.56	6.97	13.66	18
Algal flat	133.83	129.07	40.98	11.36	22.27	5

Using information on carbon levels as a proxy for other ecological functions, the highest productivity Blue Carbon sites studied can be ascertained. However, it should be noted that in the cases of plantation mangrove, or in the case of restored seagrass, it is not guaranteed that the services being generated in healthy, natural equivalent ecosystems are necessarily being provided by these 'artificial' or 'artificially-enhanced' ecosystems. Due to the underlying assumption that plantation mangrove may not necessarily provide the same ecosystem services as natural mangrove (at least insofar as connections with other linked ecosystems allow for "delivery" of services to other areas), we emphasize natural mangrove distribution and productivity as the main provider of Blue Carbon co-benefits, along with seagrass.

Figure 10 provides an indication of the highest levels of ecosystem functioning among Blue Carbon ecosystems of Abu Dhabi. These areas can be considered the highest generators of regulating and supporting services, although this does not necessarily include provisioning services (as these services are defined by use of goods or service).



SOURCE: (AGEDI 2013).

Abu Dhabi Blue Carbon Demonstration Project

Figure 6

Natural and plantation mangrove strands carbon values from sampled sites

SOURCE: (AGEDI 2013).

Abu Dhabi Blue Carbon Demonstration Project

Figure 7

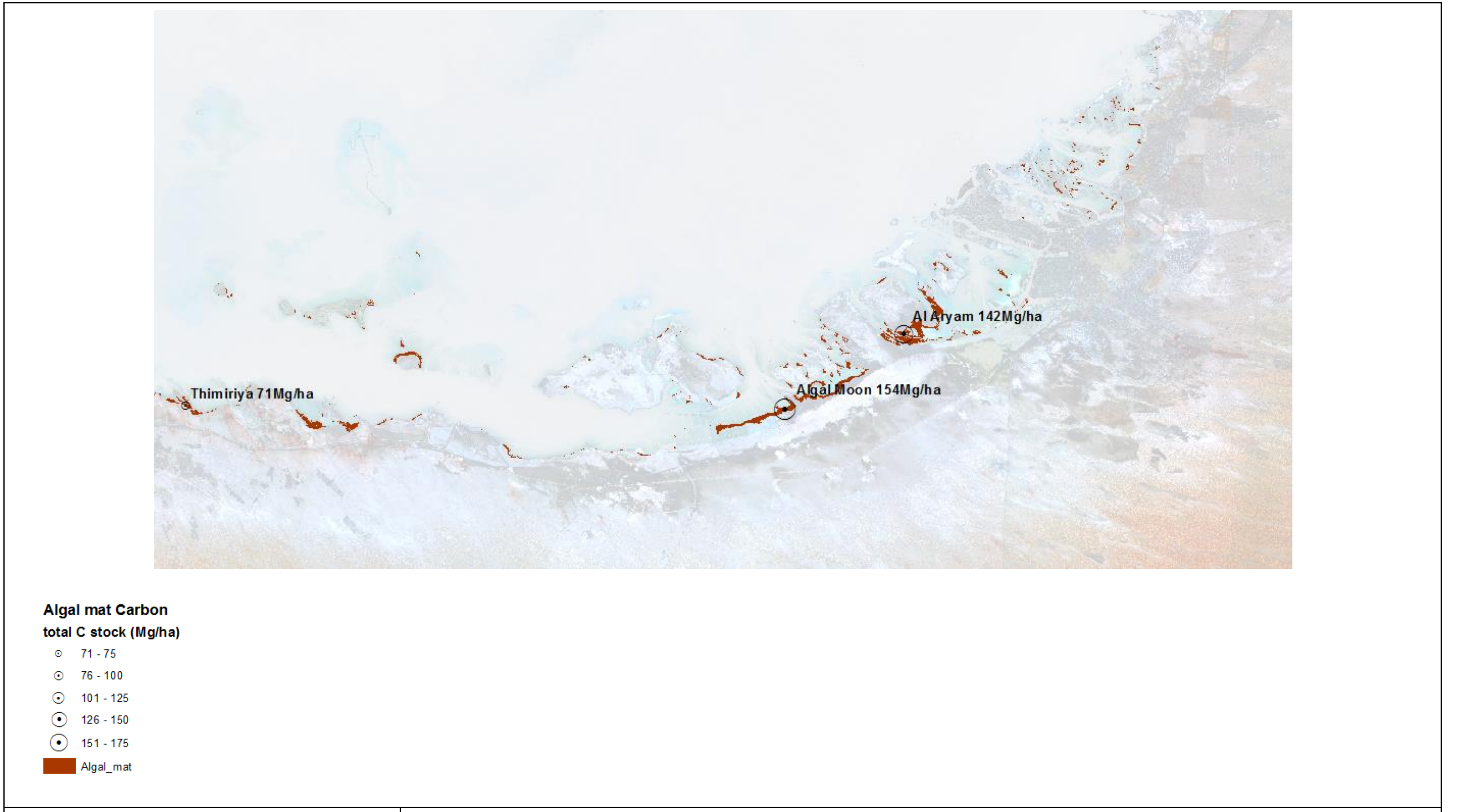
Seagrass carbon values from sampled sites

SOURCE: (AGEDI 2013).

Abu Dhabi Blue Carbon Demonstration Project

Figure 8

Salt Marsh carbon values from sample sites

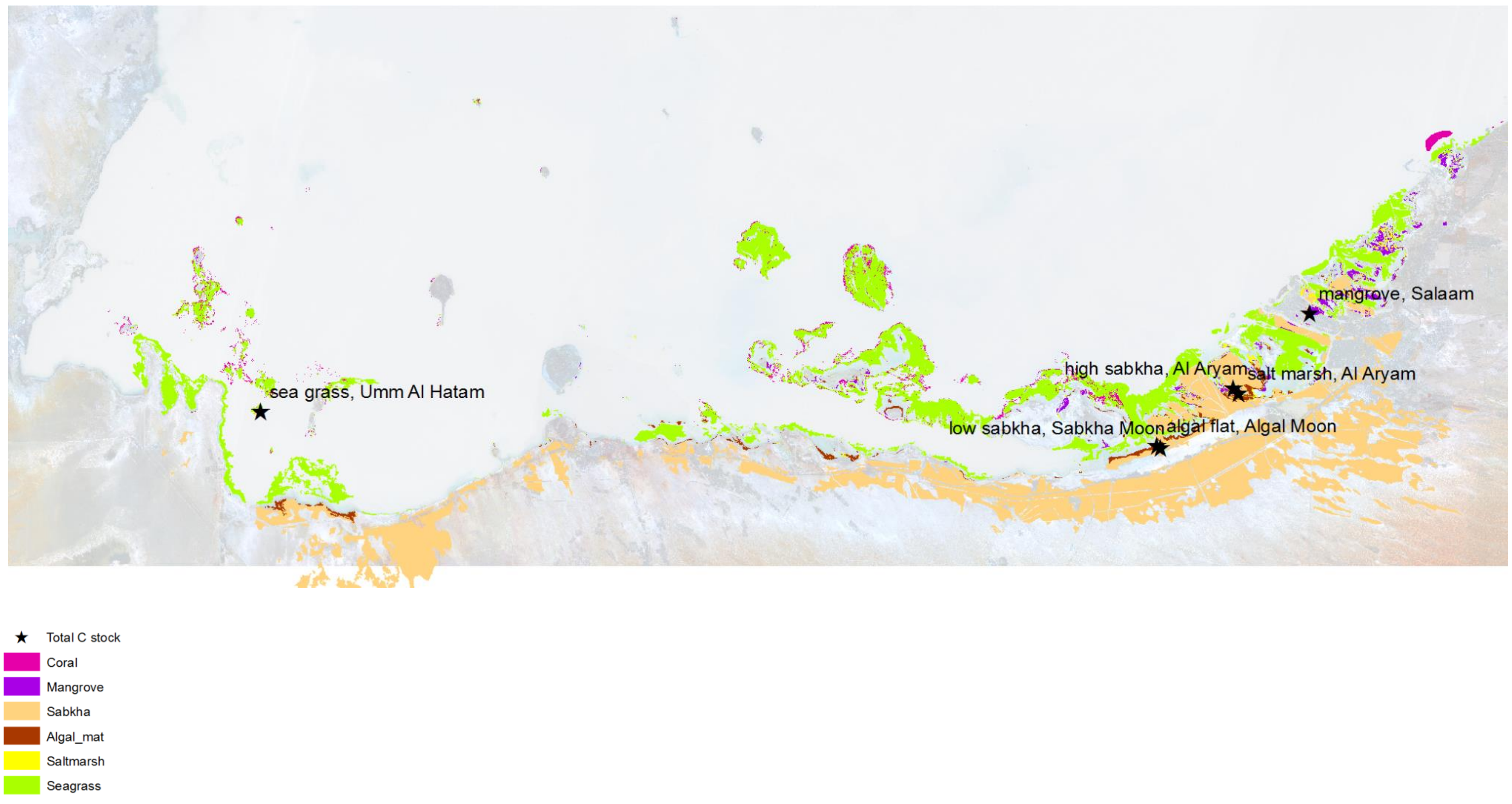


SOURCE: (AGEDI 2013).

Abu Dhabi Blue Carbon Demonstration Project

Figure 9

Algal Mat carbon values from samples sites



Abu Dhabi Blue Carbon Demonstration Project

SOURCE: (AGEDI 2013).

Figure 10

Highest levels of carbon being delivered from Blue Carbon ecosystems samples, with indication of highest overall ecosystem services delivery arising from these ecosystems

5 Interpretation: Valuation of Blue Carbon Ecosystem Services in Abu Dhabi

5.1 Ecosystem Service Valuation

Relative quantity of services being delivered provides an important base for planning. However, knowing the economic values associated with those services can provide decision-makers with even more robust information. Undertaking Ecosystem Service Valuation (ESV) can be a complex and time consuming task as the ecological and social information required to accurately calculate the different facets needed to determine the monetary value of a particular service can be difficult to collect and analyse. Developing direct measures of the value of each service is challenging due to either lack of scientific understanding on ecosystems or lack of available data on the economic conditions associated with the commodities.

ESV has however been shown to be a critical component of decision-making in a variety of situations:

a) ESV can help prioritize conservation and management efforts in the context of constrained budgets and personnel. Options can be identified to maximize benefits to people by protecting and maintaining specific ecosystem services over others;
b) ESV can also be used as a negotiation tool, a basis for discussion, where stakeholders can participate to discuss the assumptions and parameters of ESV (Pearce and Seccombe-Hett 2000);
c) Monetary values for ecosystem services can be formally included in Cost Benefit Analyses that are the foundation of making decisions on trade-offs. In this way, ESV can allow decision-makers to optimize social well-being by making choices that emphasize the benefits over the costs (Liu et al 2010);
d) ESV can be used to set prices and determine the amount payable within the context of a willingness-to-pay or receive approach. Payments for Ecosystem Services (PES) such as entrance fees to MPAs or World Heritage Sites can be built on ESV;
e) In the case of environmental damage such as ship grounding on reefs or oil pollution from a leaking vessel, ecosystem service degradation can be compensated for before (in anticipation) or after (remediating and restoring damage) environmental accidents; Ecosystem service values can also provide guidance in administrative prosecution or court proceedings and rulings (OECD 2010);
f) ESV has been used for awareness raising, justification, and persuasion as it provides clear economic arguments by placing monetary values on services that then bolsters environmental arguments in political debates and is more likely to influence choices and decision-making (Gomez-Baggethun et al 2010).

A holistic understanding of ecosystems, the services they provide in a concise socio-economic context and their importance (ecosystem values) is essential to develop an ecosystem-based management approach (McLeod and Leslie 2009). Economists sometimes measure the value of ecosystem services to people by estimating the amount people are willing to pay to preserve or enhance these services. Values are always context specific as they change across space and time. As such, it is critical to have the following basic information in order to value services provided by a site or an ecosystem and be able to spatially map them:

a) Fisheries: Landed biomass, net present value of fish and shellfish, landings' distribution and value to communities; (only data available to date were landings without georeferencing)
b) Aquaculture: Harvested biomass and net present value of fish and shellfish, distribution of biomass and value to communities; (only data available to date were number of farms)
c) Coastal protection: Avoided area of land eroded or flooded, avoided beach nourishment and costs, avoided damages to property and infrastructure, number of people affected by erosion or flooding; (no data available to date)
d) Wave energy conversion: Captured wave energy, value of captured wave energy, and environmental impact from storms; (no data available to date)
e) Recreation: Economic value of recreational activities, visitation rates, and community access to activities; (no comprehensive data available to date on tourist visitation or resident recreational activity, save number of boats registered)
f) Water purification: Filtration capacity of organisms and costs of human made water processing plants and filter systems (only data available to date are on volumes produced by desalination, no cost data available).

Both composition and functioning of ecosystems and the resultant flow of ecosystem services will directly affect socio-economic well-being. Economic value of ecosystem services depends on the condition of an ecosystem, as it affects its function and therefore its ability to deliver the services that people rely upon for their lives and livelihoods. The state of the ecosystems (or ecosystem components) that are present needs to be assessed to examine their ecological potential and economic value and capacity to provide specific ecosystem services. An ecological assessment using the appropriate field methodology for each ecosystem is a necessary part of the process, however due to the fast-tracked nature of the one year Abu Dhabi Blue Carbon Demonstration Project, seagrass ecosystems were used to test the methodology and therefore only this Blue Carbon ecosystem was assessed in this manner. For the other Blue Carbon ecosystems: mangrove; salt marshes, coastal sabkha and algal mats, a condition assessment was inferred based on carbon stock assessments (Section 4). As such the Abu Dhabi Blue Carbon Ecosystem Services Assessment provides information valuable for both guiding Blue Carbon policies, and setting a good example for rapid assessments in other regions and biomes. As Takeuchi and Je-Chul Yoo (2013) recognise in a comprehensive review of ecosystem services assessments in the Asia-Pacific region, very few included considerations of cultural value, few had a temporal component, and not all use the Millennium Ecosystem Assessment as a guiding framework. In these regards and others the Abu Dhabi assessment, although undertaken quickly and with existing information only, provides a model for other assessments.

5.2 The Potential Value of Abu Dhabi's Ecosystem Services

In the absence of economic valuations, including studies that investigate perceptions of value and willingness to pay for services of value, the quantification of ecosystem services in Abu Dhabi relies on studies from other regions. Included in Tables 2-5 are summaries of some of the economic assessments of coastal ecosystem services from other areas as presented in the literature review undertaken by Ed Barbier and his colleagues (Barbier et al. 2011). Some of these studies determined net present value for services that support marketable commodities (fisheries nursery habitat, for instance). Other studies model risk to hypothesize on the risk-reduction value provided by ecosystem services (shoreline stabilization and risk reduction in light of sea level rise and storm damage). For instance, Katie Arkema and her colleagues (Arkema et al. 2013) estimated that over the next 90 years, mangroves, coral reefs, and seagrass beds – if left intact -- would protect $4 billion US in properties from sea level rise in Florida alone. A multi-institutional review of ecosystem services values of coral reefs and associated ecosystems (Conservation International, 2008) similarly presents very high economic values for a wide range of services, from sites around the world, however these services are not disaggregated and benefits transfer to other areas may be problematic. As Ruffo and Kareiva (2009) point out, ecosystems and habitats must be individually assessed in order to make a case that a particular service is in fact being generated. This highlights the need for further, targeted, study on Blue Carbon ecosystems in Abu Dhabi as highlighted within this report.

Table 2: Examples of ecosystem services and values of mangrove, not including Blue Carbon (taken from Barbier et al., 2011); low end figures were used in benefit transfer for Abu Dhabi

Ecosystem Services	Ecosystem processes and functions	Important controlling components	Ecosystem service value examples
Raw materials and food	Generates biological productivity and diversity	Vegetation type and density, habitat quality	US$ 484 – US$ 585 $ha^{-1}yr^{-1}$ capitalized value of collected products, Thailand (Barbier, 2007)
Coastal protection	Attenuates and/or dissipates waves and wind energy	Tidal height, wave height and length, wind velocity, beach slope, tide height, vegetation type and density, distance from sea edge.	US$ 8966 – US$ 10,821/ha capitalized value for storm protection, Thailand (Barbier, 2007)
Erosion control	Provides sediment stabilisation and soil retention in vegetation root structure	Sea level rise, tidal stage, fluvial sediment deposition, subsistence, coastal geomorphology, vegetation type and density, distance from sea edge.	US$ 3679 $ha^{-1}yr^{-1}$ annualised replacement cost, Thailand (Sathirathai and Barbier, 2001)
Water purification	Provides nutrient and pollution uptake, as well as particle retention and deposition	Mangrove root length and density, mangrove quality and area.	Estimate unavailable.
Maintenance of fisheries	Provides suitable reproductive habitat and nursery grounds, sheltered living space	Mangrove species and density, habitat quality and area, primary productivity.	US$ 708 - US$987/ha capitalized value of increased offshore fishery production, Thailand (Barbier, 2007)

Table 3: Examples of ecosystem services and values arising from seagrass, not including Blue Carbon (taken from Barbier et al. 2011)

Ecosystem Services	Ecosystem processes and functions	Important controlling components	Ecosystem service value examples
Raw materials and food	Generates biological productivity and diversity	Vegetation type and density, habitat quality	Estimates unavailable
Coastal protection	Attenuates and/or dissipates waves and wind energy	Wave height and length, water depth above canopy, seagrass bed size and distance from shore, wind climate, beach slope, seagrass species and density, reproductive stage	Estimates unavailable
Erosion control	Provides sediment stabilisation and soil retention in vegetation root structure	Sea level rise, subsistence, tidal stage, wave climate, coastal geomorphology, seagrass species and density	Estimate unavailable.
Water purification	Provides nutrient and pollution uptake, as well as particle retention and deposition	Seagrass species and density, nutrient load, water residence time, hydrodynamic conditions, light availability	Estimate unavailable.
Maintenance of fisheries	Provides suitable reproductive habitat and nursery grounds, sheltered living space	Seagrass species and density, habitat quality, food sources, hydrodynamic conditions	Loss of 12,700ha of seagrasses in Australia; associated with lost fishery production of AU$ 235,000 (McArthur and Boland 2006)

Table 4: Examples of ecosystem services and values arising from saltmarshes, not including Blue Carbon (taken from Barbier et al., 2011); low end figures were used in benefit transfer for Abu Dhabi

Ecosystem Services	Ecosystem processes and functions	Important controlling components	Ecosystem service value examples
Raw materials and food	Generates biological productivity and diversity	Vegetation type and density, habitat quality, inundation depth, habitat quality, healthy predator populations	£15.27 $ha^{-1}yr^{-1}$ net income from livestock grazing, UK (King and Lester 1995)
Coastal protection	Attenuates and/or dissipates waves and wind energy	Tidal height, wave height and length, water depth in or above canopy, marsh area and width, wind climate, marsh species and density, local geomorphology	US$ 236 $ha^{-1}yr^{-1}$ in reduced hurricane damages, USA (Costanza *et al.* 2008)
Erosion control	Provides sediment stabilisation and soil retention in vegetation root structure	Sea level rise, tidal stage, coastal geomorphology, subsidence, fluvial sediment deposition and load, marsh grass species and density, distance from sea edge.	Estimate unavailable.
Water purification	Provides nutrient and pollution uptake, as well as particle retention and deposition	Marsh grass species and density, marsh quality and area, nutrient and sediment load, water supply and quality, healthy predator populations	US$ 786 – US$ 15,000/acre capitalised cost savings over traditional waste treatment, USA (Breaux *et. Al.* 1995)
Maintenance of fisheries	Provides suitable reproductive habitat and nursery grounds, sheltered living space	Marsh grass species and density, marsh quality and area, primary productivity, healthy predator populations.	US$ 6,471/acre and US$ 981/acre capitalized value for recreational fishing for the east and west coasts respectively, of Florida, USA (Bell 1997) and US$0.19 – 1.89/acre marginal value product in Gulf Coast blue crab fishery, USA (Freeman 1991)
Tourism, recreation, education, and research	Provides unique and aesthetic landscape, suitable habitat for diverse fauna and flora	Marsh grass species and density, habitat quality and area, prey species availability, healthy predator populations	£31.60/person for otter habitat creation and £1.20/person for protecting birds, UK (Birl and Cox 2007)

Table 5: Examples of ecosystem services and values deriving from shoreline habitats (dunes, sabkha, etc.), not including Blue Carbon (taken from Barbier *et al., 2011)*

Ecosystem Services	Ecosystem processes and functions	Important controlling components	Ecosystem service value examples
Raw materials and food	Provides sand of particular grain size, proportion of minerals	Dune and beach area, sand supply, grain size, proportion of desired minerals (e.g., silica, feldspar)	Estimates unavailable for sustainable extraction
Coastal protection	Attenuates and/or dissipates waves and reduces flooding and spray from sea	Wave height and length, beach slope, tidal height, dune height, vegetation type and density, sand supply	Estimate unavailable.
Erosion control	Provides sediment stabilisation and soil retention in vegetation root structure	Sea level rise, subsistence, tidal stage, wave climate, coastal geomorphology, beach grass species and density	US$ 4.45/household for an erosion control program to preserve 8km of beach for Maine and New Hampshire beaches, USA (Huang *et al.,* 2007)
Water catchment and purification	Stores and filters water through sand; raises water table	Dune area, dune height, sand and water supply	Estimates unavailable
Maintenance of wildlife	Biological productivity and diversity, habitat for wild and cultivated animal and plant species	Dune and beach area, water and nutrient supply, vegetation and prey biomass and density.	Estimates unavailable

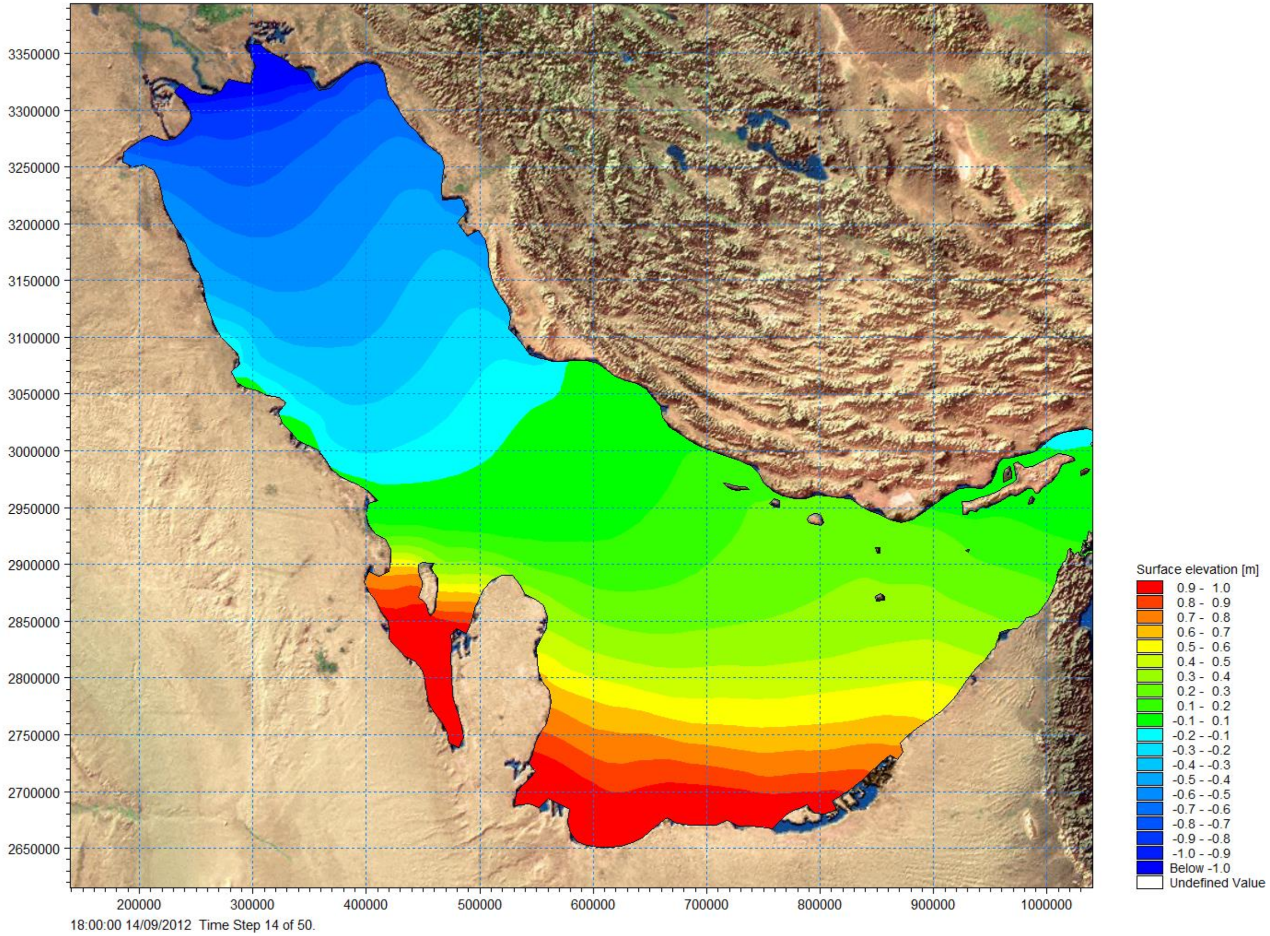
A rigorous look at ecosystem services values must both appraise net present value and perceptions of value; and must also look into the future. The two considerations that must be addressed in this regard are how value changes over the passage of time (including, but not limited to, discounting rates) and the sustainability of stocks (for goods) and services (Bateman et al. 2011). It is thus recommended that future work target the development of predictive models that can better elucidate trade-offs. The result will lead to conserving and enhancing as much as possible of Abu Dhabi's Blue Carbon ecosystems, which will in turn yield valuable ecosystem services for many years to come.

In the following section the information on Abu Dhabi's Blue Carbon ecosystems assessed in terms of their potential contribution of services is aggregated, with discussion of each major ecosystem service presented individually.

5.2.1 Shoreline and Channel Stabilisation, Erosion Control and Storm Surge Buffering

Though there is not much longshore drift in Abu Dhabi's nearshore environment, mangroves and other Blue Carbon ecosystems may nevertheless be important for shoreline stabilization, as they are in other locations where they occur around the world (McIvor et al., 2012, 2013). Cyclonic events are probably more of a threat than chronic erosion or sea level rise, although the preponderance of investment in development is taking place along the shore and on islands, suggesting that sea level rise may increasingly be a concern. Catastrophic events are nonetheless considered a greater risk because they are difficult to anticipate. According to one of the stakeholders interviewed, a single shamal event in Dubai caused a 50cm drop in sea level in 5 minutes, then a 1.5m rise in the next five minutes. Intergovernmental Panel on Climate Change (IPCC) forecasting of increased intensity and frequency of storm events in a climate-changed future suggest vulnerabilities can be expected to increase. Earthquake-generated tsunamis and storm surges are also a threat to coastal property that can be mitigated by Blue Carbon ecosystems (Alongi 2008).

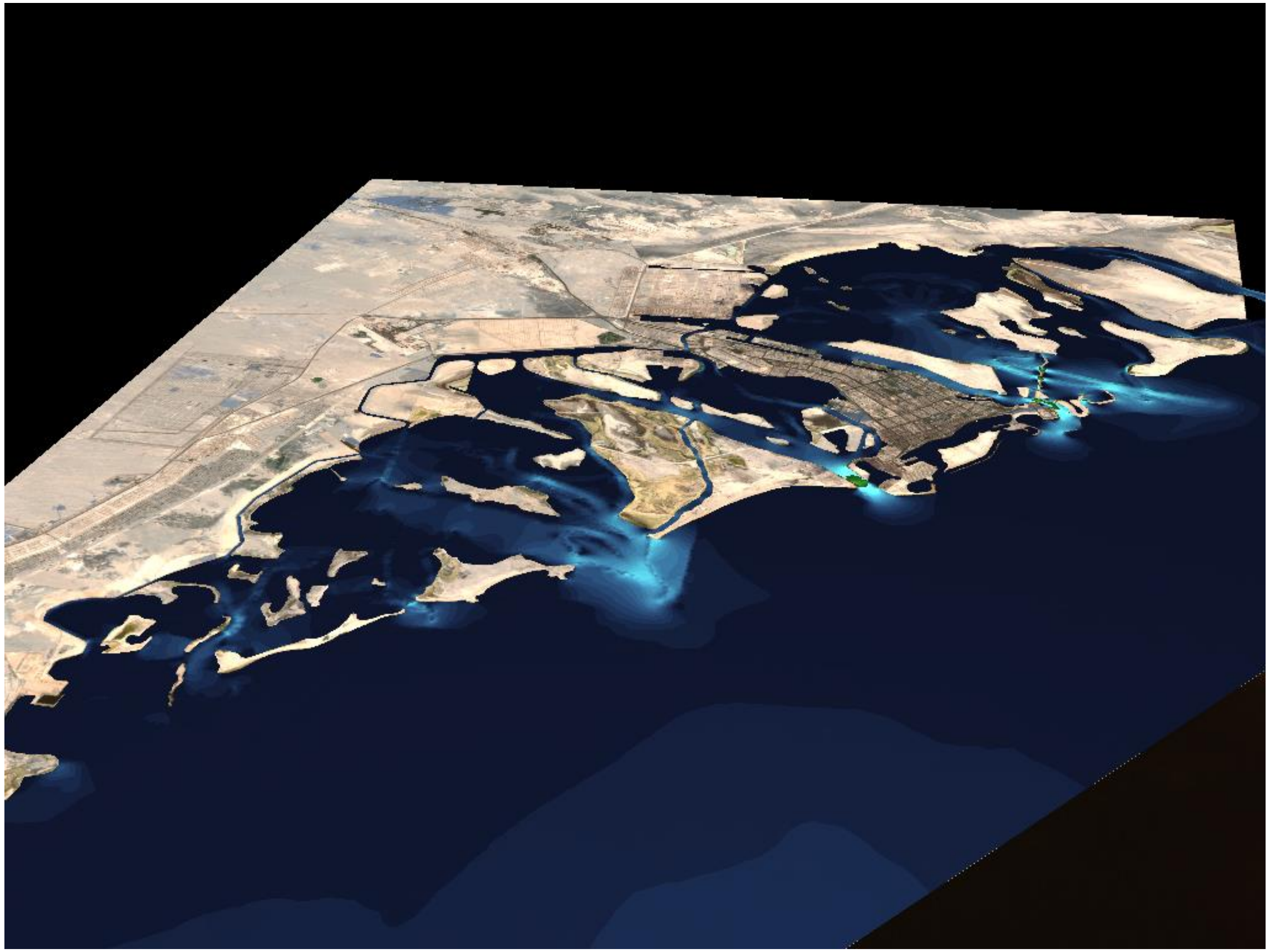
Whilst elevation and modelling at the fine scale to evaluate the contribution of Blue Carbon ecosystems to shoreline stabilization and surge buffering, has not been undertaken, existing models can give some indication of risk reduction performed by natural and planted Blue Carbon ecosystems. Figure 11 shows the storm surge build up of water as modelled for a typical intense wind event across the whole of the Arabian Gulf. Figure 12 illustrates a hydrographic model of the coast in the Abu Dhabi City region. The presence of mangrove in the Eastern mangroves and within the city itself can be expected to mitigate such surge activity.



SOURCE: Baird & Associates

Abu Dhabi Blue Carbon Demonstration Project

Figure 11
Modelled wind-induced surges across the Arabian Gulf



SOURCE: Baird & Associates

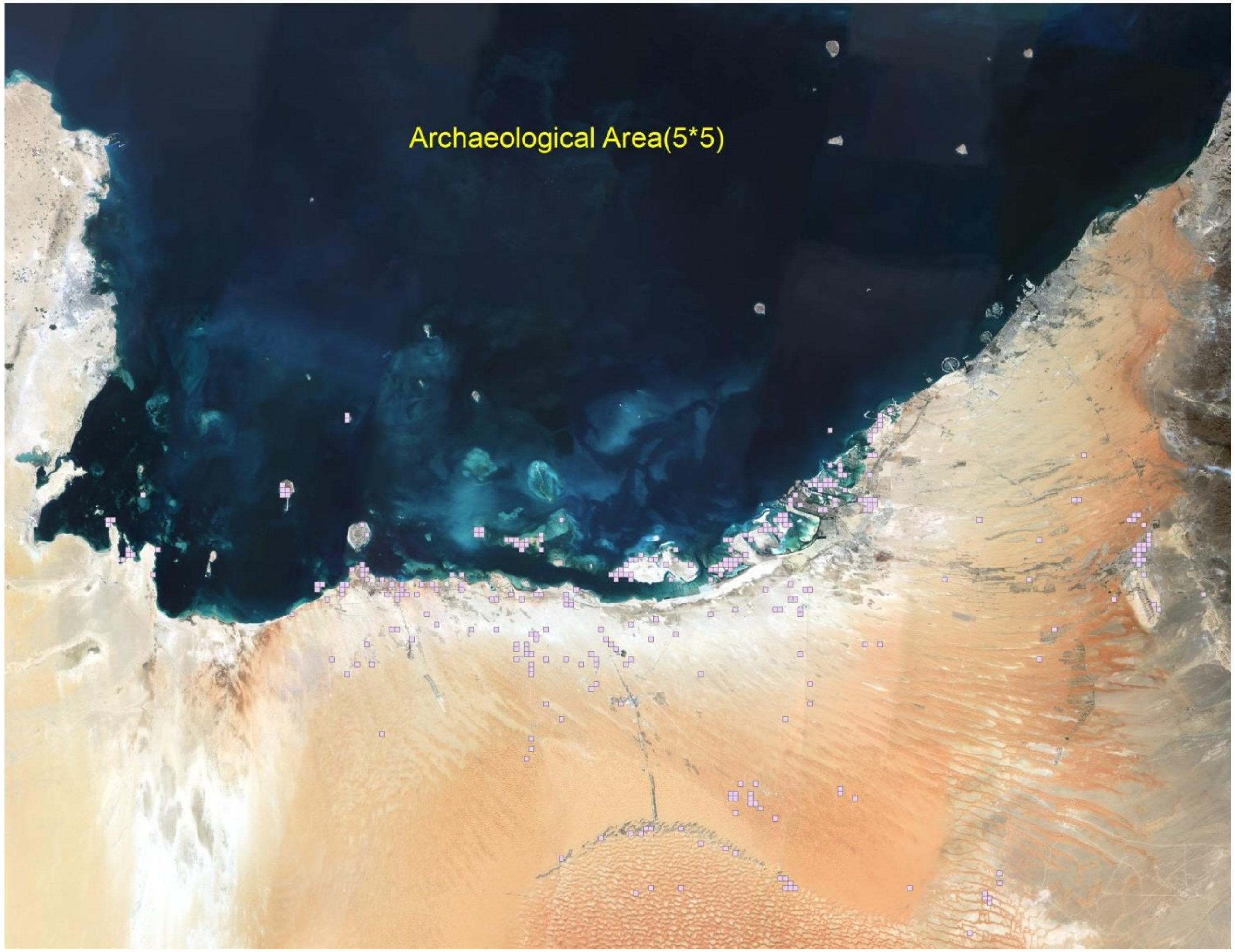
Figure 12
Modelled bottom topography around Abu Dhabi City

Many of the studies on ecosystem services derive value from costs accrued after the loss of the service (Agardy and Alder, 2005); existing ecosystem service value is thus thought of as avoided loss. For example, in Cancun (Mexico), the destruction of mangrove and poor building siting that did not obey set-backs has resulted in such severe erosion that the government spent over US$ 70 million recently to renourish resort beaches, at likely significant but unquantified cost to the source environment and the coral reefs offshore (the north end of the MesoAmerican Reef). Sand is already eroding away, this after the third major renourishment in the last ten years. In recent years sand erosion rates have been so high that hotels have had to close or limit access to grounds mid-season.

In SE Asia, the value of mangroves as a form of coastal protection was estimated at US$ 367,900---US$ 470,000 per square kilometre (Walters et al. 2008). Mangroves have also prevented extensive soil loss and water contamination that result from large storm surges; they have been found to similarly prevent declines in fisheries yields that result from storm-related changes in water chemistry, as well as declines in agricultural yields that occur as soils become salinized (Glantz 1992).

To estimate the value of shoreline stabilization and buffering performed by Abu Dhabi's Blue Carbon ecosystems, it is useful to assess what is at risk from erosion, sea level rise, and storm events. Many of the Emirates highest value assets are at risk of inundation, including office buildings and resorts, civil engineering infrastructure such as corniches, roads, and causeways, energy and desalination installations, homes and palaces, as well as cultural sites.

Abu Dhabi's Tourism and Cultural Authority (ADTCA) is working to identify and preserve valuable coastal archaeological and paleontological sites and buildings with cultural heritage value. There are 2600 of these sites throughout UAE (many of which can be seen in the EAD GIS environmental portal). There are 300 fossil sites, 300 historic buildings, and the remainder archaeological sites of various types; there is certainly no blank canvas when it comes to Abu Dhabi cultural landscape/ coasts (Michael Beech, Tourism and Cultural Authority, pers. comm.) In the western region, cultural sites are adjacent to mangrove and coastal sabkha, and many sites are on islands with a range of Blue Carbon and associated ecosystems, including the "Stonehenge of Abu Dhabi" site with Bronze Age artefacts dating to 2600-2000 BC. The value of many of these cultural assets is well recognized; prospects exist for getting some of these sites designated as Cultural World Heritage (and possibly Natural World Heritage, in combination) sites. Many cultural areas and Blue Carbon ecosystems clearly overlap, and the shoreline stabilization service (as well as any corollary benefits that can be afforded cultural sites when natural sites are protected) is immensely important. ADTCA has identified areas of special interest (Figure 13); many of these have coastal sabkha, seagrass, or mangrove in close proximity to sites and therefore may be less at risk thanks to the important buffering role played by these Blue Carbon ecosystems.



Source: EAD Geoportal

Figure 13
Important archaeological and paleontological sites

5.2.2 Water Quality Maintenance

Coastal wetlands and marine ecosystems provide the vital ecosystem service of maintaining water quality, even in the face of significant pollution inputs that result from dumping, outfall discharge, riverine inputs, and run-off from land-based sources of pollutants. In the absence of these ecosystem services, threats exist to vulnerable species and humans alike. Human health is impacted by exposure to degraded water during bathing, ingestion of tainted seafood, and indirectly by the cascading effects of poor water quality that often leads to algal blooms and fish kills. There is some evidence that tipping the water quality balance towards degradation can trigger pathogenic activity in marine dinoflagellates and in pathogenic bacteria like *Cholera vibrio* (Anderson 2009). Gilbert et al (2002) makes the link between eutrophication, harmful algal blooms, and bacterial disease, citing research in Kuwait. Degraded water also affects fisheries productivity, mariculture production, and degrades recreational and tourism experiences, including creating the conditions that lead to beach closures (Robertson and Phillips 1995).

The consequence of poor water quality that results from loss or decrease of these ecosystem services is also a feedback loop that causes ecosystem services impairment in associated ecosystems. If, for instance, salt marsh is destroyed to accommodate land reclamation, and if no additional offsetting or mitigation takes place, the impact of the resulting lowered water quality can be to cause degradation of seagrasses and coral reefs, and declines in the delivery of the ecosystem services they provide.

Lowered water quality can occur when Blue Carbon ecosystems cannot keep pace with pollution inputs, as sometimes occurs with desalination operations. The drop in water quality then bears costs for desalination, as more energy and effort needs to be put into extracting pollutants from the source water. Apropos, there are indications that the Arabian Gulf as a whole is becoming more saline in response to the massive number of desalination plants operating in the region and releasing their brines into nearshore waters (Bashitialshaaer et al, 2011). The brines contain not only salts and concentrations of the metals found in the source water, but also treatment chemicals that include heavy metals, chlorine, volatile hydrocarbon, anti-foaming, and anti-scaling agents (Abazza, 2012). The environmental impacts of desalination have been well-studied, particularly in the Middle East where desalination will be the major source of freshwater going into the future (Lattemann and Hopner 2008; NAS 2008). However, no published studies to date look at the comprehensive costs in terms of ecosystem services loss or declines in ecosystem services value, though some studies address certain values, such as the impacts on ecotourism (Abazza, 2012). In addition, desalination costs themselves increase as feed water quality diminishes; this is the result not only of brine discharge with its salts, concentrated metals that were already present in seawater, and chemical additives, but also due to the overall degradation of coastal waters from industrial discharge, shipping pollution, sewage effluents, and run-off from land (as well as atmospheric deposition).

5.2.3 Fisheries Production / Provision of Fish Nursery Habitat

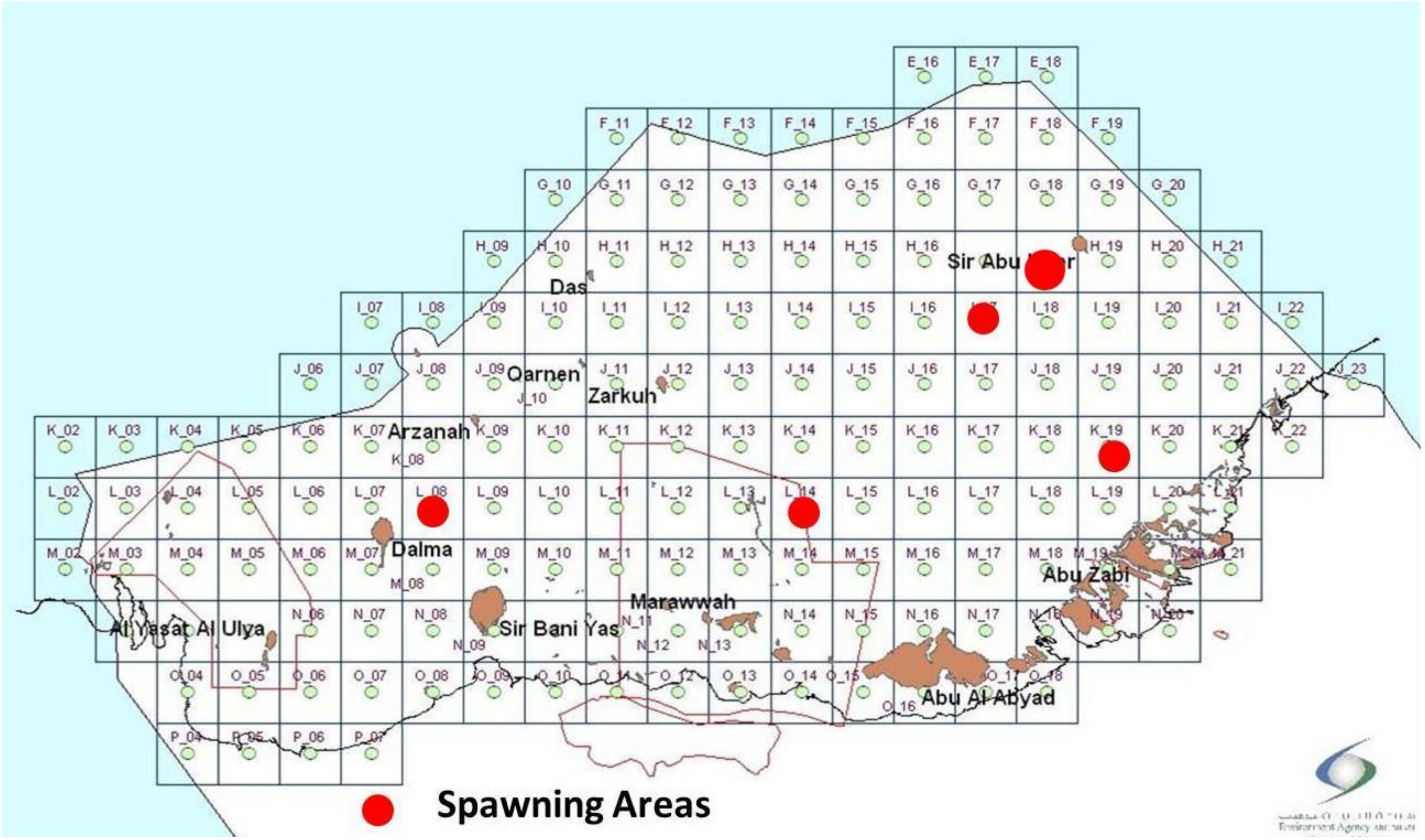
It is well known that mangrove and other Blue Carbon ecosystems provide essential support to fisheries production (fish, shellfish, molluscs, etc.). Organic matter produced by mangroves and associated species can be exported to adjacent ecosystems or consumed in the mangrove ecosystem itself. In Mexico, estimates of the amount of organic matter produced range from 1,100 to 1,417gm per year (Flores---Verdugo *et al.* 1990), providing food for economically important filter-feeding organisms such as clams and oysters. Export of this production also supports zooplankton in the Gulf of California, which in turn support higher trophic levels of organisms including commercially important species (Bouillon *et al.* 2002). Aburto-Oropeza et al. (2008) estimated the value of mangrove fish nursery habitat in the Gulf of California (Mexico): for every kilometre of mangrove forest fringe, an annual value of US$ 25,149 of services was provided to the coastal fish and crab fisheries. Organic matter exported by mangroves can also support localized agricultural or mariculture production (Hussain and Badola 2008).

In Abu Dhabi, fisheries statistics are available on quantity and species composition, based on data collected at landing sites (there is no observer programme as yet, and fishing is small scale with all catches landed). There are also data on spatial distribution of fishing effort however this is ongoing and at the time of writing data is unpublished. Fishery species in Abu Dhabi fisheries are commonly attributed to one of three categories: resident fauna; those that are more abundant in summer, and; those that are less abundant in summer. Commercial fisheries are well regulated, stock management occurs for 25 species (accounting for 90% of landed weight resource base). There is a moratorium on demersal fishing with traps. Traditional fishers use nets or trawls, while commercial fishers can use traps (for a maximum of 125 per boat). There is some indication that the shark-finning operations in Dubai may be affecting populations of sharks in Abu Dhabi, however no data are available (although it is known that there are 23 species of shark in the area). Stakeholder consultation revealed that pelagics are thought to be under-utilised (especially small lutjanids), and apparently there is no significant by-catch that is usable. Expatriate operators must have at least one Emirate on board, and compliance with regulations (such as those forbidding the taking sea turtles or dugong) is assumed to be good.

No tracking of the recreational fisheries (which may be substantial) systematically occurs. Week or year licenses are granted to those fishing from shore, and recreational fishers are thought to use primarily hook and line or handlines. There are an estimated 5000 recreational vessels, with some proportion being used for fishing.

There are existing fisheries protected areas/reserves, and also some information about spawning sites; Figure 14 shows the results of a 2006 synaptic survey at 25 sites that provided data which were combined with hydrodynamic models to determine the most important fish spawning areas (EAD, 2013*)*. In addition, a wide swath of Abu Dhabi's waters is considered critical spawning area for sailfish, an economically important and iconic species for recreational fisheries (Figure 15). Coral reef fisheries are underdeveloped and may have the potential for growth, if carefully regulated and enforced (Grandcourt *et al.* 2011). The most valuable reefs for supporting such fisheries have not been identified, however important reefs have been mapped (see Figure 16).

Some local communities have a strong attachment to fishing, even if economic reliance on fisheries is not strong (though there is some element of desiring food security and fishing for oneself to achieve that). There are some communities that have traditional marine tenure, known as buhoor areas (Figure 17). Fish farming occurs for cobia, Spanish mackerel and hamour, and the largest sturgeon farm in the world exists here. Farming operations are illustrated in Figure 18 and it is also understand that a number of private fish farms may additionally exist. Finally, pearls were once a lucrative trade and pearl diving areas were scattered across the coastal area (Figure 19); there may be interest in reviving the pearl industry. All existing and prospective mariculture or fish farming industries benefit from the support of Blue Carbon ecosystem services, as none are closed systems.



Source: EAD Geoportal

Abu Dhabi Blue Carbon Demonstration Project

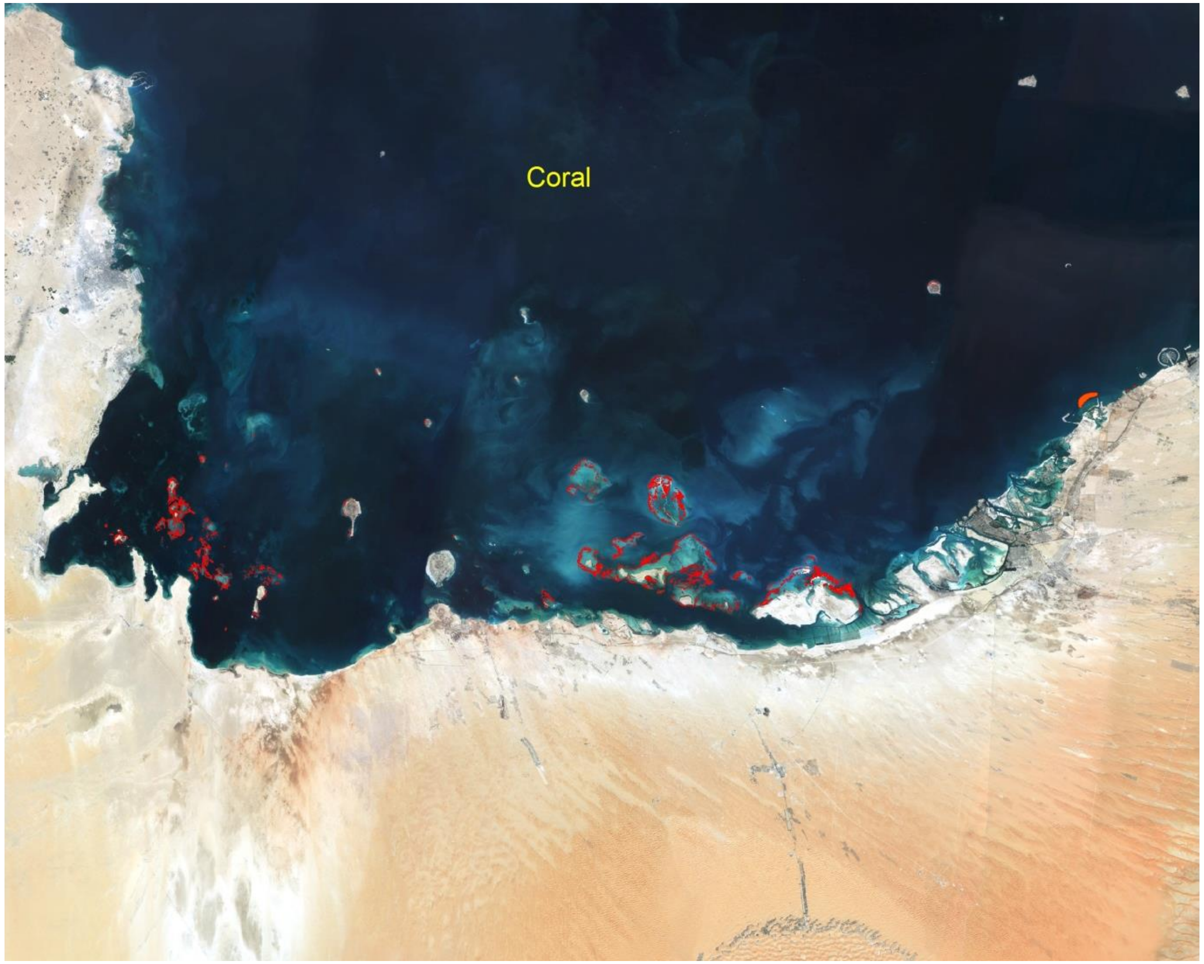
Figure 14

Important Fish Spawning Areas

Source: EAD Geoportal, 2013

Figure 15

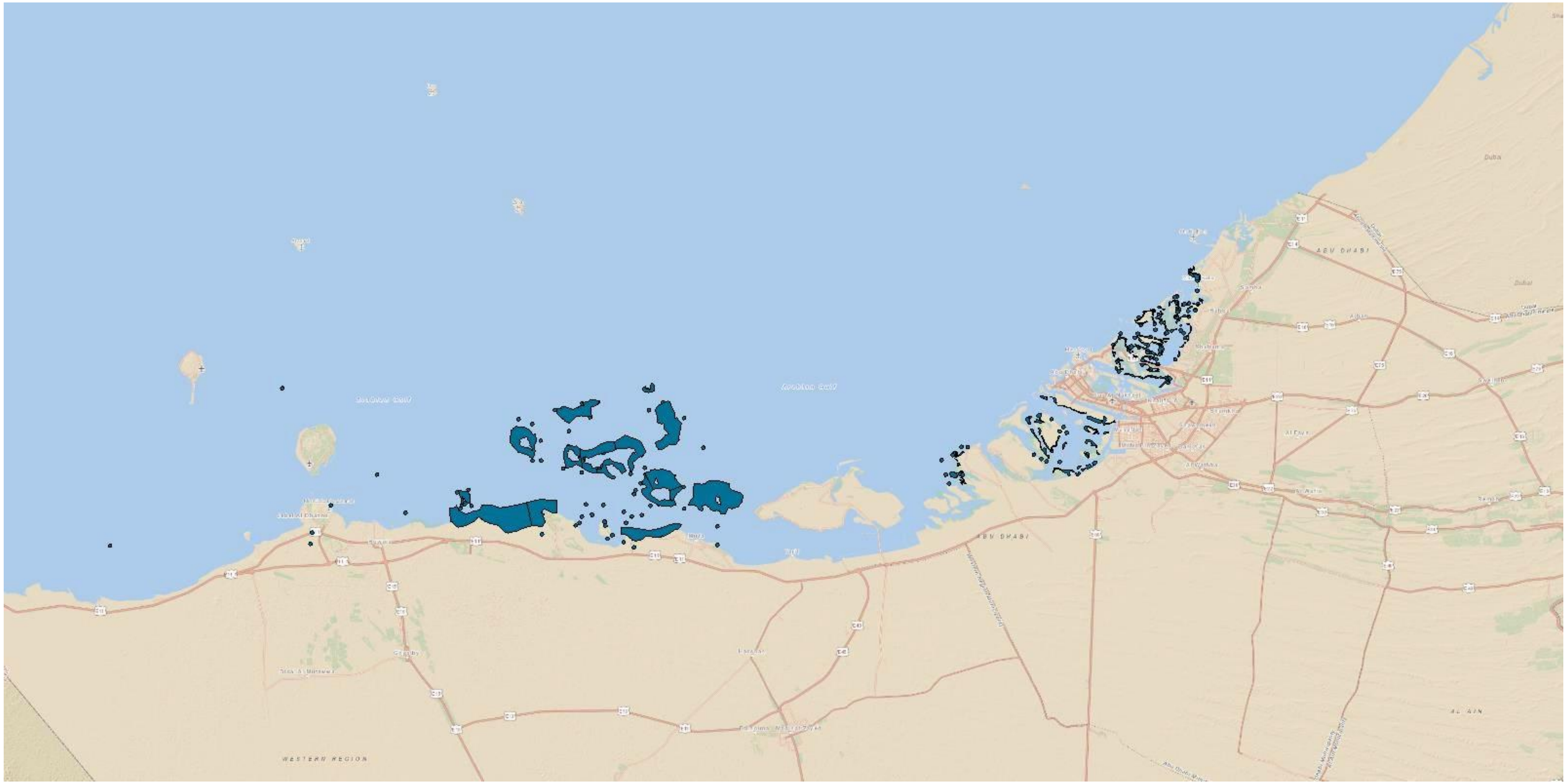
Important Sailfish reproductive area



Source: EAD Geoportal, 2013

Figure 16

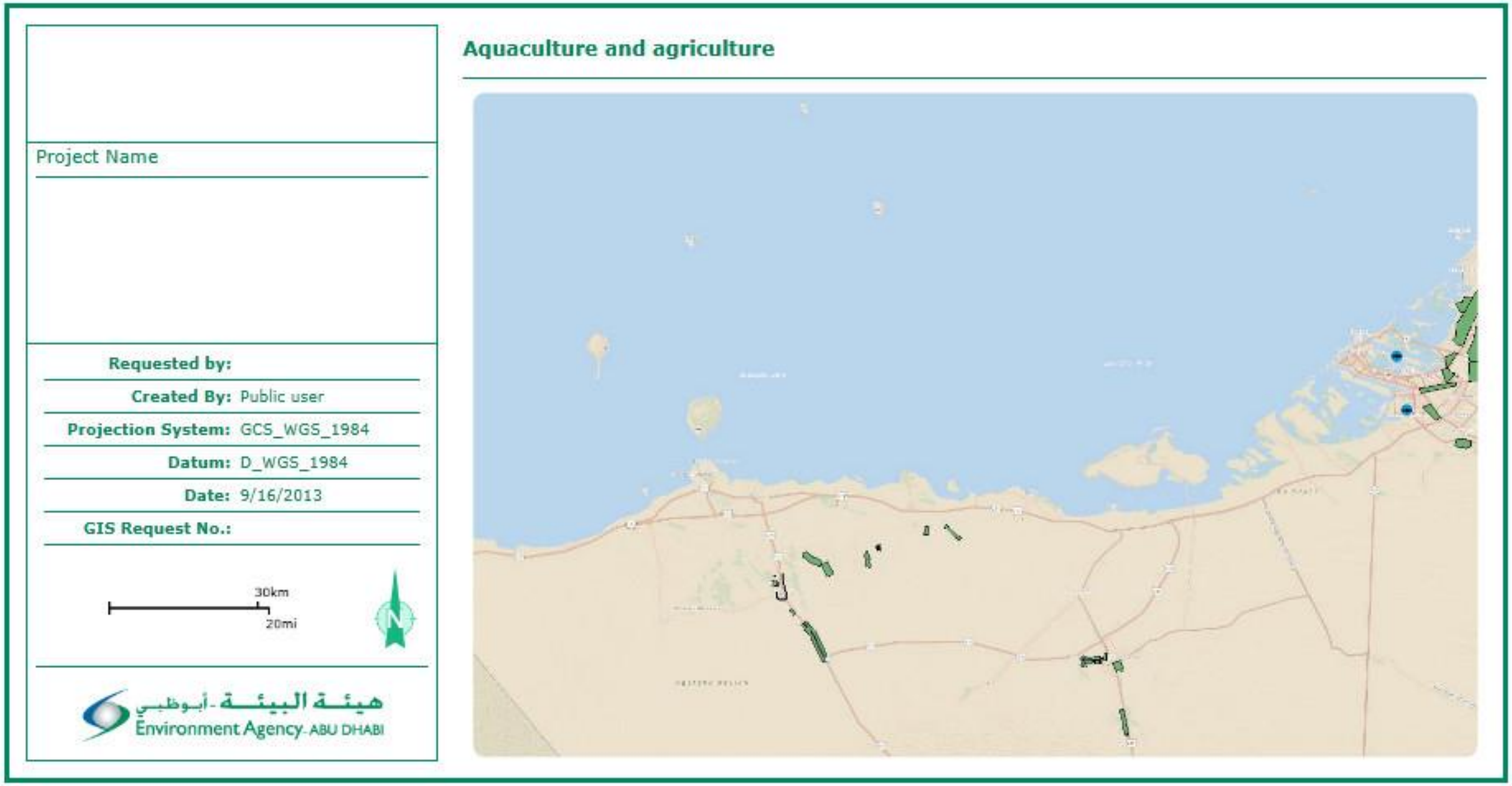
Known coral reefs high live coral cover



Source: EAD Geoportal, 2013

Figure 17

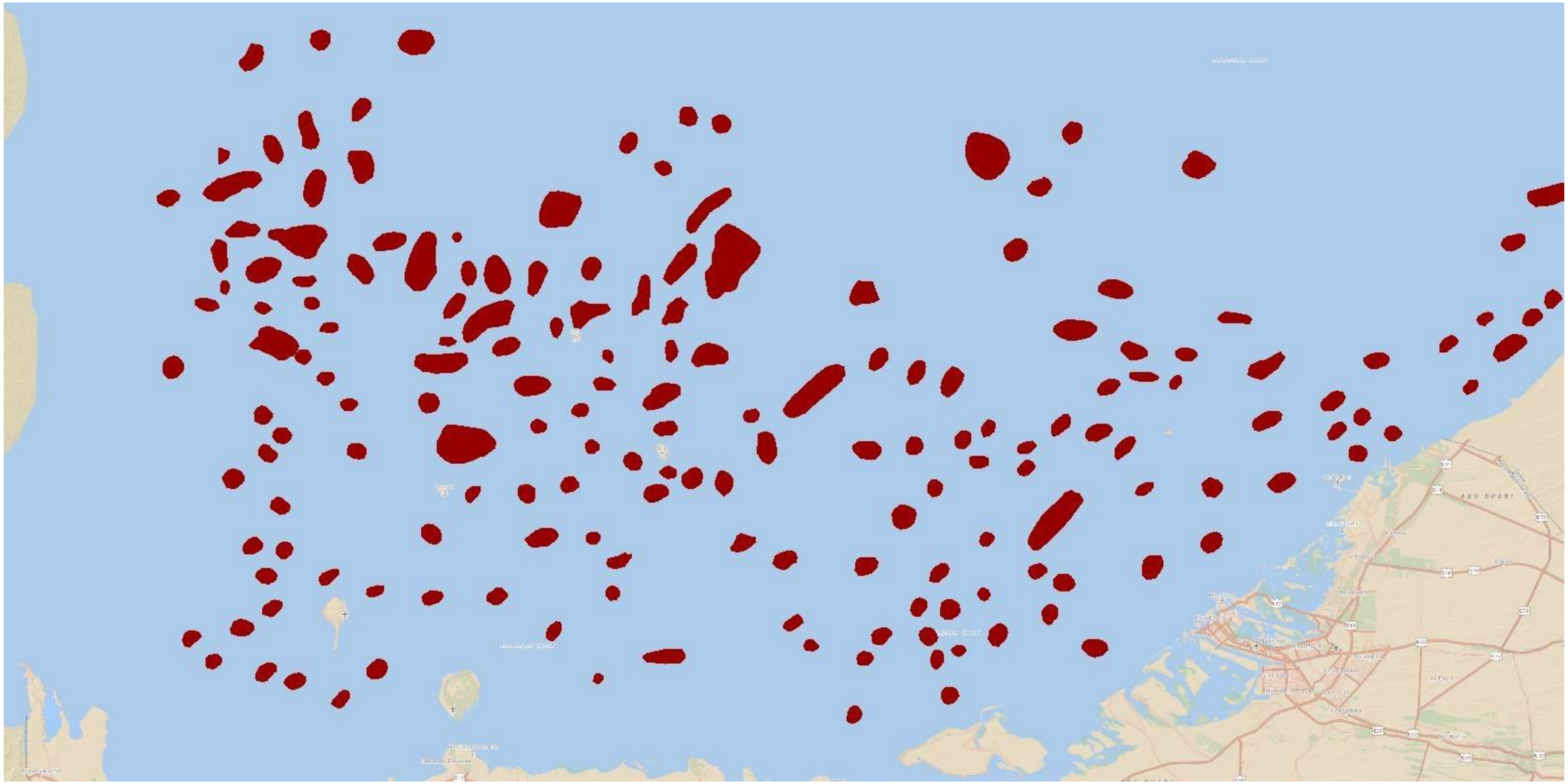
Traditional marine tenure, or Buhour, areas



Source: EAD Geoportal, 2013

Figure 18

Existing coastal aquaculture areas



Source: EAD Geoportal, 2013

Abu Dhabi Blue Carbon Demonstration Project

Figure 19

Historic Pearl Diving areas in Abu Dhabi

5.2.4 Support to Biodiversity, and in turn, Eco-tourism and Recreation

Abu Dhabi has important biodiversity that merits special attention and conservation. Biodiversity at every level: genetic, species, and ecosystem or habitat level has intrinsic value. In most assessments, the value of biodiversity is measured by how it enhances experiences: recreational use, tourism, cultural values embedded in a species or a suite of species, and maximised resilience of ecosystems in the face of large scale pressures and environmental changes. Most often, biodiversity values are determined by looking at recreational use centred upon it, such as value to bird-watchers, whale watchers, or other eco-tourists (McDonald 2009). Clearly the full suite of values must go beyond this, here in Abu Dhabi as elsewhere.

Much of Abu Dhabi is noteworthy in terms of regional and even global biodiversity. For instance, seagrasses support the world’s second largest population of dugong, a charismatic flagship species that may be considered an indicator or umbrella species as well. Seagrass is also critical ecosystem for Abu Dhabi’s sea turtles (both green and hawksbill turtles). Sea turtles can also be considered as both flagship and umbrella species, and indicators of ecosystem condition, and sea turtles hold traditional and cultural values (hunting is banned, but eggs are sometimes eaten).

The avifauna of Abu Dhabi is also significant: 452 species of birds are found in UAE, with 85% of those occurring in Abu Dhabi. Javet and Khan (2003) list existing and new important bird breeding areas and rookeries in the Emirate, most occurring on islands with Blue Carbon ecosystems (Figure 20).

Source: EAD Geoportal, 2013

Figure 20

Important bird areas of Abu Dhabi

The offshore islands were mentioned in numerous stakeholder consultations as being particularly rich, and several stakeholders drew particular attention to the Socotra cormorant (with one of seven known worldwide breeding colonies occurring in Abu Dhabi, with 15,000-20,000 breeding pairs). There are also 5 species of breeding terns (Lesser Crested, Bridled, White-Cheeked, Saunders, and Little), as well as Sooty gulls, ospreys and crab plovers (which nest on two islands and heavily use mangroves, where they feed on ghost crabs). Consultations indicated that there are an exceedingly high number of shorebirds in winter; this could provide the foundation for bird-watching eco-tourism industry. Even now, many bird-watchers in the local populace, as well as visitors, enjoy the abundance of bird life, much of it associated with Blue Carbon ecosystems.

Abu Dhabi's Blue Carbon ecosystems thus provide, food, living and breeding space and refuge to hundreds of marine, transitional, and coastal species (Nagelkerken et al 2008). Some of these species have particular value to humans. Flagship species like sea turtles, dugongs, seabirds, and shorebirds are, on the one hand, umbrella species that indicate condition and trends for wider ecosystems; on the other they are some of the 'commodities of greatest value' for nature tourism, recreation, and natural heritage value.

There are links between all of the ecosystem services provided by Blue Carbon ecosystems. For instance, seagrasses, mangroves, and salt marsh stabilize shorelines, which then allow for further growth of these and other related ecosystems, like coral reefs, which also support a wide array of biodiversity. The reef-building corals of Abu Dhabi (including the very resilient *Porites* and *Flavites* species) exist in very high temperatures, yet there is little bleaching (and no destruction from crown of thorns), so this adds value to the Blue Carbon ecosystems in supporting reefs that tolerate extreme temperatures. The entire environment of Abu Dhabi and the surrounding region would be considerably different if the Blue Carbon ecosystems were not in place and continuing to function.

5.3 Hypothesised Ecosystem Services Values as Co-Benefits to Blue Carbon

Quantifying these ecosystem services being generated by Blue Carbon ecosystems in Abu Dhabi and determining their economic value requires additional study to follow the initial findings of the Abu Dhabi Blue Carbon Demonstration Project. However, the potential economic value of one suite of ecosystem services (provision of fish nursery habitat, export of organic matter to support fisheries, regulating services that act to safeguard other habitats essential to fisheries production) can be estimated for Abu Dhabi given fisheries statistics collected by EAD.

Approximately 14% (AED 17,780,000) of the total value of commercial fish landings in 2010 (AED 127 million) is attributed to carangids, which are the only taxonomic group identified which is not likely to be supported by Blue Carbon ecosystems. This suggests that Blue Carbon ecosystems support nearly AED 110 million per annum in commercial fish landings value, based on 2010 data. Additional value, as yet unquantified, must be attributed to Blue Carbon ecosystems for the support of recreational fisheries, as well as protection of, and support to, the fledgling mariculture industry.

In the absence of economic valuations for other ecosystem services associated with Blue Carbon in Abu Dhabi's mangrove, seagrass, salt marsh, coastal sabkha, and algal mat ecosystems, published studies from other regions of the world where these ecosystems exist must be utilised. Dr. Rula Qalyoubi, in her "Economic Valuation of Mangrove Ecosystem in Abu Dhabi" report prepared for EAD in 2012, discusses net present value of mangrove based on proxy information taken from other studies around the world. In this the derivation of mangrove values as performed in landmark studies, appropriate discounting rates, and ways that other ecosystem services and other habitats could be further assessed are discussed. The work of the Abu Dhabi Blue Carbon Demonstration Project components takes these recommendations even further.

Using known values of annual per hectare service value, as summarized by Barbier and his colleagues (2011) for the major classes of ecosystem service addressed in the Abu Dhabi Blue Carbon Demonstration Project's Ecosystem Services Assessment, it is possible to derive some indication of the possible magnitude of values arising from these ecosystems. Conservatively taking the low end totals across the few ecosystem services that have been quantified in terms of economic value (see Table 2-5 pages 23-26), totals across all services per hectare per annum can be estimated minimally as: US$ 13,353 for mangrove; US$ 2,529 for seagrass; and US$ 14,699 for salt marsh (values for coastal sabkha and for algal mats are unknown).

These values were derived by taking the lowest published values for each habitat from other parts of the world, added across several ecosystem services where these data exist, for each habitat type. For instance, for mangrove the benefits transfer values for mangrove given by Barbier in his literature review were those for storm protection at $8966/ ha, for erosion control at $3679 / ha, and maintenance of fisheries at $708/ha. Material goods from mangrove that Barbier listed as $484/ha were not included because there is no evidence of mangroves being used in this way in Abu Dhabi. The sum total of these known minimum values is $13,353 per annum. For seagrass, the estimated net benefit comes from data on Australia shrimp and finfish fisheries: $2511/ha for support to shrimp and $18/ha value from other fisheries (as estimated by losses in fisheries revenues due to habitat loss). It should be noted that this is very likely a gross underestimate of seagrass value, since Barbier did not uncover economic valuations of other services, such as support to endangered species, water quality maintenance, flood control, erosion prevention, etc. Another study (Terrador and Borum 2004) estimated that the minimal value of seagrass in European Seas at $20,746 per hectare per annum. However, they did not elucidate the derivation of this figure, therefore the lower benefit transfer value from Barbier's review was used in this study. Finally, the estimates for saltmarsh are taken from low end values from Barbier: hazard mitigation was estimated at $8236/ha; water purification at $318/ha (low end estimate of $785/acre converted to hectares); maintenance of fisheries at $2620 (estimate from east coast Florida of $6741/acre converted to hectares); and bird-watching, estimated at $3525/hectare based on an estimate of 1800 birdwatchers with a willingness to pay of $1.96 per person.

Again, these values are without doubt underestimates; based on a more recent study of coastal ecosystems in the UK (see Beaumont et al., 2013), estimated values are significantly higher – though these are not suitable for benefit transfer since the environments are not similar to Abu Dhabi's.

Potential total economic values of Blue Carbon ecosystems for quantifiable uses and/or market values can be estimated using the coverage data presented by the mapping component (WCMC 2013). Multiplying the low end values determined in other study locations as listed in the previous paragraph by the ecosystem coverage ascertained by the Abu Dhabi Blue Carbon Demonstration Project, yields total potential ecosystem service values of approximately: US$ 188 million per year for mangrove; US$ 70 million per year for salt marsh; and US$ 400 million for seagrass. The total per year for the three Blue Carbon ecosystems for which there are economic studies from other parts of the world (mangrove, seagrass, salt marsh) thus translate into a total of over six hundred and fifty million U.S. dollars per year (US$ 658,863,426 based on known benefits transfer values (see Table 6 below).

Table 6. Derivation of minimum potential values for three Blue Carbon ecosystems (mangroves, seagrass, and saltmarsh) based on benefits transfer

Blue Carbon Ecosystem	Low end value per hectare from Barbier across all assessed services in USD	Coverage in Abu Dhabi in hectares	Total potential value in Abu Dhabi in USD
Mangroves	$13,353	14,117	$188,504,000
Salt marsh	$14,699	4770	$70,114,230
Seagrass	$2,529	158,262	$400,244,600

There are, however, reasons why these figures may prove unreliable, and why extrapolation from other areas may not elucidate true values in Abu Dhabi. Firstly, these numbers are likely to be an underestimate, since many ecosystem services such as water quality maintenance, disease regulation, support to biodiversity, and cultural/spiritual values, are not included within the total. An example of this is eco-tourism. This is a relatively new concept catalysed by private enterprise. The interest in eco-tourism reflects a tacit appreciation of the values being provided by Blue Carbon and associated ecosystem. Coastal ecosystems are considered to be particularly valuable to the relatively small local fishing community and the traditional pearlers, who are granted access and use rights to certain areas. The subsidization of traditional fishers is less an economic investment in Abu Dhabi, and more of a "social glue". This is an ecosystem service that has no tangible economic value but is important nonetheless.

Conversely, the known values taken from other locations as proxy values for Abu Dhabi may not reflect the amount of service being delivered in Abu Dhabi's Blue Carbon ecosystems, since these ecosystems are in general less diverse, less extensive and productive, and less well-established than Blue Carbon ecosystems in the wet tropics of Australia, Asia, Latin America, the Caribbean, or the Pacific region. This is reflected in the carbon stock and soils values, as determined by the Abu Dhabi Blue Carbon Demonstration Project. With the exception of algal mats, which have not been assessed elsewhere in the world, the carbon values are relatively low compared to other parts of the world.

An important point raised in other components of the Abu Dhabi Blue Carbon Demonstration Project is that not all Blue Carbon ecosystems are the same, even within a relatively small area like Abu Dhabi. Natural mangrove undeniably provides a greater array of ecosystem services than recently planted mangrove, just as it sequesters on average more carbon than plantation forests per equal unit area (Table 7).

Table 7: Comparison of carbon stocks in planted mangrove versus natural ecosystems

Sampled Mangrove	Median Rates of Carbon
10-15yrs	68.95
2-10yrs	84.48
25-50yrs	n/a
Natural	109.79
Planted (all)	79.92

It is recommended that further targeted research be focused on illuminating the true values of these Blue Carbon co-benefits, allowing for enhanced informed decision-making and coastal/ marine policy formulation, as per the recommendations of many authors on the subjects (see for instance Cowling et al. 2008; Daily and Matson, 2008; Lau, 2010; van Lavieren et al 2011; Maynard et al. 2011; etc.).

5.4 Linkages to other ecosystems of value and assets

Abu Dhabi once had extensive coral reefs offshore, and at least fragments of those many reefs exist today. Although these are not technically considered Blue Carbon ecosystems (though they may in fact sequester vast quantities of carbon), the numerous and highly valuable ecosystem services that they generate are being substantially supported by the Blue Carbon ecosystems studied. These values include shoreline stabilization and buffering land and lives from cataclysmic storm events, providing areas for diving and other recreation, and supporting biodiversity and fisheries (Barbier et al, 2011; Moberg and Folke, 1999; TEEB 2009). An additional known value of coral reefs is the value of bioprospected pharmaceutical compounds.

Physical, biogeochemical, and ecological interactions occur between mangroves, seagrasses, and coral reefs, making these known interconnected systems (Moberg and Ronnback 2003). By dissipating wave and current force, reefs create shallow lagoons and bays that are suitable ecosystem for mangrove and seagrass growth. This is essentially a symbiotic relationship at the beta or habitat level, wherein mangroves and seagrasses then filter pollutants and sediments from the marine waters, allowing further development of the complex reef system. It has been thus hypothesized that the presence of these interlinked ecosystems within a region may considerably enhance the ecosystem services provided by one single ecosystem (Moberg and Ronnback 2003).

Alongi (2008) suggests that the extent to which mangroves offer protection against catastrophic storm events, such as tsunamis, may depend not only on the relevant features and conditions within the mangrove ecosystem, such as width of forest, slope of forest floor, forest density, tree diameter and height, proportion of aboveground biomass in the roots, soil texture, and forest location (open coast vs. lagoon), but also on the presence of foreshore ecosystems, such as coral reefs, seagrass beds, and dunes. Other researchers hypothesize a similar systems interaction for coral reef, seagrass, and salt marsh complexes, as are found in Abu Dhabi (Koch et al. 2009; Mumby 2010). Given the rapid rate of change in Abu Dhabi, and the fact that losses exceed restoration in all ecosystem types excepting mangrove, the consequences for ecosystem services may be severe. This is reflected in the statement published in the UNU Report (Van Lavieren et al. 2011) “The loss of productive natural coastal ecosystems and associated marine life as a result of development is a major environmental issue facing the Gulf today”.

5.5 Threats to Abu Dhabi Marine and Coastal Ecosystem Services

Habitat loss appears to be the major driver of ecosystem services decline; many of the services being provided by Blue Carbon, and associated, ecosystems are compromised as the collective pressures from development, land reclamation, and pollution exact multiple cumulative impacts on these ecosystems. The condition of the marine and coastal environment is not purely a function of what happens at sea and along the shore, these ecosystems are all intricately interlinked, with connections to land use, aquifer condition, and environmental trends happening at the regional and global scales.

At sea, major threats to Blue Carbon ecosystems and delivery of their services comes from dredging and infilling, which disrupts the seafloor and also releases sediment into the water column, potentially smothering coral reefs and seagrass beds (Al-Madany et al. 1991; van Lavieren et al. 2011). Infilling and channelization may also be disrupting the coastal oceanography that links marine systems and allows water flushing, nutrient delivery, and movement of organisms from one ecosystem to another. This is turn can affect water quality, fisheries production, and overall environmental (and thus public) health (Kahn 2007; Kahn et al 2002). Researchers cited in van

Lavieren et al 2011 indicate that land reclamation and dredging has caused permanent loss of primary nursery grounds for commercial shellfish and fish species in the Gulf (Bishop 2002; Munawar et al. 2002).

Information provided by Dr. Waleed Hamza of UAE University illustrates the link between terrestrial and marine environments. Hamza and Munawar (2009) discuss nutrient inputs, water quality, the role of atmospheric inputs, cross-subsidies among ecosystems (of nutrients) and general marine conservation in Abu Dhabi. One important line of inquiry that merits further research is the relationship between water quality and land degradation, especially as climate change and development in the region exacerbate both (Al-Madany et al. 1991, Khan 2007, Hamza and Munawar 2009, UNEP 2010b).

Flagship marine species such as dolphin, dugong and sea turtles continue to be at some risk from illegal fishing activity. It appears that most non-natural mortality of sea turtles and dugong is attributable to drowning in nets (illegal drift nets used at night). Nonetheless, sea turtle populations appears healthy, 60-70% of all sightings are green turtles, and this population extends to Pakistan and Oman; there are 6000-7000 adults in total. Hawksbill turtles are residents. There are 150-200 hawksbill turtle nests per year occurring on 17 islands, with another 150-200 occurring in UAE outside of Abu Dhabi. It is not known how many dolphins (Indopacific humpback dolphin, finless porpoises, bottlenose dolphin, or common dolphin) die or are injured due to fisheries interactions or boat strikes.

Overfishing and illegal fishing may be undermining Abu Dhabi's marine ecosystems, however this may pale in comparison to the cumulative other pressures that occur locally, regionally and globally, which collectively affect the health of the wider environment. In light of this, it may be that fishing regulations will need to be adjusted in order to accommodate climate change-driven impacts on fish production, as well as related impacts on Blue Carbon ecosystems that support fish production.

According to several stakeholders consulted, there remain serious threats to the coastal ecology and marine biodiversity of Abu Dhabi, including the soon-to-be-built nuclear plant, where it is estimated that 16 billion gallons a day of superheated (at 5 degrees C over ambient temperatures) effluent will be pumped onto shallow water seagrass habitats. There has also been an alarming increase in red tides, with incidences rising in the last 10-15 years (though baseline was only established in 2002). Some stakeholders speculate that alien species are being transported through ballast water, and have a role to play in bloom outbreaks (Anderson, 2009). The duration of some blooms (up to 2 months) suggests that flushing may be compromised in places such as the Eastern Mangroves; this interference with physical oceanography and coastal processes suggests impediment of ecosystem health and a corresponding loss of ecosystem services. Infilling, dredging, land reclamation, and coastal constructions impact not only the natural ecosystems directly in the footprint of development activity, but surrounding and linked areas as well.

All activities that affect the water quality of Abu Dhabi's marine areas have the potential to seriously undermine Blue Carbon ecosystems and the services they provide; this in turn can feed a positive feedback loop in which water quality accelerates in its decline. Such situations concerning Blue Carbon ecosystems and other regulating services that they generate, are best avoided by continued careful assessment and thoughtful planning which may be enhanced and informed through scientific outcomes of project such as the Abu Dhabi Blue Carbon Demonstration Project. Being able to identify Blue Carbon areas of high value, and consideration of the current and future threats that these areas may face, should provide one of the necessary elements for careful planning.

5.6 Areas of High Ecosystem Services Value

Valuable Blue Carbon ecosystems in Abu Dhabi occur where the benefits they provide, across a wide range of services, are already being realized. Particular concentrations of ecosystem services values are expected to occur in the following: mature mangrove stands of ample size and with little direct or indirect degradation; extensive seagrass beds that exhibit high diversity and little algal overgrowth; intact salt marsh areas with unrestricted hydrological flows to surrounding habitats; and coastal sabkha that is found in combination with algal mats. Especially important are areas in which multiple healthy Blue Carbon ecosystems are present and interconnected ecologically. The identification of these sites was not done using decision-support software and GIS, though this might be done in the future when data on known values can be georeferenced. Instead, the areas highlighted are based on best available expert opinion. These findings will need to be verified or adjusted with further research and GIS mapping.
Any future assessment would benefit from further data, particularly data that is spatially referenced. For further detail on the type of data please refer to section 5.1

These are sites that are doing more than their fair share of supporting ecosystem function, and are thus generating potential ecosystem services. But the value of those ecosystem services is a function of location, linkage to things that humans value, and the perception that services have economic value in addition to other social values. For this reason, it is important to know, in general terms, what assets and parts of the marine and coastal areas of Abu Dhabi are highly valued.

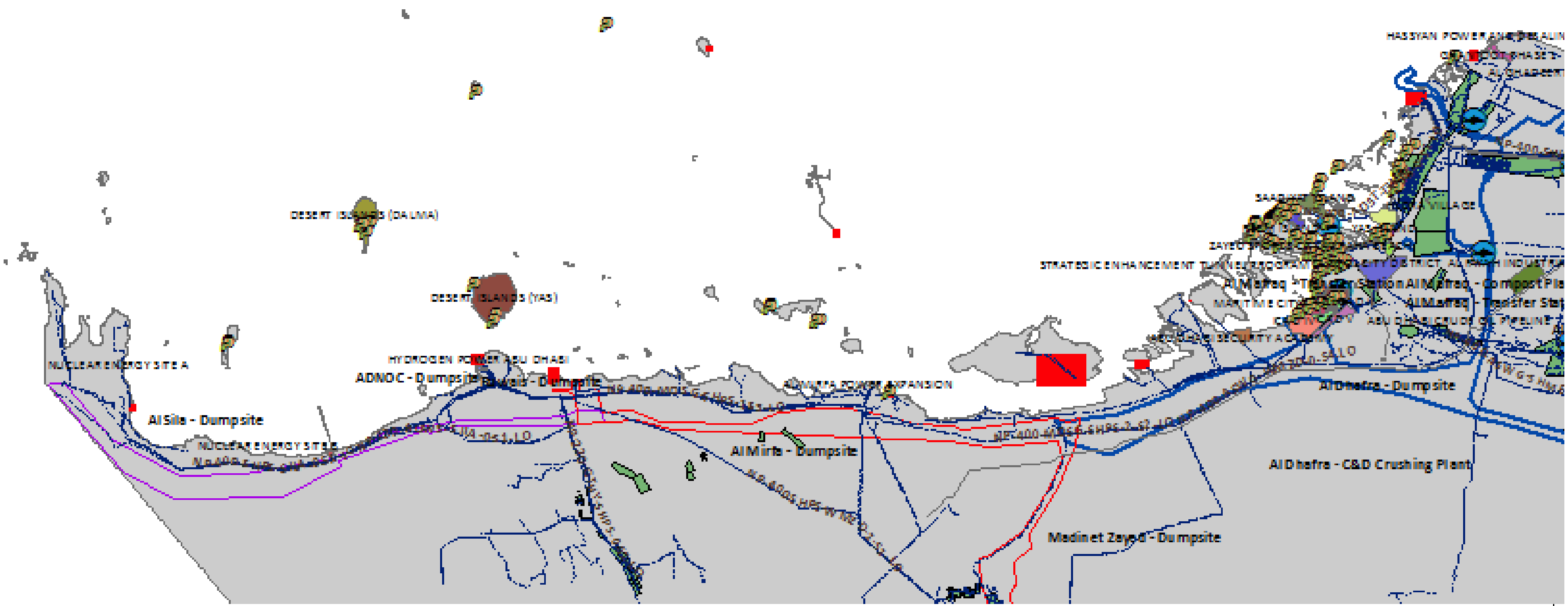
Those Blue Carbon ecosystems that occur in close proximity to rich fishing grounds (commercial and recreational), areas of high biodiversity and spectacular scenic value, sites of cultural and archaeological importance, and carefully developed areas of high asset value (luxury beach and island resorts, civil engineering infrastructure that are particularly influenced by the sea, such as corniches, ports, and marinas, private residences, desalination plants, and aquaculture operations) can be said to have particularly significant ecosystem services value (Figure 21). For the purposes of this assessment, analysis is concentrated on the current situation, however planned development must also be considered when determining where valuable Blue Carbon Ecosystem Services are being delivered.

Given that each Blue Carbon ecosystem and the ecological community it supports provide different ecosystem services, the most valuable areas will be those that have a combination or mosaic of these ecosystems, especially those in relatively close proximity to assets of value. Five areas within Abu Dhabi stand out in this regard:

1) A large portion of the western region, centred on the area between Yasat Island and Dalma, especially in the southern reaches of polygon;
2) The area around Marawah Island, particularly off its southern and eastern coast;
3) The west and north/ northeast portions of Abu al-Abyad,
4) The marine and peninsular areas east of Bul Syayeef Marine protected Area; and
5) The eastern mangroves and environs of Saadiyat Island

These areas are illustrated in Figure 22. The polygons within this Figure are not precise in the sense that the boundaries are somewhat subjective; nonetheless each area captures maximum ecosystem services by including areas in which the combination of Blue Carbon ecosystems, and associated ecosystems of value such as coral reefs, is optimized. Furthermore, these areas capture highest level of productivity (carbon and other), maximum capacity for shoreline buffering and erosion control, sites important for water quality maintenance, special areas for species across bird, dugong, sea turtle, and other taxa, important fish spawning and traditional use (buhour) areas, and archaeological and cultural areas of importance.

The westernmost priority area is notable due to its seagrass ecosystems, support to a wide range of biodiversity, and the ability of Blue Carbon ecosystems within that region to stabilize seafloor and shorelines, especially as future new developments come online. Other priority areas are in close proximity to cultural and historic areas, and their role in reducing hazard risk to these important sites is immeasurable. In the eastern region, priority sites have value in supporting fisheries (recreational and commercial), and providing both water quality maintenance and aesthetic and recreational values. These values will need to be further defined, and economically quantified, in the future, through a targeted research program.

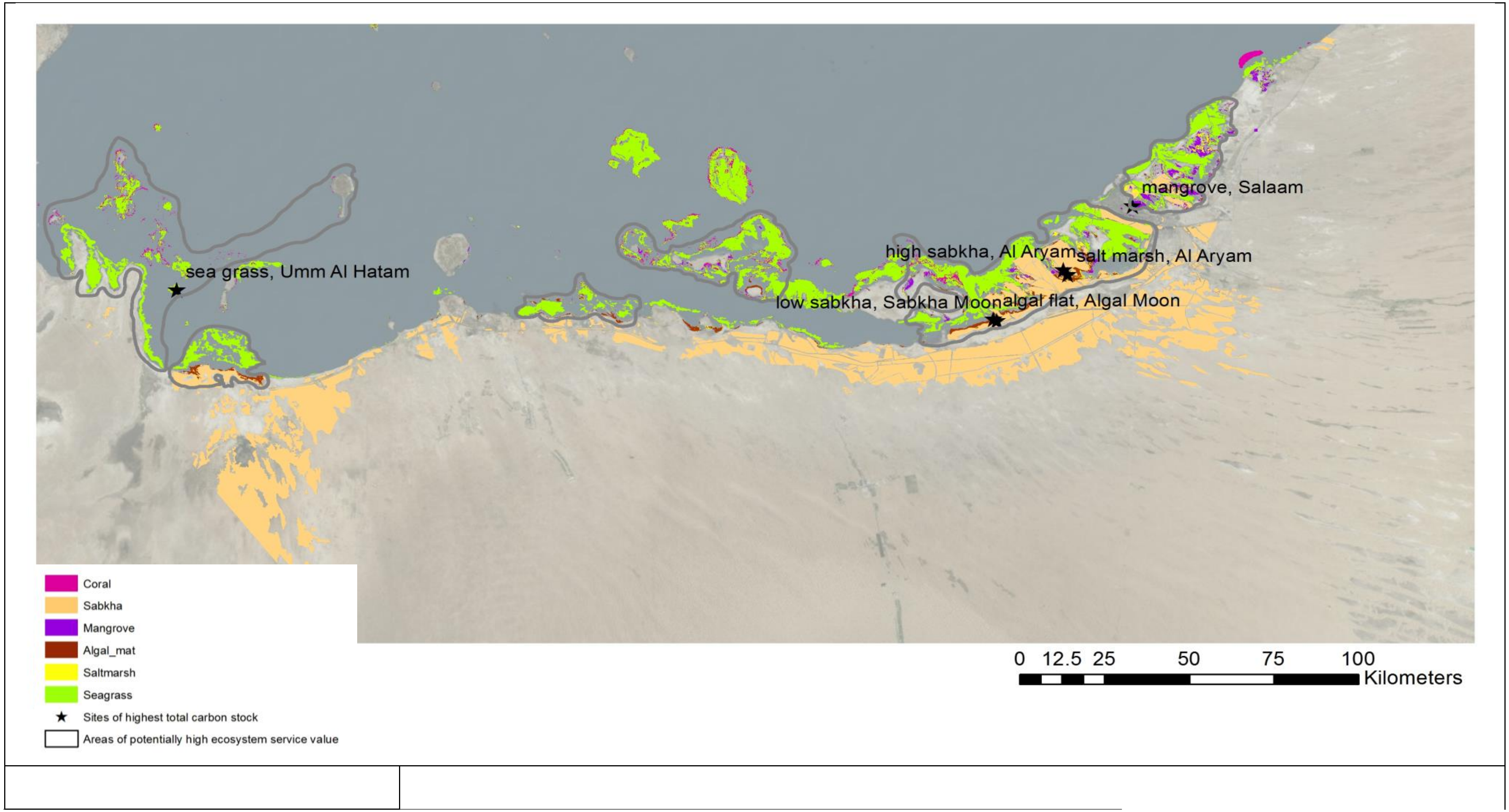


Source: EAD Geoportal 2013

Abu Dhabi Blue Carbon Demonstration Project

Figure 21

Particularly valuable assets affected by Blue Carbon Ecosystems in Abu Dhabi



SOURCE: AGDEI, 2013

Abu Dhabi Blue Carbon Demonstration Project

Figure 22

Estimated potential areas of highest concentration of co-benefits arising from Blue Carbon Ecosystems

6 Implications of Findings

The values attached to these Blue Carbon ecosystems for the services delivered can be described in three ways: local value to Abu Dhabi and its residents; regional values given the trends in ecosystem degradation and loss throughout the Arabian Gulf region, and the value of these Blue Carbon ecosystems at the global scale.

Clearly, the Blue Carbon ecosystems of Abu Dhabi provide valued ecosystem services beyond the sequestration of carbon, some of which are already being realized locally. More precise economic values that these Blue Carbon ecosystems generate for Abu Dhabi and its inhabitants can be determined with future targeted economic studies and surveys, now that the information on ecosystem coverage and potential ecosystem services has been synthesized. It is recommended that future research use the Integrated Assessment and Valuation of Ecosystem Goods and Services Provided by Coastal Systems methodology (Wilson et al., 2012), utilizing the following tools (where appropriate): avoided and replacement costs, factor income, travel cost, hedonic pricing, marginal product estimation, contingent valuation, and group valuation. Some of these values can be estimated by examining market values; others relate more to perceived value and can only be determined by 'willingness to pay' and other information derived by interviewing users. However, as Wilson and colleagues state (Wilson et al. 2012), no methodology is able to capture the total value of goods and services.

The identification of valuable co-benefits to Blue Carbon allows a focus on coastal areas that may need additional protection in the future. Some of the regions of Abu Dhabi generating the most ecosystem services values are already under special spatial management regimes, such as the Marawah Marine Biosphere Reserve, the Bul Syayeef Marine Protected Area, and the Al Yasat Marine Protected Area. An objective assessment of management effectiveness within these protected areas is however recommended, especially as it relates to compliance with regulations, and whether the regulations themselves address the highest priority threats to ecosystem function and health. Additionally, there are areas that fall outside protected areas that exhibit high ecosystem services values, in particular those in close proximity to high value assets, such as the potentially high value area in the western region of the Emirate (area 1 above). Future development in these areas will need careful planning to ensure that Blue Carbon benefits are not sacrificed.

It is also important to recognise that the values arising out of Blue Carbon ecosystems are not confined to Abu Dhabi alone. There are numerous ways that the Blue Carbon ecosystems provide value outside Abu Dhabi and its surrounding Emirates. For the Gulf region, the value of these Blue Carbon ecosystems include support to a wide array of regional (and supra-regional) biodiversity and fisheries, regulation of regional scale fluxes, and mitigation of catastrophic events, the costs of which might otherwise spill over to neighbouring countries in the region. In terms of Both Carbon stock, sequestration and the myriad other services being delivered, the importance of Abu Dhabi's Blue Carbon ecosystems is expected to increase over time, as regional coverage and condition of mangroves, seagrass, and salt marsh (as well as coral reefs and shellfish reefs) are expected to decline. Abu Dhabi Blue Carbon ecosystems also have value as laboratories for learning, and as such present a hugely valuable resource for the countries of the Gulf region, which share these challenges with Abu Dhabi.

At the global level, Abu Dhabi's Blue Carbon ecosystems have immense value in allowing us a glimpse into the future, especially as it relates to climate change impacts on ecosystems and ecosystem services. Many of the world's marine regions will face a future which will arrive sooner to the Gulf than to most other parts of the world: warmer seas; higher salinities in marine and coastal environments alike; increasing acidification, and; potential increase in storm frequency and intensity. Abu Dhabi can demonstrate how to maximize the resilience of these Blue Carbon ecosystems, and can further educate and train others in adopting a holistic approach to ecosystem services.

To make this Abu Dhabi Blue Carbon Demonstration Project and its methodologies as replicable as possible, and as useful as possible in the Abu Dhabi policy context, it is recommended that targeted research be undertaken in relation to the economic studies mentioned above, more detailed hydrographic modelling and surveys with greater sample sizes, across different seasons, and including associated ecosystems such as coral reefs. Targeted economic analysis using contingent valuation (willingness to pay) surveys of residents and selected groups of tourists (i.e. those visiting mangroves, birdwatchers, scuba divers, etc.) is recommended as first step to improve knowledge on the appreciation of ecosystem service values. As stressed by Daily et al. (2009), production functions in these ecosystems must be fully understood before the continued rates of services delivery can be predicted – in the absence of this, and even if economic values are ascertained, policy decisions rest on shaky ground.

Economic valuations will be critical for guiding Abu Dhabi in its Blue Carbon financing and policy options, as well as in helping to steer sustainable growth policies. Some of this valuation is already underway, for example the fisheries socio-economic survey (as per RFP issued by Terrestrial and Marine Biodiversity Sector EAD, May 2012) currently being undertaken, as well as the on-market valuations being done under the auspices of UPC (Steve Scott, pers. comm.).

The potential for ecosystem services valuation to influence policy will depend on contextual, procedural, and methodological factors integrated in the process. A clear policy question and objective is necessary to trigger robust Ecosystem Services Valuation. In addition, it is also recommended that this be based on a local demand for ecosystem services valuation and assessment, including strong local partnerships with key stakeholders like tourism operators to allow discussion of the assumptions behind value calculations and dialogue regarding the perceived values of the services presented.

Effective communication and information flows to decision makers is imperative if the economic argument is to bolster or influence political considerations. Strong governance by an authority institution over the site/ecosystem in discussion will enable the decisions made to be implemented. Opportunities for raising revenue such as payments for ecosystem services (e.g. park entry or use fees) will facilitate the uptake of the Ecosystem Services Valuation results. Finally, a clear presentation of methods, assumptions, and limitations is critical throughout the process so as to manage expectations and perceptions.

A rigorous look at ecosystem services values must both appraise net present value and perceptions of value; and look into the future. The two considerations that must be addressed in this regard are how value changes over the passage of time (including, but not limited to, discounting rates) and the sustainability of stocks (for goods) and services (Bateman et al, 2011). It is thus recommended that future work in Abu Dhabi target the development of predictive models that can better elucidate trade-offs. The result will lead to conserving and enhancing as much as possible of Abu Dhabi's Blue Carbon ecosystems, which will in turn yield valuable ecosystem services for many years to come.

7 Recommendations

Six overall conclusions can be drawn about Blue Carbon ecosystems co-benefits:

1) Ecosystem services have both market and non-market values in Abu Dhabi, and for the region; total economic values are likely to exceed US$ 650,000,000 per annum
2) Certain areas that have a mosaic of Blue Carbon ecosystems in close proximity, or have extensive and productive Blue Carbon habitats, or both, can be flagged as delivering a concentration of ecosystem services beyond carbon; the potentially most valuable areas with maximum ecosystem services have been tentatively mapped (see Figure 22)
3) The costs of losing the valuable ecosystem services being generated from Blue Carbon ecosystems will be high and felt for many generations to come, and while some restoration may be possible, full ecosystem function is rarely achieved even despite significant investment of time and resources; and
4) Blue Carbon ecosystems can be considered to provide risk minimization for existing and prospective investments, as Abu Dhabi continues to grow and as it diversifies its economic base, through Plan Maritime 2030 and other strategic planning initiatives which have been developed and are being implemented; and
5) Maintaining connections between Blue Carbon ecosystems (and with associated ecosystems like coral reefs or the pelagic zones) will allow maximum service delivery, maintenance of values, and maximum resilience in the face of climate change.
6) The potentially most valuable areas should be confirmed as a priority, and should be in the focus of planning and conservation efforts, in addition to being targeted areas for further economic valuation.

To fully capitalize on the Blue Carbon ecosystem service values and ensure that important ecosystem services are not compromised by poorly planned development or by the indirect effects of land and sea use, it is recommended that Abu Dhabi undertake three immediate research activities, with outputs feeding into planning and policy development:

1) More fully determine the condition of Blue Carbon ecosystems, using widespread application of the Ecosystem Services Assessment protocol under a statistically robust sampling regime. The purpose of this would be to better understand which Blue Carbon ecosystems are delivering maximum services, and for those Blue Carbon ecosystems that are degraded, allow identification of the root causes or drivers behind threats. It is recommended that targeted studies begin with the 5 hotspots highlighted in this study.

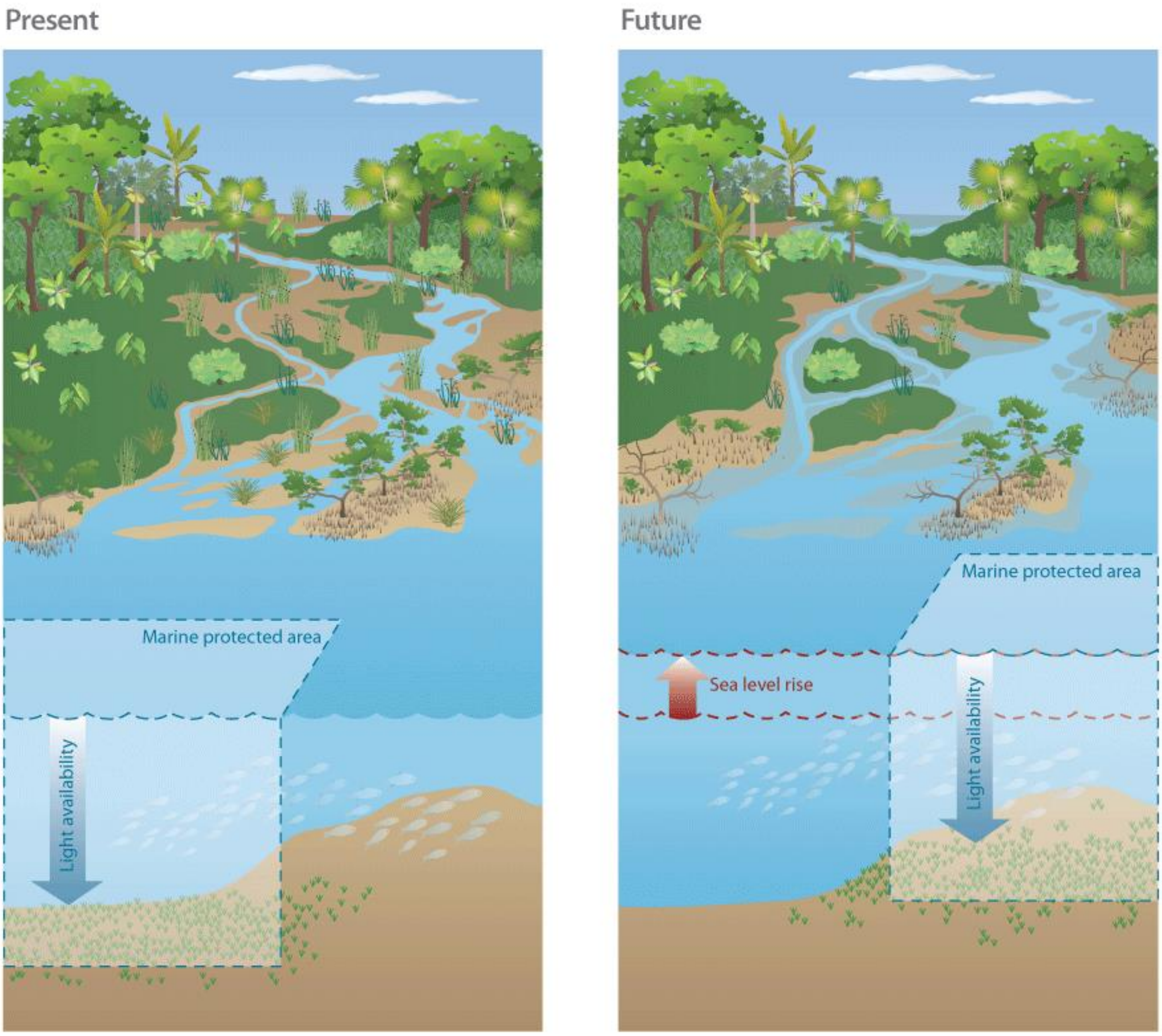
2) Enhance the understanding of the hydrology and oceanography of Abu Dhabi's nearshore waters and coastal systems, including flows through mangrove channels, sea level changes, and patterns of inundation. This is necessary to be able to model responses to climate change, as well as predicted outcomes resulting from restoration, protection, or – alternatively – habitat loss. It is suggested that such applied research be focused first and foremost on the areas estimated to support the greatest concentration of services (as

identified in this assessment).

3) Survey stakeholders and the populace of Abu Dhabi to appraise the perceived value of marine goods and services, including recreational and cultural values attached to coastal landscapes/seascapes, the value of hazard risk minimization for developers, insurers, and investors, and the public health values associated with maintaining ecosystem health and minimizing disease. The purpose of this is to allow a wider base of investors to participate in the protection or restoration of Blue Carbon ecosystems, and allow provide a more robust basis for determining compensation fees for damage to these ecosystems.

Improving the robustness of information relating to ecosystem services in this way will facilitate enhanced planning, in which trade-offs can be evaluated and outcomes predicted. Reliable ecosystem services information will also allow *bona fide* adaptive management, through which natural capital can be optimally safeguarded (see Figure 23 below). Such adaptive management will both increase efficiency and reduce costs of management and, importantly allow for greater resilience in the face of climate change and other global scale variability to come (Beatley 2009).

Figure 23: Adaptive management requires understanding and embracing change (from Agardy et al 2011 UNEP EBM Manual).



Abu Dhabi already stands much to gain from the Blue Carbon Demonstration Project, as it has shed light on how to recognize, capture, and safeguard important values being provided by this rich mosaic of coastal ecosystems. The world stands much to gain as well, as Abu Dhabi provides leadership in this cutting edge and important field.

Abu Dhabi faces an exciting future. With good information about natural capital and the benefits it provides, and with an improved understanding of how these ecosystems function, the Emirate will be able to anticipate and accommodate change, and grow sustainably. Blue Carbon ecosystems will be a crucial component of that growth.

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Appendix A

Stakeholder Consultation List

The following organisations were consulted in the preparation of this document. The authors are sincerely grateful for their time and contributions to the development of the Ecosystem Services component of the Abu Dhabi Blue Carbon Demonstration Project.

Abu Dhabi Department of Economic Development (ADDED)
Abu Dhabi Department of Transport (DoT)
Abu Dhabi National Oil Company (ADNOC)
Abu Dhabi Marine Operating Company (ADMA-OPCO)
Abu Dhabi Ministry of Foreign Affairs, Directorate of Energy and Climate Change (MoFA, DECC)
Abu Dhabi Tourism and Cultural Authority (ADTCA)
Critical Infrastructure and Coastal Protection Authority
Emirates Diving Association
Emirates Natural History Group
Emirates Wildlife Society – World Wildlife Fund for Nature (EWS-WWF)
Masdar
Mubadala Petroleum
Municipality of Abu Dhabi City (ADM)
New York University – Abu Dhabi
Tourism Development Investment Company (TDIC)
Urban Planning Council (UPC)
United Arab Emirates Ministry of Environment and Water (MoEW)
United Arab Emirates Ministry for International Development and Cooperation (MIDC)
United Arab Emirates University (UEAU)

Appendix B

Protocol Scoring Approach and Sample Scoring Sheets

Intertidal ALGAL ASSEMBLAGES – Rapid Assessment Protocol RECORDING FORM

Date:	Time:	Surveyor(s):	Location (location number and code):
GPS Positions:	At start of transect (0m):	At end of transect (50m):	Water depth (measured):

50 m transect		
Rugosity of substratum (H/M/L):	Presence of fish larvae (Y/N):	Horizontal visibility (estimated):
Abundance of herbivores, partic. *Echinometra*, surgeonfishes, parrotfishes. no. seen per 2 m x 50 m):		Diversity of herbivores (no. of species per 100 m^2):
Presence of solid waste (no. of items per 100m^2):		

Quadrats																	
Quadrat no.		% hard substratum (to nearest 10%)		Of which ?% is macroalgae (to nearest 10%)		No. of algal genera present (1 - 5+)		Abundance of inverts. (no. of individs. per m^2)		Diversity of inverts. (no. of species per m^2)		Abundance of animal burrows (no. per m^2)					
0 – 3 m	**1**																
	2																
	3																
25 – 28 m	**4**																
	5																
	6																
47 – 50 m	**7**																
	8																

SALT MARSH / ALGAL MATS – Rapid Assessment Protocol RECORDING FORM

SALT MARSH

Date:	Time:	Surveyor(s): Location No.	Approx. location (near to…):
GPS Position(s):			State of tide (estimated/measured):

Saltmarsh (20m x 20m)											
Aerial extent of saltmarsh: A: 20m x 20m; B: 17m x 17m; C: 14m x 14m; D: 10m x 10m; E: < 10m x 10m		Mixing with mangroves (proportion S:M to nearest 10%)		No. of saltmarsh plant species		No. of bird species		Presence of solid waste (no. of items per $400m^2$)		Presence of tyre tracks (Heavy; Common; Occasional; Present; None)	

Plots/quadrats (3m x 3m) within saltmarsh										
Quadrat no.	% cover of saltmarsh plants (to nearest 10%)		% cover of cyanobacterial mats within saltmarsh (to nearest 10%)		Presence of crab burrows (count of burrows within 3m x 3m plot)					
1										
2										
3										
4										

ALGAL MAT

Date:	Time:	Surveyor(s): Location No.	Approx. location (near to…):
GPS Position(s):			State of tide (estimated/measured):

Algal mat (20m x 20m)									
Aerial extent of cyanobacterial mat: A: 20m x 20m; B: 17m x 17m; C: 14m x 14m; D: 10m x 10m; E: < 10m x 10m		Mixing with saltmarsh (proportion of Mat:Saltmarsh to nearest 10%)		No. of bird species		Presence of solid waste (no. of items per $400m^2$)		Presence of tyre tracks (Heavy; Common; Occasional; Present; None)	

Plots/quadrats (3m x 3m)										
Quadrat no.	% cover of mats (to nearest 10%)		Abundance of grazers (High; Moderate; Low)		No. of crab burrows (count of burrows within 3m x 3m plot)					
1										
2										
3										
4										

SEAGRASS MEADOW – Rapid Assessment Protocol RECORDING FORM

Date:	Time:	Surveyor(s):	Approx. location (near to…): Location No.
GPS Positions:	At start of transect (0m):	At end of transect (50m):	Water depth (measured):

50 m transect		
% of sea floor covered by seagrass (?m/50m):	Species diversity (no. of spp. present):	Horizontal visibility (estimated):
No. of erosion patches (0 – 4+):	Presence of dugong feeding trails (Y/N):	
Presence of solid waste (no. of items per $100m^2$):		

Quadrats

Quadrat no.		Abundance / % cover (to nearest 10%)		% cover of epiphytes on leaves (to nearest 10%)		Abundance of macroherbivores (no. of individs. per m^2)		Abundance of animal burrows (no. per m^2)		Abundance of *Pinna* shells (no. per m^2)			
0 – 3 m	**1**												
	2												
	3												
25 – 28 m	**4**												
	5												
	6												
47 – 50 m	**7**												
	8												
	9												

MANGROVES – Rapid Assessment Protocol RECORDING FORM

Date:	Time:	Surveyor(s): Location No.	Approx. location (near to…):
GPS Position(s):			State of tide (estimated/measured):

Mangrove stand (as a whole)									
Aerial extent of stand: [>300m^2; 200-300m^2; 100-200m^2;50-99m^2; <50m^2]		Proportion of trees with flowers/fruit (to nearest 10%):		Mean tree height of randomly-selected trees (to nearest 0.5m):		Maximum tree height (to nearest 0.5m):		Presence of solid waste (no. of items per 100m^2):	

Plots/quadrats (3m x 3m) within stand														
Quadrat no.	Density of mature plants (not saplings) /9m^2: ≥ 5 3-4 1-2		% cover of foliage (to nearest 10%):		Density of saplings (i.e. < 0.5m in height): ≥9 down to 1-2/9m^2		Proportion of dead trees (to nearest 10%):		Proportion of damaged trees (to nearest 10%):		Amount of solid tree-waste (1 – 5 items):			
1														
2														
3														
4														

Date:	Time:	Surveyor(s): Location No.	Approx. location:	GIS	Tide state

Mangrove stand (as a whole)									
Aerial extent of stand: [>300m^2; 200-300m^2; 100-200m^2;50-99m^2; <50m^2]		Proportion of trees with flowers/fruit (to nearest 10%):		Mean tree height of randomly-selected trees (to nearest 0.5m):		Maximum tree height (to nearest 0.5m):		Presence of solid waste (no. of items per 100m^2):	

Plots/quadrats (3m x 3m) within stand														
Quadrat no.	Density of mature plants (not saplings) /9m^2: ≥ 5 3-4 1-2		% cover of foliage (to nearest 10%):		Density of saplings (i.e. < 0.5m in height): ≥9 down to 1-2/9m^2		Proportion of dead trees (to nearest 10%):		Proportion of damaged trees (to nearest 10%):		Amount of solid tree-waste (1 – 5 items):			
1														
2														
3														
4														

CORAL ASSEMBLAGES – Rapid Assessment Protocol RECORDING FORM

Date:	Time:	Surveyor(s):	Approx. location (near to…): Location No.
GPS Positions:	At start of transect (0m):	At end of transect (50m):	Water depth (measured):

50 m transect	
Reef zones (1 - 3+):	Horizontal visibility (estimated):
Abundance of herbivores, partic. *Echinometra*, surgeonfishes, parrotfishes: (no. seen per 2 m x 50 m, or 100 m^2):	
Diversity of herbivores (which spp. seen?)	
Presence of solid waste (no. of items per 100m^2):	

Quadrats

Quadrat no.		% hard substratum (to nearest 10%)		% of living coral (to nearest 10%)		Max. size of coral colony (to nearest 5 cm)		No. of coral genera present (1 - 5+)		% of coral genera resilient to temp. changes (to nearest 10%)		% of frame-building corals (massive & sub-massive, espec. *Porites* & Favidae)		Presence of bio-eroders (in partic. urchins) (no. per m^2)	
0 – 3 m	**1**														
	2														
	3														
25 – 28 m	**4**														
	5														
	6														
47 – 50 m	**7**														
	8														

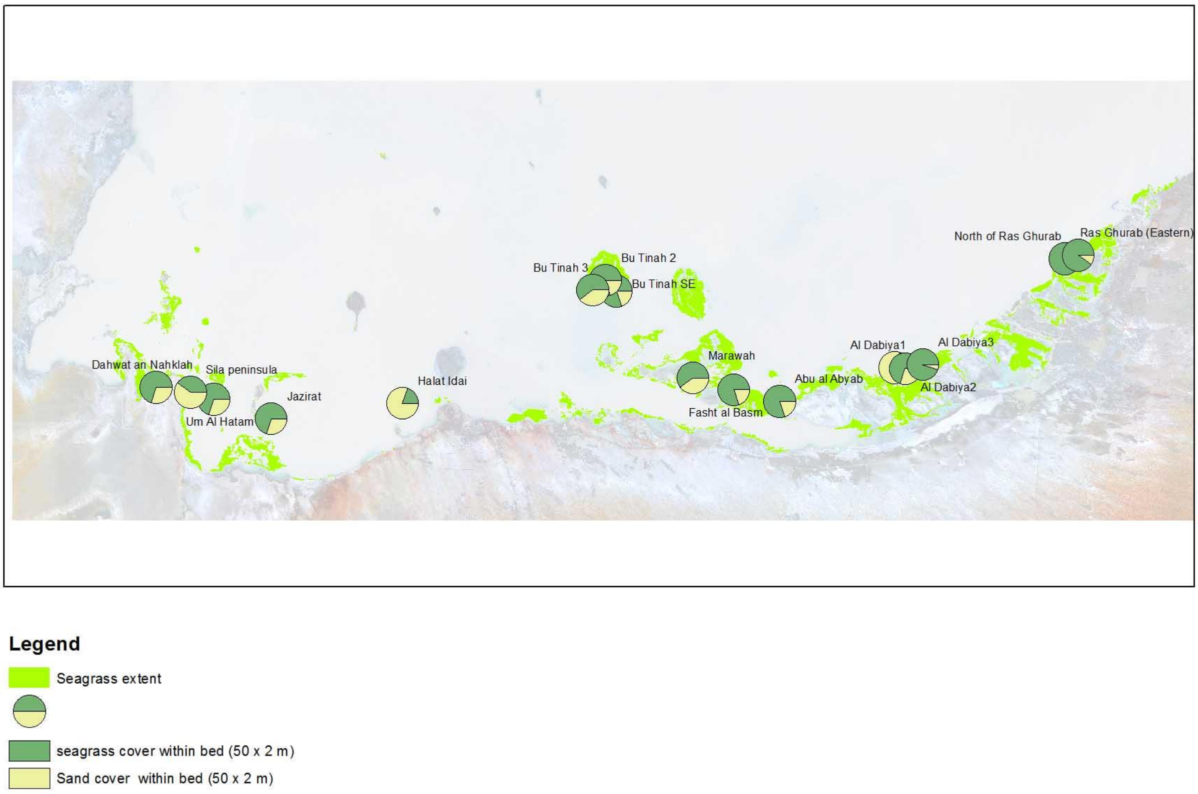
Appendix C

Field Survey Report: Summary of Fieldwork undertaken, 28 April – 7 May 2013 by Dr. Robert Irving

Ten days of diving fieldwork were undertaken to assist with the assessment of ecosystem services within the Abu Dhabi Blue Carbon Demonstration Project, with the aim of testing the application of Rapid Assessment Protocol (RAP) and assessing the Ecosystem Services of the Blue Carbon in Abu Dhabi. The RAP was assessed for seagrass. This was conducted along the seagrass carbon survey team (led by Prof. Jim Fourqurean), whose main task was to obtain seagrass sediment and biomass carbon samples. Dive pairing with a member of the seagrass team also satisfied 'buddy' safety requirements.

Seagrass occurs within shallow water (< ~14 m depth) off the whole coast of Abu Dhabi. However, the most extensive beds are off the coast of the Western Region. The location of sample sites was chosen by the seagrass survey team after consultation with Environment Agency - Abu Dhabi. The intention was to have a geographical spread of sites along the coastline, with some inshore and some offshore (Figure C1).

Figure C1: RAP Seagrass sample locations



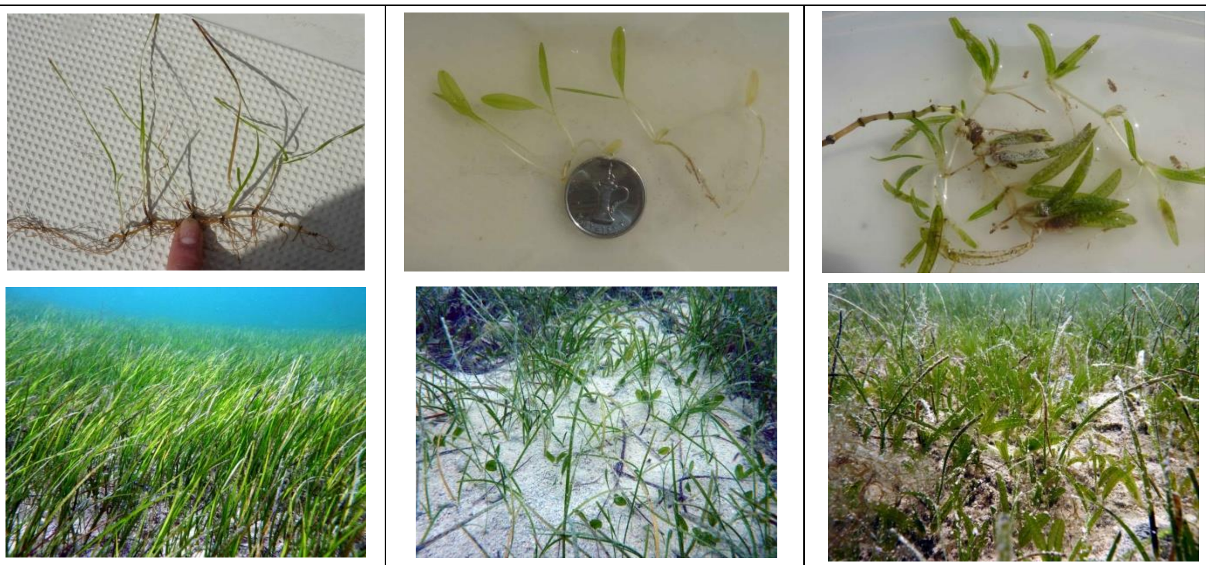
Site attributes

Sites were varied in appearance, with the overall cover of seagrass within any one bed ranging from 20 - 90% and the underlying substratum ranging from coarse clean sand to fine silty mud. The depths of the beds that were dived also varied considerably, the range being from 2.5 - 12m, though most were around 5 - 6m. All bar one site had no evidence of litter items within the 100 m^2 inspected. Underwater horizontal visibility ranged from a murky 2m to a clear 10m. The full range of attributes which were recorded from each site, along a 50m transect, are set out in the recording form included in **Appendix B.**

Biodiversity

All three species of seagrass which are known to occur in Abu Dhabi waters were recorded: *Halodule uninervis*, *Halophila ovalis* and *Halophila stipulacea* (Figure C2). At most sites, two species were present (typically *H. uninervis* and one of the *Halophila* species) mixed in with each other; at one site there was only *H. uninervis* present; and at three sites all three species were present in varying proportions.

Figure C2: The three species of seagrass present in Abu Dhabi



Halodule uninervis | *Halophila ovalis* | *Halophila stipulacea*

The most recorded invertebrate groups within the beds were ascidians (sea-squirts) and porifera (sponges). At several sites, where *Halodule uninervis* dominated, individual blades (leaves) of this seagrass had large numbers of epiphytic sea squirts (as yet unidentified) associated with them (Figure C3). Fish were only seen rarely (Figure C4), as were sightings of crustacea and mollusks. Their low numbers may be indicative of the time of year (late April) when the surveys were undertaken. Another group conspicuous by their absence were sea cucumbers, which one would have expected to have seen. It is known that there has been a fishery for these in the past, which may have affected their numbers.

Figure C3 (left): Orange and white colonial sea-squirts. Figure C4 (right): Juvenile golden trevally *Gnathanodon speciosus* foraging in amongst *Halodule uninervis*

One dugong *Dugong dugon* and one green turtle *Chelonia mydas* were seen under water during survey dives, though several more (perhaps 20 of each) were seen from the surface whilst on board the dive boat. Although dugong feeding trails were searched for under water, their presence could not be confirmed with absolute certainty, these trails closely resemble naturally-occurring channels through the seagrass beds.

Coral reefs

One dive (site no. M07.4, Al Dhabiyah) and one snorkel (site no. M11.1) were undertaken on coral reefs. At least 5 genera representing approximately 8-12 were present at each site. There was a noticeable dearth of fish life present at the Al Dhabiyah site, the reason for which was unknown, though by contrast at site M11.1 representatives of at least 10 fish families were noted. There were some signs of anchor damage at both sites, probably reflecting the popularity of these sites for dive groups and the anchoring of their boats. The full range of attributes which were recorded from each site, along a 50 m transect, are set out in the recording form included in **Appendix B.**

Figure C5 (left): Laying out a 50 m transect tape at Al Dhabiyah reef (M07.4) Figure C6 (right): Submassive *Platygyra* and *Porites* corals with a shoal of juvenile barracuda in the distance at Saadiyat Reef (M11.1).

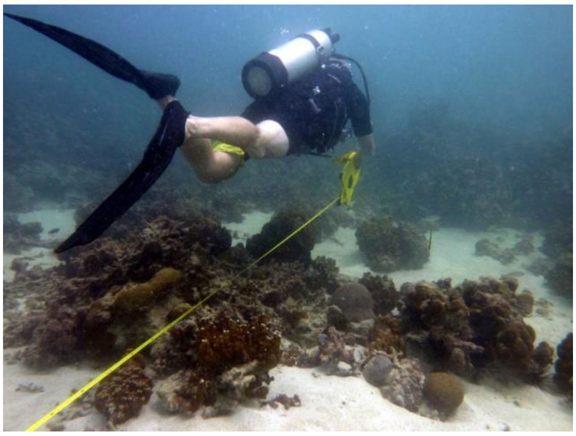


Table C1: Metadata associated with the 16 seagrass and 2 coral reef survey sites.

Date	Site no.	Site name	Location	Position	Ecosystem	Substratum	% cover of seagrass	Depth
28-Apr-13	A28.1	North of Ras Ghurab	NE of Abu Dhabi city	24.64473° N 54.49500° E	Seagrass	Sand	90%	6.8 m
	A28.2	Ras Ghurab (Eastern)	NE of Abu Dhabi city	24.65578° N 54.53673° E	Seagrass	Sand	90%	6.4 m
29-Apr-13	A29.1	Um Al Hatam	Nr Sila, Western Region	24.21152° N 51.87123° E	Seagrass	Sand	70%	5.5 m
	A29.2	Sila peninsula	Nr Sila, Western Region	24.23258° N 51.79963° E	Seagrass	Mud	40%	12.0 m
30-Apr-13	A30.1	Dahwat an Nahklah	Nr Sila, Western Region	24.24783° N 51.69341° E	Seagrass	Fine sand	70%	5.3 m
02-May-13	M02.1	Jazirat	Nr Sila, Western Region	24.15132° N 52.04760° E	Seagrass	Sand	70%	5.0 m
	M02.2	Halat Idai	Nr Sila, Western Region	24.19905° N 52.45295° E	Seagrass	Sand	20%	8.9 m
05-May-13	M05.1	Marawah	Nr Mirfa, Western Region	24.27702° N 53.34829° E	Seagrass	Muddy sand	60%	6.6 m
	M05.2	Fasht al Basm	Nr Mirfa, Western Region	24.24085° N 53.47422° E	Seagrass	Fine sand	80%	2.6 m
	M05.3	Abu al Abyab	Nr Mirfa, Western Region	24.20513° N 53.61585° E	Seagrass	Fine sand	80%	3.5 m
06-May-13	M06.1	Bu Tinah SE	approx. 10 km S of Bu Tinah	24.54534° N 53.11234° E	Seagrass	Fine sand	80%	6.0 m
	M06.2	Bu Tinah 2	approx. 3 km S of Bu Tinah	24.57855° N 53.07900° E	Seagrass	Fine sand	80%	2.5 m
	M06.3	Bu Tinah 3	Nr Bu Tinah	24.54852° N 53.03997° E	Seagrass	Fine sand	60%	5.0 m
07-May-13	M07.1	Al Dabiyah1	West of Abu Dhabi city	24.30876° N 53.97083° E	Seagrass	Coarse sand	20%	5.0 m
	M07.2	Al Dabiyah2	West of Abu Dhabi city	24.30582° N 54.00273° E	Seagrass	Coarse sand	70%	4.0 m
	M07.3	Al Dabiyah3	West of Abu Dhabi city	24.31826° N 54.05725° E	Seagrass	Fine sand	90%	8.0 m
	M07.4	Al Dhabiyah	West of Abu Dhabi city	24°20.347' N 54°04.389' E	Coral reef	Rock	65%	6.0 m
11-May-13	M11.1		Reef NW of Sadiyaat Island	?	Coral reef	Rock/sand	70%	6.0 m

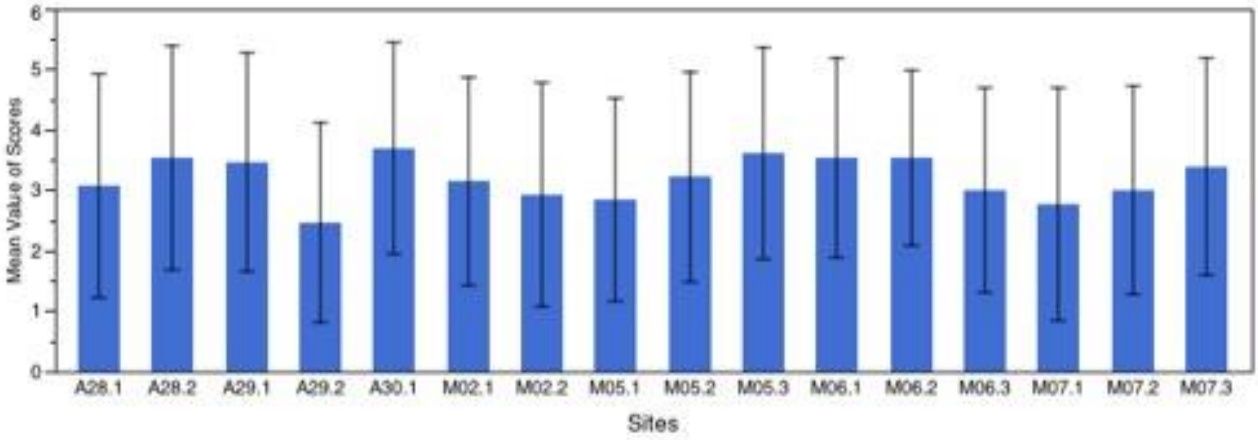
Appendix D

Statistical analysis of Abu Dhabi Rapid Assessment for Seagrass habitat condition and integrity

Description of data sets

Three data sets of seagrass habitat attributes and their scores, recorded from quadrats and transects at 16 sites in Abu Dhabi were analysed. The data included (i) scores, (ii) weighted scores using proportions and (iii) only highest weighted scores (attributes with weights higher than 5). Data were analysed using the statistical program MVSP (MultiVariate Statistical Package).

Site scores

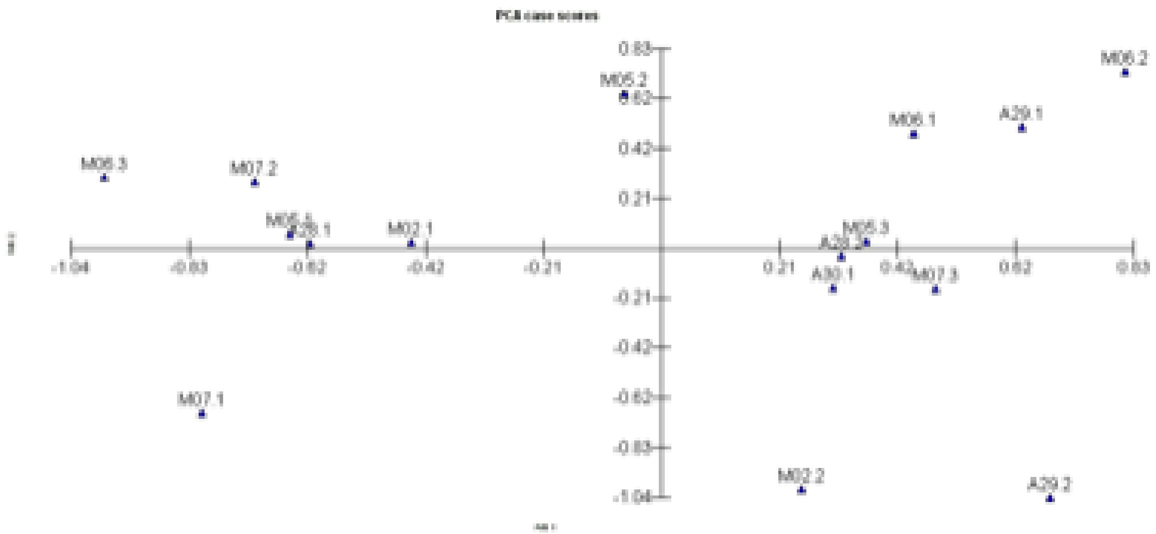


Comparing the average site scores shows no significant difference between sites if all attributes are considered. Bars represent +/- one standard deviation from the mean. Individual attributes are graphed and presented in this Appendix. To get a better understanding of the drivers of each site score, a few multivariate analyses were undertaken.

Principal Component Analysis (PCA)

Generally, a PCA reveals the internal structure of the data in a way that best explains the variance in the data. If a multivariate dataset is visualised as a set of coordinates in a high-dimensional data space (1 axis per variable), a PCA can supply the user with a lower-dimensional picture, a "shadow" of this object when viewed from its most informative viewpoint. This is done by using only the first few principal components so that the dimensionality of the transformed data is reduced.

Figure D1: PCA Scatterplot WEIGHTED SCORES- sites



Results for sites (and attributes) were nearly identical if either the weighted or unweighted scores are used; therefore unweighted (unmodified) scores have been used in the remainder of the analyses.

Figure D2: PCA Scatterplot unweighted scores - sites and attribute vectors

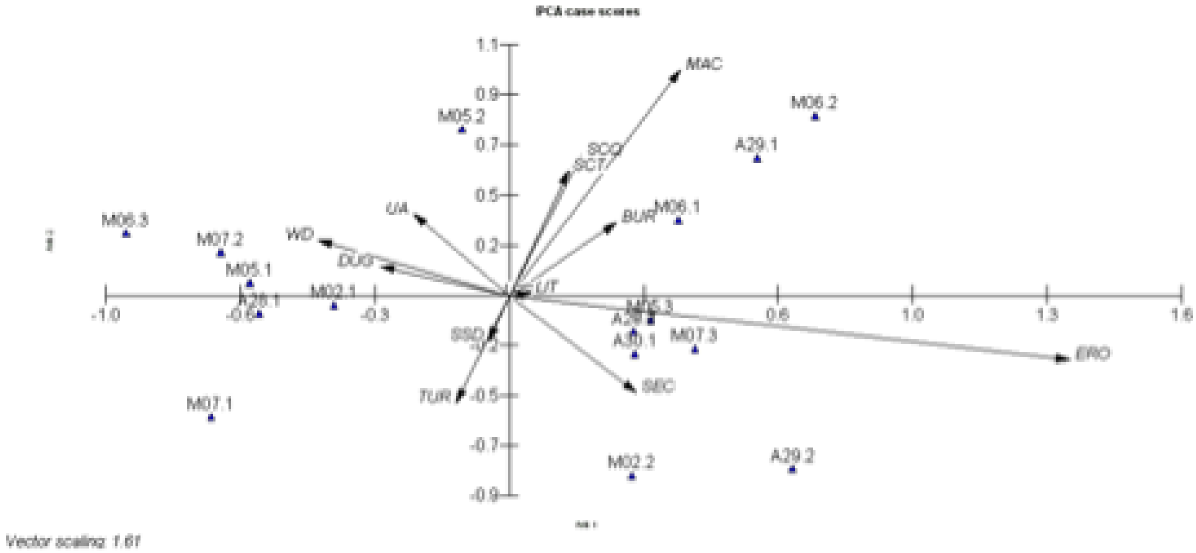


Figure D2 illustrates that there are 3 main clusters of sites (left, center, and right in the plot) that are similar / related. Sites A28.1, M02.1, M05.1, M06.3, M07.1, and M07.2 represent one cluster on the left of the plot and sites A28.2, A29.2, A30.1, M02.2, M05.3, and M07.3 represent another cluster on the right. The third and central cluster is made up of A29.1, M06.1, M06.2. One site M05.2 can be seen as an outlier. Principal Components 1 and 2 explain 52% of the variation in the data of the scores. The attributes seagrass erosion (ERO), seagrass epiphyte cover (SEC) and to some extent litter (LIT) have heavy loadings (not similar) on principal component 1. Seagrass cover quadrat (SCQ), transect (SCT), macroherbivores (MAC), and animal burrows (BUR) have heavy loadings (but different) for principal component 2.

The vectors correspond to habitat attributes. The left cluster of sites (A28.1, M02.1, M05.1, M06.3, M07.1, and M07.2) positively correlate with optimum water depth (WD), dugong feeding trails, and sea urchin abundance. The right cluster of sites (A28.2, A29.2, A30.1, M02.2, M05.3, and M07.3) positively correlate with low erosion (ERO) and low seagrass epiphyte cover (SEC). The central cluster of sites A29.1, M06.1, M06.2, positively correlate with high seagrass cover (in quadrate and transect), macroherbivores, and animal burrows.

Figure D3: Dendogram of sites using all attributes and their scores

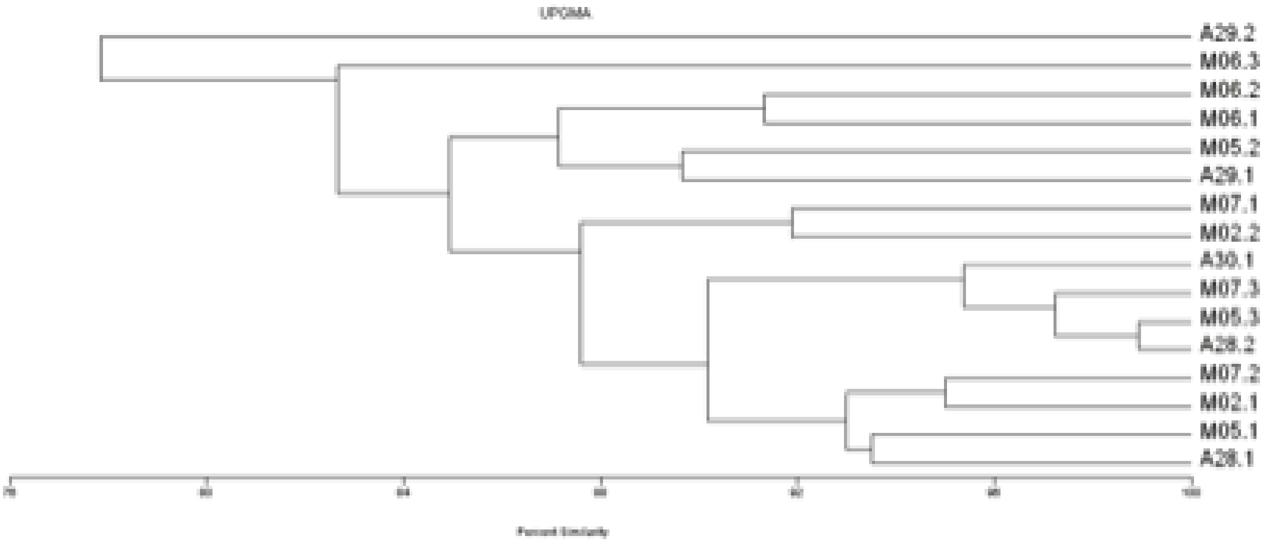
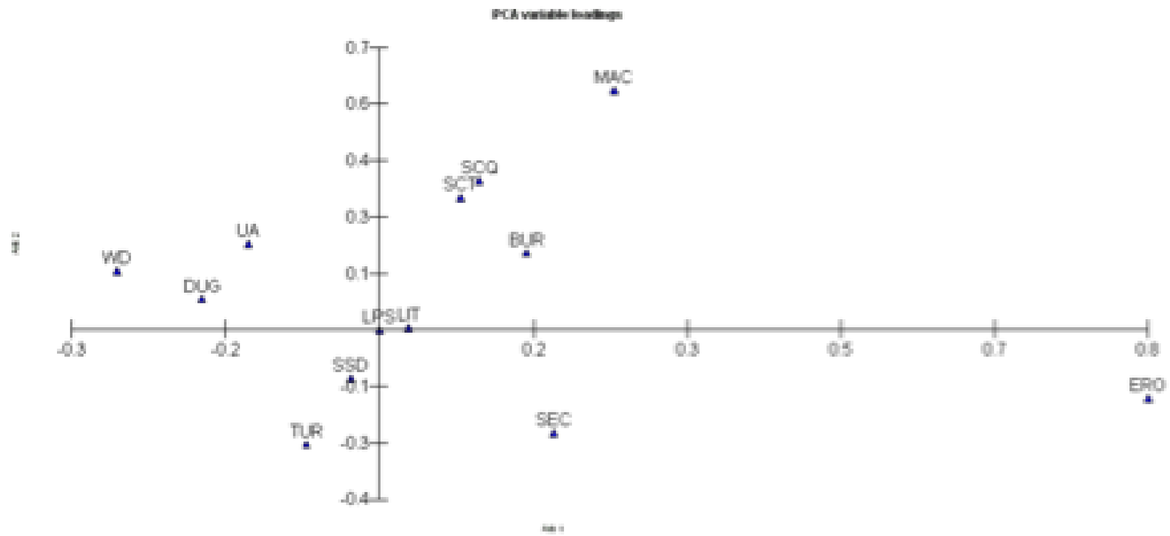


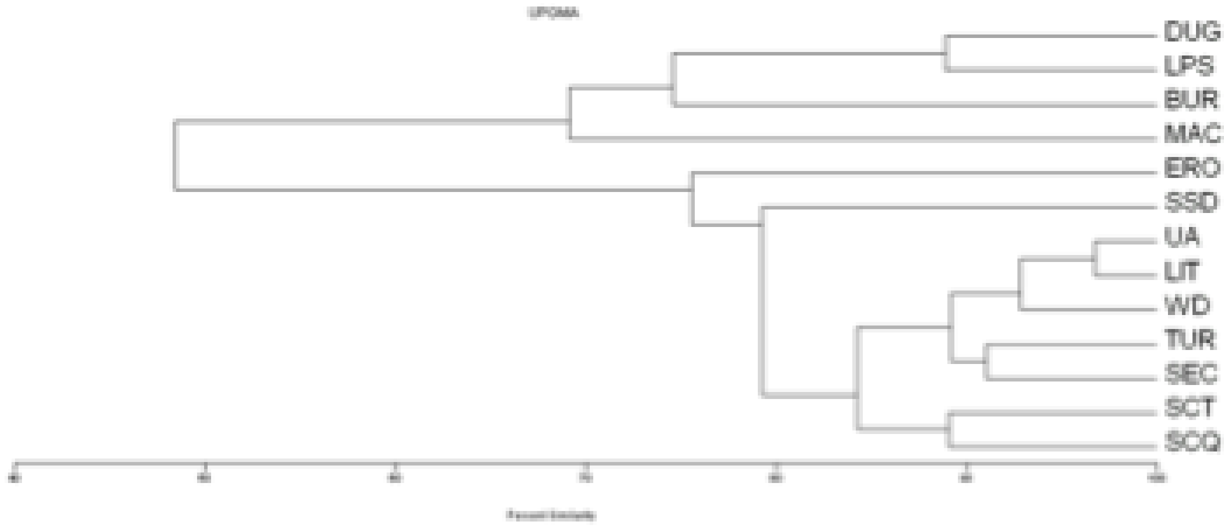
Figure D3 shows the ecological similarities between sites based on their attribute scores. Sites M05.3 and A28.2 are most similar and they are in turn most similar to site M07.3. All three are most similar to A30.1. Site 29.2 is the most dissimilar from all the other sites.

Figure D4: PCA Scatterplot SCORES- attributes



No distinct clustering occurs when we plot attribute scores from all sites.

Figure D5: Dendogram of attributes



Similarities between attributes (of all sites) can be seen between:

a) Sea urchin abundance (UA) and litter (LIT),

b) UA, LIT and water depth (WD)

c) Turbidity (TUR) and seagrass ephiphyte cover (SEC)

d) Seagrass cover transect and seagrass cover quadrat

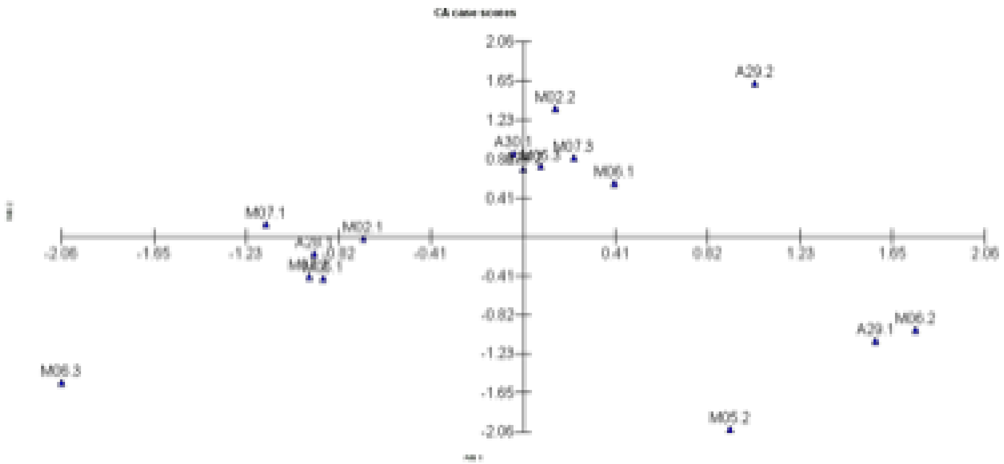
e) Dugong feeding trail (DUG) and live Pinna shells (LPS)

Results of Correspondence Analyses using (Un-weighted) Scores

Correspondence analysis is a descriptive/exploratory technique designed to analyze simple two-way and multi-way tables containing some measure of correspondence between the rows and columns. The results provide information which is similar in nature to those produced by factor analysis techniques such PCA, and they allow you to explore the structure of categorical variables included in Table C1.

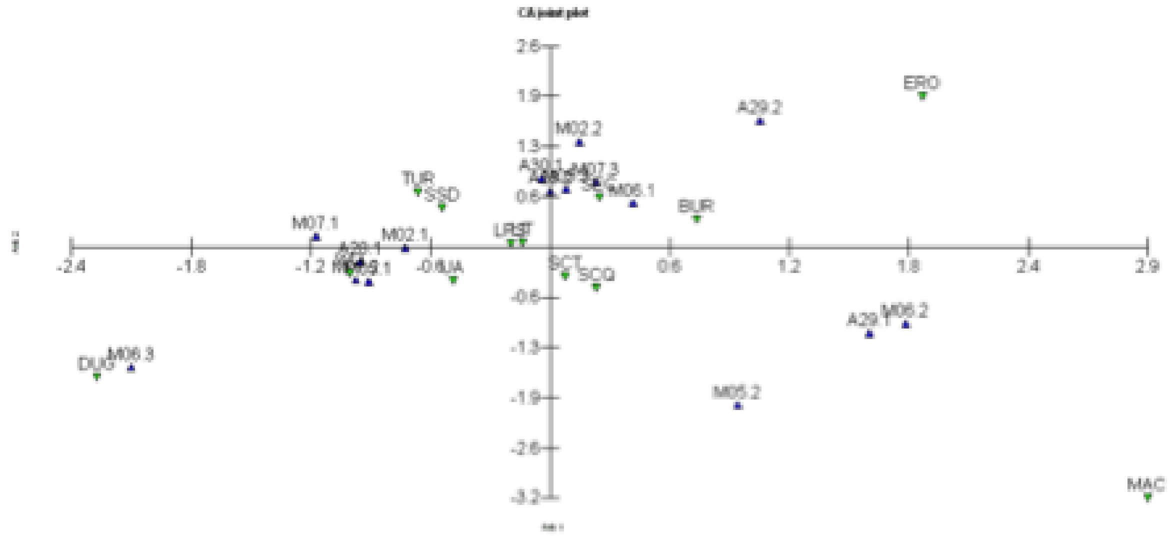
Importantly, the purpose of correspondence analysis is to reproduce the distances between the row and/or column points in a two-way table in a lower-dimensional display. What is important are the distances of the points in the two-dimensional display, which are informative in that row points that are close to each other are similar with regard to the pattern of relative frequencies across the columns.

Figure D6 CA Scatterplot for all sites



In this analysis, we can see that the similarities between sites display in three main clusters again. Higher score / condition sites tended to cluster in the top right panel (with the exception of A29.2) while lower score / condition sites tended to the bottom left of the scatterplot.

Figure D7: CA Scatterplot sites and attributes



Displaying the attribute layer with the sites gives us the similarities and associations between the sites and attributes. For example site M06.3 has a lower score / condition site but because it exhibits dugong feeding trails (with dugong being a flagship species of particular value), its condition vis a vis delivery of ecosystem services is likely to be higher than the physical condition might suggest.

Additional Supporting Data from Seagrass Analysis

Figure D8: Scores for seagrass cover (%) in quadrats between sites.

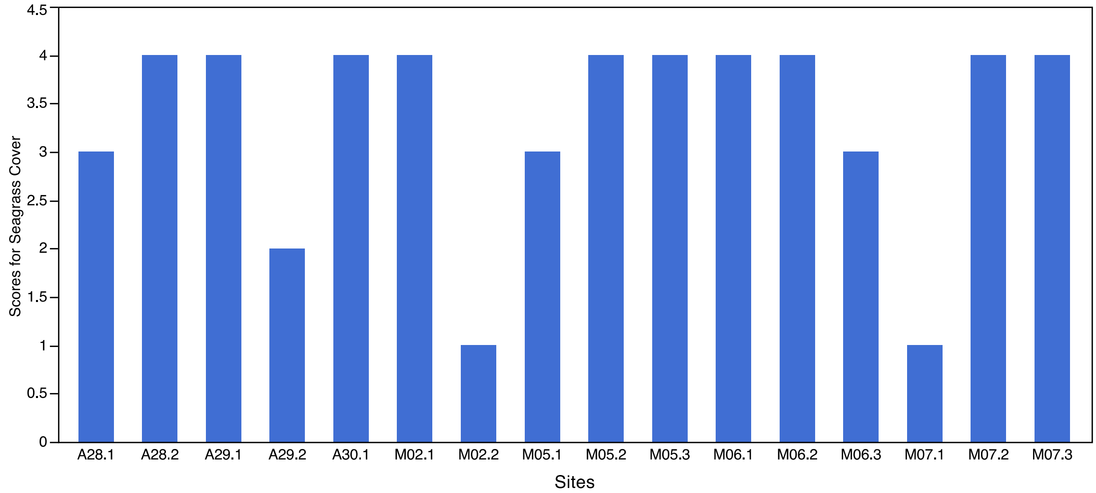


Figure D9: Scores for epiphytes cover (%) in quadrats between sites.

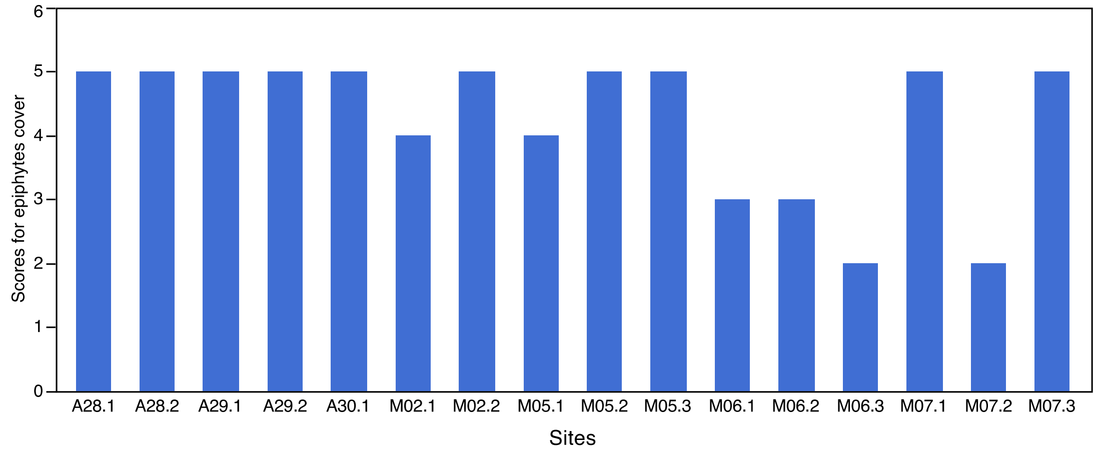


Figure D10: Scores for Number of Macroherbivores per m^2 between sites.

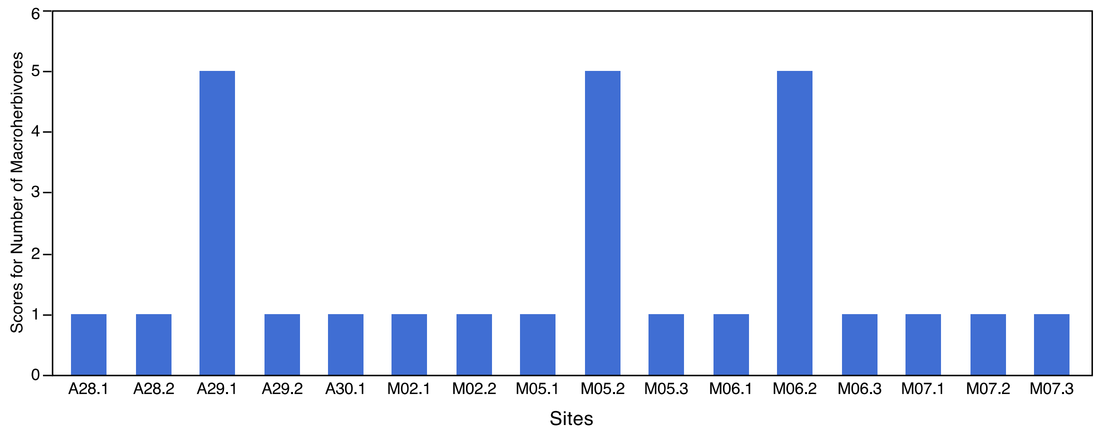


Figure D11: Scores for the number of animal burrows between sites

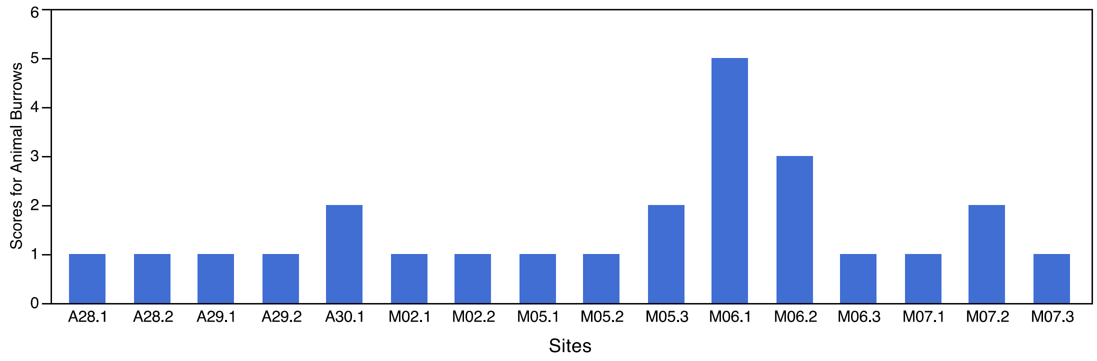


Figure D12:Scores for the number of alive *Pinna* shells per m^2 between sites.

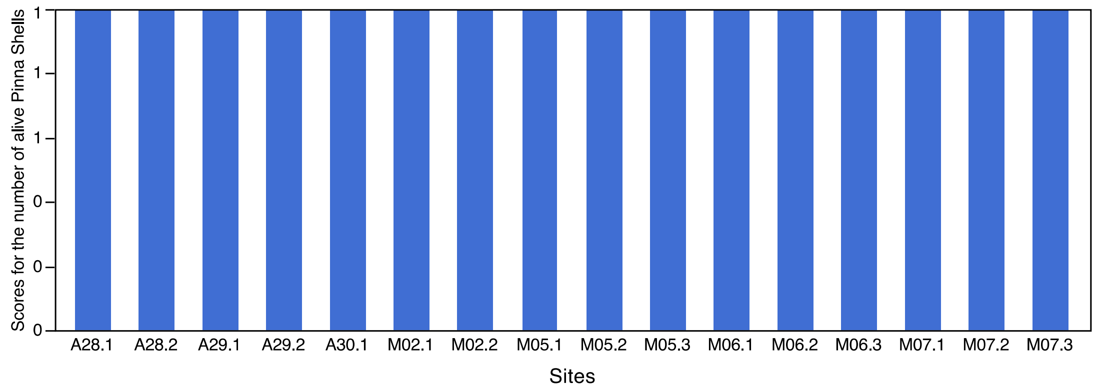


Figure D13: Scores for number of seagrass species between sites.

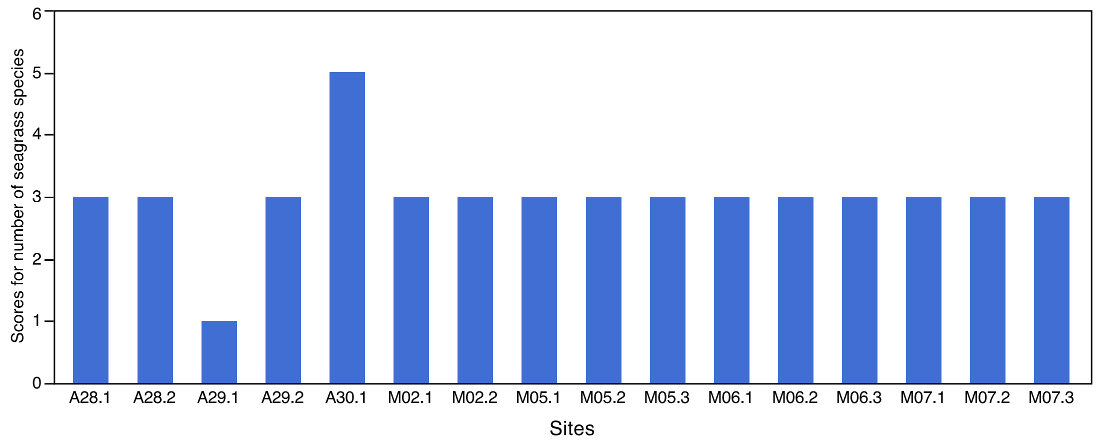


Figure D14: Scores for seagrass cover (%) along transects between sites.

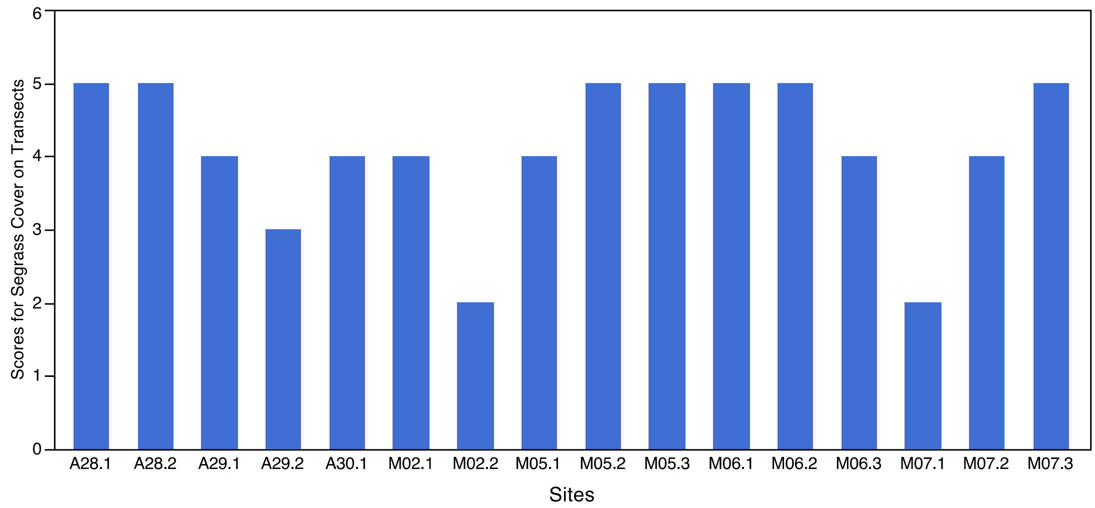


Figure D15: Scores for water depth between sites.

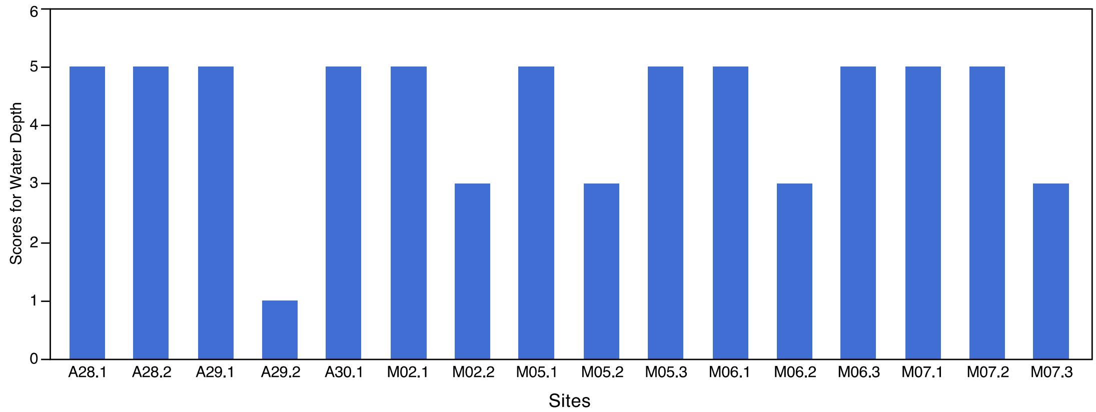


Figure D16: Scores for Turbidity between sites.

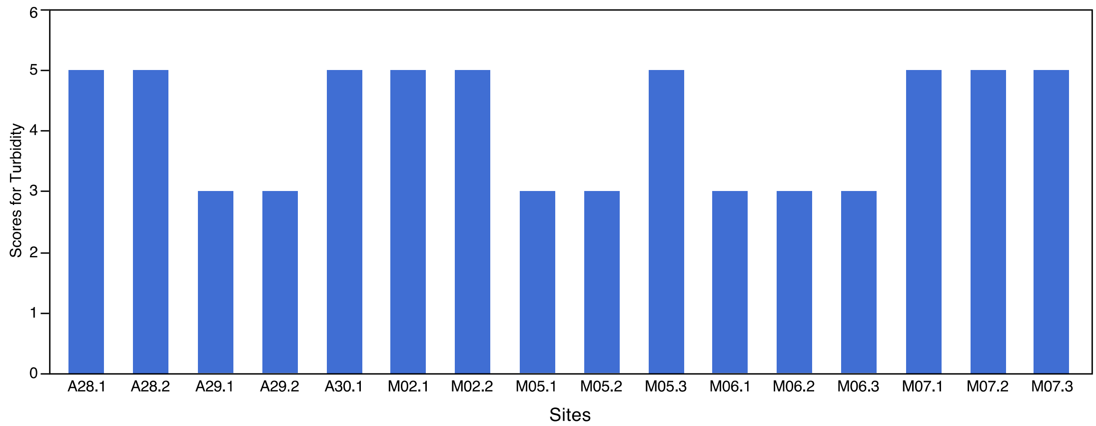


Figure D17: Scores for sign of erosion between sites.

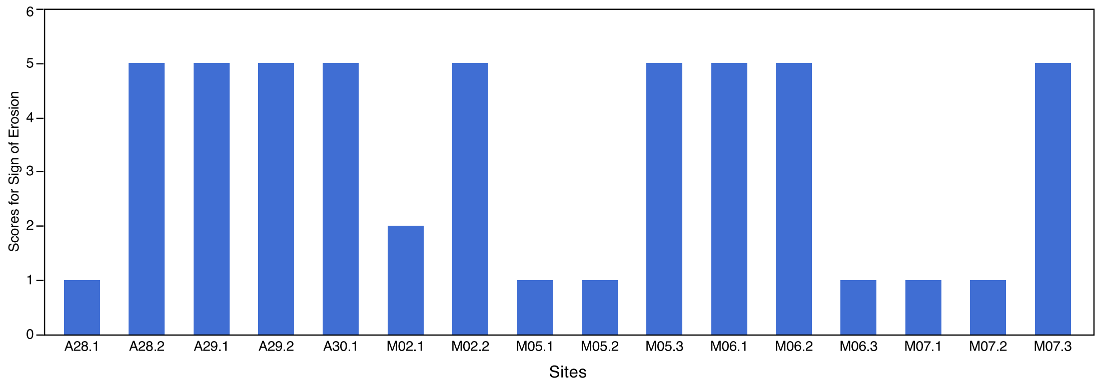


Figure D18: Scores for dugong feeding trails between sites.

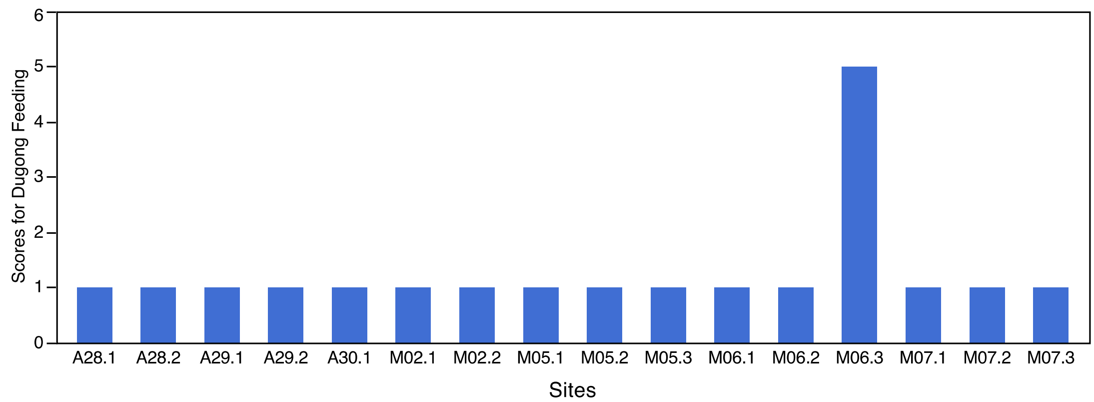


Figure D19: Scores for litter items along a 50x2 m transect present between sites.

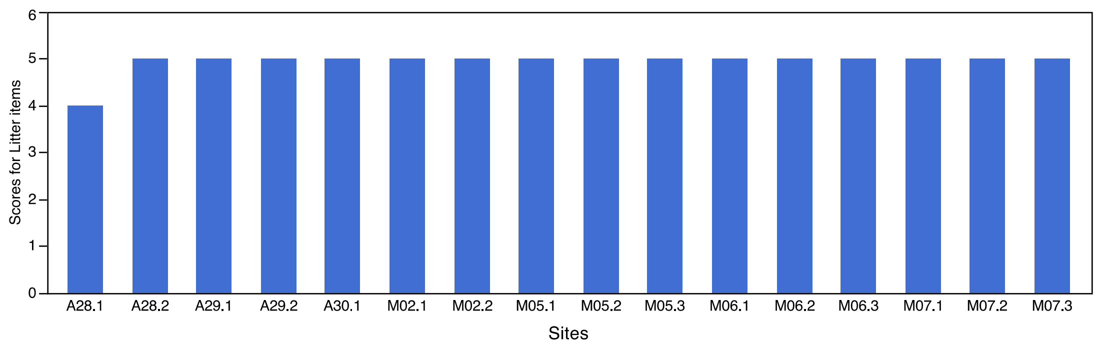
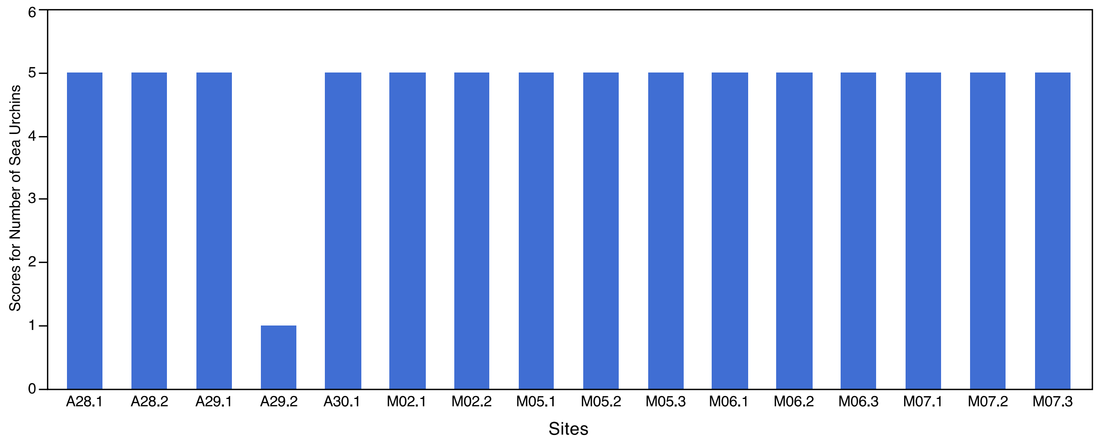


Figure 20: Scores for number of sea urchins present between sites.



Appendix E

The Ecosystem Services Assessment Team

The Ecosystem Services Assessment component was lead by Dr. Tundi Agardy of Forest Trends., s senior expert on marine and coastal ecosystem management. Dr. Agardy is an internationally renowned expert in marine conservation, with extensive field and policy experience in Africa, Asia, the Caribbean, the Mediterranean, North America and the Pacific. Tundi specializes in coastal planning and assessment, marine protected areas, fisheries management and ocean zoning, and has published widely in these fields. She founded Sound Seas in 2001 as an independent group working at the nexus of policy and science to promote marine conservation. At Forest Trends, she is heading up the MARES initiative – a program looking to protect Marine Ecosystem Services through Payments for Ecosystem Services (PES) markets. Tundi works with international think tanks, foundations, multilaterals, museums and academic institutions, environmental groups and consortia with interest in solving local and regional coastal and marine conservation problems. She completed her undergraduate work at Wellesley and Dartmouth Colleges and then received her Ph.D. in biological sciences and Masters in Marine Affairs from the University of Rhode Island and was postdoctoral fellow at the Woods Hole Oceanographic Institution. She has served as Senior Scientist for the World Wildlife Fund and began Conservation International's Global Marine Program, which she oversaw as Senior Director. She also led the coastal portion of the Millennium Ecosystem Assessment – a 3-year global analysis released in 2005 that represents the consensus of over a thousand scientists on the state of the world's ecosystems. Tundi has published extensively, and is the author of two widely used texts on marine planning: Marine protected Areas and Ocean Conservation (1997) and Ocean Zoning: Making Marine Management More Effective (2010).

To undertake the rapid assessment of ecosystem services being generated by Abu Dhabi's Blue Carbon ecosystems, a core team of marine ecologists was assembled, some working remotely and others in-country. Dr. Ameer Abdullah of IUCN provided his expertise, both global and regional, and created a rapid assessment protocol specifically designed to quickly assess Blue Carbon sites as to their condition and their ability to generate services (Appendix B). Dr. Abdulla is a marine ecologist by training and has worked with the IUCN Global Marine Programme (GMP) since June 2004. His work stretches over vast areas, including small island developing states (SIDS) in the Indian Ocean where he focuses on the detection and monitoring of marine introduced species on coral reefs. In the Red Sea, Ameer conducts behavioural observations on Samadai Reef spinner dolphins in Marsa Alam, Egypt, and conducts long term research on reef health and resiliency. As Ameer is based at the GMP's regional office in Malaga, Spain, his other main area of work is the Mediterranean Sea, where he is helping to assess the ecological status of Mediterranean shark species and supporting a regional program of North African Marine Protected Areas. He completed his PhD training in Coral Reef Ecology at the James Cook University, Australia and has over ten years of experience in tropical marine ecology in the Indian Ocean, Red Sea, Arabian Gulf, Great Barrier Reef, Mediterranean Sea, and the Gulf of Mexico. Ameer also holds a MSc. degree in Tropical Environmental Management with specific emphasis on marine impact assessment and monitoring in protected areas. Ameer is the author of a number of scientific papers and technical reports that address marine ecology, conservation, species, and impact assessment.

Dr. Robert Irving, owner of Sea-Scope Consultants (and also a member of the WCMC team delivering the Geographic (Mapping) component and supporting in the development of the Abu Dhabi Blue Carbon Mapping Toolkit) applied the protocol in the field, testing its utility in the seagrass surveys. Dr. Irving's expertise lies in undertaking marine ecological survey work (coastal, littoral & sublittoral) both in the UK and overseas. He has undertaken surveys and provided advice to four of the UK's nature conservation agencies, other governmental agencies (e.g. Sea Fisheries Committees, Environment Agency etc.), non-governmental organisations (e.g. Worldwide Fund for Nature, Marine Conservation Society) and other environmental consultancies (e.g. ERT, Royal Haskoning, Wimpey, Emu, BMT Cordah etc.) and has also been involved with fish-farm pollution studies; bait-digging studies; marine nature reserves; marine nature conservation issues.