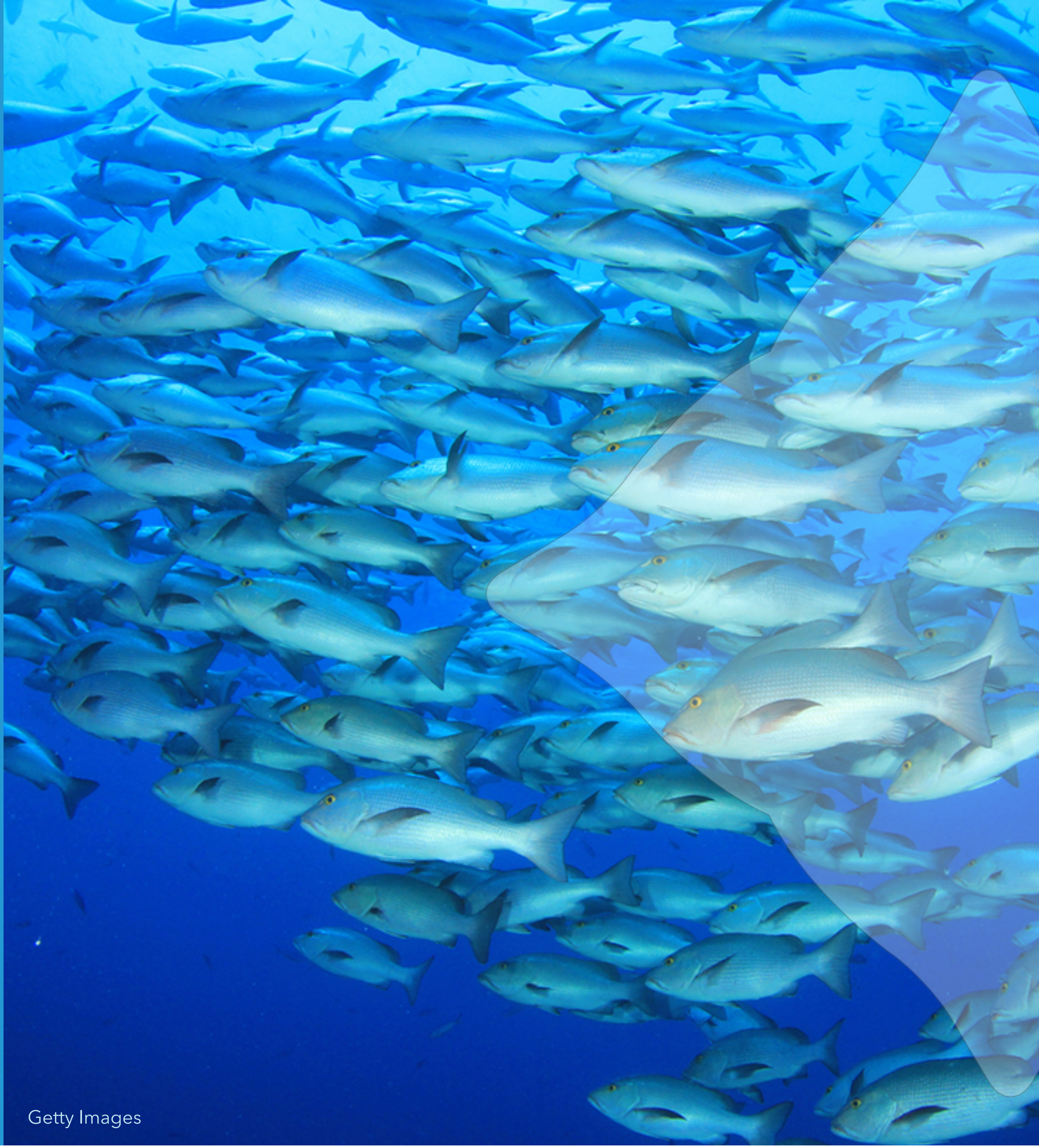
Assessment of One Oceanic Blue Carbon Mechanism in the UAE: Biomass Carbon Audit Test Case with a Focus on Abu Dhabi Emirate



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UAE Oceanic Blue Carbon Pilot Study

Abu-Dhabi Global Environmental Data Initiative (AGEDI)

GRID-Arendal

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ABOUT THIS REPORT

AN AGEDI COLLABORATION PROJECT WITH GRID-ARENDAL

The UAE Oceanic Blue Carbon project aims to provide an assessment of oceanic blue carbon ecosystems within the UAE. The authors have utilised existing datasets and methods to quantify and assess the capacity for fish, cetaceans, dugongs, sea turtles and seabirds inhabiting UAE's marine environment to store and sequester carbon. The analysis represents the world's first oceanic blue carbon audit and policy assessment at the national level and will allow relevant policy and management entities in the UAE to evaluate options for the potential implementation of oceanic blue carbon policies at the local and national level.

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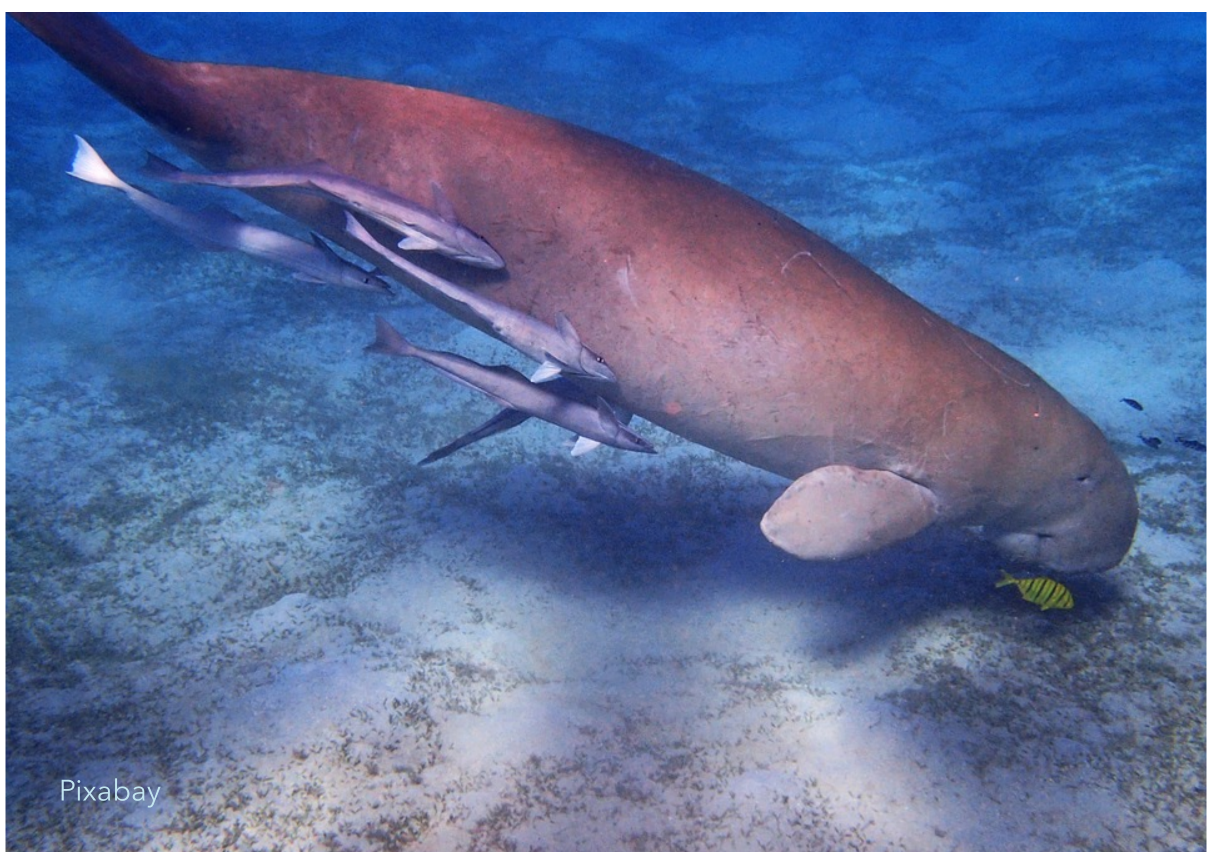

Abstract

Oceanic blue carbon refers to the natural ways that marine vertebrates can trap carbon. Protecting and enhancing oceanic blue carbon stores can potentially lead to conservation and climate change mitigation benefits. Biomass carbon is one of nine identified oceanic blue carbon pathways whereby marine vertebrates can mediate carbon storage and sequestration. The larger and more long-lived an animal is, the more biomass carbon can be stored. The goal of this preliminary, exploratory test case was to evaluate the UAE's marine vertebrate biomass carbon stores with a focus on Abu Dhabi emirate. Existing databases, reports, and publications were mined for data on fisheries catch and marine vertebrate population abundance over as many years as possible. While the entire UAE was considered, the highest resolution and most consistent data were available from Abu Dhabi Emirate; thus, results focus on this emirate. Biomass carbon storage potential was assessed in two ways. First, lost biomass carbon storage potential was estimated by analyzing fisheries catch data. Second, current biomass carbon storage potential (i.e., biomass carbon standing stock) for marine mammals, sea turtles, and seabirds was estimated by analyzing abundance data. Due to a lack of data on fish abundance at the time of analysis, fish were excluded from estimates of biomass carbon standing stock but these data should be included in future studies.

An estimated cumulative total of 369,824 tonnes of biomass carbon storage potential was lost through UAE fisheries catch from 1980 to 2017. In Abu Dhabi emirate, an estimated cumulative total of 11,295 tonnes of biomass carbon storage potential was lost through fisheries catch from 2001 to 2018. During 2018, an estimated 532 tonnes of biomass carbon storage potential was lost due to fisheries catch which is nearly equivalent to the current estimated biomass carbon standing stock of marine mammals, sea turtles, and seabirds in Abu Dhabi emirate of 520 tonnes.

This biomass carbon standing stock is composed of dugongs (51%), sea turtles (24%), dolphins (19%), and seabirds (6%). Of the 66 species analyzed (53 fish species, three marine mammal species, two sea turtle species, eight seabird species) in this study, eight (12%) are threatened, with conservation status as vulnerable or higher. As this study focused on Abu Dhabi emirate, results should not be extrapolated to the rest of the UAE.

Biomass carbon (and oceanic blue carbon in general) is just one of many ecosystem services provided by these species and thus should not be viewed in isolation or as a replacement for other conservation strategies. Protection and enhancement of marine vertebrate biomass carbon stores can potentially be one of many strategies for conservation planning and climate change mitigation in the UAE. Future research should focus on increasing a wider spectrum of species, frequency, and consistency of marine vertebrate population monitoring throughout the UAE.


Arabian Business

INTRODUCTION

The Arabian Gulf has a rich biodiversity of marine vertebrates including fish, marine mammals, sea turtles, and seabirds (UNEP 2016). Juxtaposed against this biological richness, however, is a high level of anthropogenic impact from activities such as oil extraction, land reclamation, dredging, and overfishing (Burt 2014, Díaz López et al. 2017, EAD 2017b, Vaughan et al. 2019). The Arabian Gulf is also expected to experience the effects of climate change (e.g., via rising sea surface temperatures, increasing salinity) which is predicted to reduce habitat for many important marine species (AGEDI 2015b, Wabinitz et al. 2018). In particular, UAE's fisheries are vulnerable as all 23 coral-dependent fish species in the Arabian are considered at elevated risk of extinction, mostly as a result of coral reef habitat degradation. Further, 8% of all bony fishes in the Arabian Gulf are considered at risk of extinction, primarily due to over-harvesting and habitat degradation (AGEDI 2015a; Buchanan et al. 2016, 2019).

For charismatic marine megafauna such as dolphins and sea turtles, habitat availability is expected to decline by the end of the century as a result of climate change and the rate at which suitable habitat is being lost in the UAE is among the highest in the Gulf (Wabnitz et al. 2018).

While the Arabian Gulf is subjected to high levels of anthropogenic activity (EAD 2017b), it also offers a powerful opportunity for development of conservation strategies to mitigate negative anthropogenic impacts. One strategy for mitigating climate change is to conserve and protect oceanic blue carbon stores, which refers to the natural ways that marine vertebrates can trap carbon (Lutz et al. 2018). While this concept is clearly not the only answer to climate change, it can be included as one of the many data layers required to develop climate mitigation and conservation strategies. It should be further noted that carbon storage merely provides an additional value to marine species and should not be seen as a substitute for other ecosystem services they provide.

At least nine discrete "oceanic blue carbon" mechanisms have been identified through which marine vertebrates can store and sequester carbon and potentially help to mitigate climate change (Fig. 1; for a full explanation of the nine oceanic blue carbon mechanisms see https://url.grida.no/oceanicbc). "Oceanic" is a general term used to distinguish carbon storage that is mediated by vertebrates from "coastal blue carbon" which refers to carbon stored in coastal ecosystems (i.e., salt marshes, seagrass beds, mangrove forests; Mcleod et al. 2011). Specifically, the present study focused on biomass carbon, which is one of nine currently identified oceanic blue carbon mechanisms (Lutz et al. 2018).

Biomass carbon refers to carbon stored in the bodies of marine vertebrates. Like all living things, marine vertebrates are made of carbon and thus can serve as carbon reservoirs throughout their lives. Consequently, an individual that is large and/or long-lived can store more carbon than a small-bodied, short-lived individual which will store small amounts of carbon for very short periods of time. This study focuses on biomass carbon as it is expected that this mechanism can be examined using pre-existing data; i.e., without requiring additional empirical data collection. As such, this is an appropriate mechanism to examine for this initial, exploratory test case of oceanic blue carbon in the UAE.

1 Carbon storage refers to carbon removed from the atmosphere for decades while carbon sequestration refers to carbon removed from the atmosphere for hundreds of years or more.

A previous study in the Eastern Tropical Pacific assessed the biomass carbon value of the commercial tuna fishery from 1919 to 2011 by quantifying the amount of carbon removed via commercial fisheries catch and cetacean bycatch (Martin et al. 2016). Results showed that 543,533 tonnes of tuna (*Thunnus albacares, T. obesus, Katsumanus pelamis*) were removed per year, representing 62,500 tonnes of carbon per year and a cumulative total of 28,281,645 tonnes of carbon. Total bycatch removal of 3,477,121 spinner (*Stenella longirostris*) and offshore spotted (*S. attenuata*) dolphins represented a total loss of 54,509 tonnes carbon (Martin et al. 2016).

The goal of the present study was to evaluate the UAE's marine vertebrate biomass carbon storage potential. Fisheries catch data in addition to marine mammal, sea turtle, and seabird abundance data were analyzed. Study design and data analysis were modeled after Martin et al. (2016). As the concept of biomass carbon, and oceanic blue carbon in general, is still very much in its infancy, the results herein should be viewed as a highly exploratory, preliminary test case. Preliminary results are provided and several data needs and knowledge gaps are identified that will help to advance future work on biomass carbon if the UAE should choose to explore this concept further.

METHODS

Existing databases, reports, and publications were mined for information on fisheries catch, marine vertebrate population abundance, and strandings (marine mammals and sea turtles only) over as many years as possible. Biomass carbon storage potential in marine vertebrates was assessed in two ways. First, lost biomass carbon storage potential was estimated by analyzing fisheries catch data. This represents carbon that would have been stored in the bodies of fish had they not been caught in fisheries. Second, current biomass carbon storage potential (i.e., biomass carbon standing stock) was estimated by analyzing abundance data for marine mammals, sea turtles, and seabirds. This represents the amount of carbon stored in the bodies of a marine vertebrate for the duration of its life. For estimates of marine mammal, sea turtle, and seabird biomass carbon standing stock, the most recent population abundance estimates were used.

Seabirds were defined according to Schreiber and Burger (2001) as those birds living in and making their living from the marine environment; that feed at sea, either nearshore or offshore; and are members of Orders Sphenisciformes, Procellariiformes, Pelecaniformes, or Charadriiformes (excluding waders and shorebirds). Thus, waders and greater flamingos (*Phoenicopterus roseus*) were not included in this preliminary analysis.

Data analysis was restricted to those species for which systematically-obtained abundance estimates were available over geographically-distinct areas. Further, only species with the most recent abundance estimates occurring ≤5 years ago were included. In an attempt to reduce sampling bias, long time series were used only if data were collected by the same agency.

Detailed fisheries data are only provided for Abu Dhabi emirate due to inconsistencies in reporting at the national level. Specifically, at the time of analysis, catch data by species at the national level was only available for 2008-2010 and 2012 which precluded analysis of long-term trends and comparison with Abu Dhabi emirate. For Abu Dhabi emirate, catch data for the top nine families constituting the greatest catch were analyzed.

For all other marine vertebrates, datasets meeting the above inclusion criteria were only available from Abu Dhabi emirate at the time of analysis. Thus, analysis of dugong, dolphin, sea turtle, and seabird abundance was restricted to this emirate.

The abundance estimates presented in this study should be considered minimum values as they represent recorded abundance rather than pure abundance. For example, dugong aerial surveys were primarily focused on protected areas (EAD 2014b) and not all seabird breeding colonies were surveyed each year. For sea turtles and seabirds, only foraging and breeding individuals, respectively, were considered as these population segments were sampled the most consistently.

Biomass carbon values (BCV) were estimated by multiplying catch (for fisheries) or abundance (for all other vertebrates) estimates by the estimated total body carbon content (% body mass composed of carbon). The following published values for total body carbon content were used: i) fish: 11.5% (Czamanski et al. 2011), ii) marine mammals: 16% (Horn and de la Vega 2016), iii) sea turtles (Angilletta 1999): 13.9%, and iv) seabirds: 18.4% (Horn and de la Vega 2016).

The following equations were used to estimate BCV:

$BCV_{fisheries}$ = Catch (tonnes) * %C
BCV_{other} = Abundance * weight (tonnes) * %C

For example, BCV for Abu Dhabi fisheries catch during 2018 was estimated to be 532 tonnes. This is based on the annual catch value of 4624 (Table 2) multiplied by the estimated total body carbon content for fish of 11.5%. Thus, 4624 * 0.115 = 532 tonnes. As another example, BCV for dugongs in Abu Dhabi during 2014 was estimated to be 262 tonnes (Table 3).

2 Refer to Table 1 for scientific names of all non-fish species assessed in this report.

3 "Tonnes" refers to the metric unit of measurement

This is based on the estimated abundance during 2014 of 2876 (Table 4) multiplied by the estimated body weight of 0.57 tonnes (Table 1) and the estimated total body carbon content for marine mammals of 16%. Thus, 2876 * 0.57 * 0.16 = 262 tonnes. This method was used to estimate BCVs for all species and years.

Data on species body mass and lifespan were obtained from published sources (Table 1). Information specific to the UAE/Arabian Gulf was only available for hawksbill turtle body mass. Otherwise, published estimates for body mass and lifespan pertaining to the global species as a whole were used. However, it should be noted that in some cases, species body masses and lifespans in the UAE/Arabian Gulf will differ from global estimates and thus these estimates should be updated to the region accordingly.

For simplicity, it was assumed that all individuals included in abundance estimates for marine mammals, sea turtles, and seabirds were adults. Fisheries data constituted catch data which were already provided in biomass units and not abundance units.

RESULTS

The current biomass carbon standing stock of marine mammals, sea turtles, and seabirds in Abu Dhabi emirate is estimated to be 520 tonnes (Table 3). This is nearly equivalent to the estimated lost biomass carbon storage potential (532 tonnes) via fisheries in Abu Dhabi emirate in 2018.

Fisheries

From 1980 to 2017, a cumulative total of 3,215,861 tonnes of fish was caught in the UAE. This equates to an estimated 369,824 tonnes of lost biomass carbon storage potential (Fig. 2). By comparison, the total global marine fisheries catch in 2016 was 79.3 million tonnes (FAO 2018).

From 2001 to 2018 in Abu Dhabi emirate, a cumulative total of 98,200 tonnes of fish were caught, equating to an estimated 11,295 tonnes of lost biomass carbon storage potential (Table 2). After peaking in 2003, fisheries catch and estimated lost biomass carbon storage potential has shown an overall decline (Fig. 3).

At the family level, catch of Lethrinidae (emperors) was estimated to represent the greatest source of lost biomass carbon storage potential in Abu Dhabi emirate from 2001 to 2018 (Fig. 4). Considering the top nine families with the highest catch from 2001 to 2018, catch of Epinephelida (groupers), Gerreidae (mojarras,), Haemulidae (grunts), Lethrinidae and Sparidae (seabreams) showed a decreasing trend, catch of Scombridae (mackerel) and Sphyraenidae (barracuda) showed an increasing trend, while catch of Carangidae (jacks) and Lutjanidae (snappers) showed a trend that generally remained the same (Fig. 5).

Of the 53 species assessed within these nine families, two (*Epinephelus coioides*, Hamour, orange-spotted grouper, Fig. 6; *Scomberomorus commerson*, Kanaad, narrow-barred Spanish mackerel, Fig. 7) have a conservation status of “threatened” or higher (Russell et al. 2015, Buchanan et al. 2019). Further, Hamour, Farsh (*Diagramma pictum*, painted sweetlips, Fig. 8), and Shaari (*Lethrinus nebulosus*, spangled emperor, Fig. 9) are key demersal species in the UAE (Blooshi et al. 2017) and catch of all of these species has declined since 2005.

Marine Mammals

Dugongs are estimated to be the most abundant marine mammal in Abu Dhabi emirate (Table 4) based on surveys primarily focused on protected areas (EAD 2014b). Dugongs are also estimated to make the largest contribution towards biomass carbon standing stock (Fig. 10). Their population has remained relatively stable from 2004 to 2014. The current population of 2876 individuals is estimated to store 262 tonnes of carbon (Fig. 11). From 2000 to 2013, 139 cases of dugong mortality were reported. Of these 73% were attributed to drowning in fishing gear and 16% were attributed to vessel strikes (EAD 2014b). This amounts to an estimated 11,218 kg of biomass carbon storage potential lost due to anthropogenic activities.

Indo-pacific bottlenose and Indian Ocean humpback dolphins in Abu Dhabi emirate were considered in the dolphin standing stock of biomass carbon, totaling an estimated 99 tonnes. Indo-pacific bottlenose dolphins are estimated to be the second most abundant marine mammal in Abu Dhabi emirate and the current estimated population of 1834 individuals (Table 4) is estimated to store 67.5 tonnes of carbon. Indian Ocean humpback dolphins are estimated to be the third most abundant marine mammal species in Abu Dhabi emirate and the current estimated population of 701 individuals (Table 4) is estimated to store 31.5 tonnes of carbon.

Sea Turtles

Foraging green and hawksbill turtles in Abu Dhabi emirate were assessed. The current populations of green (5616) and hawksbill (1872) turtles are estimated to store 116 and 10 tonnes of carbon, respectively (Fig. 12). The green turtle population appears to be increasing (Table 5) while the hawksbill turtle population is considered to be stable (UAE Ministry of Climate Change and the Environment, 2019).

From 2000 to 2015, an estimated total of 511 adult sea turtle deaths were attributed to anthropogenic causes, either due to drowning in illegal or abandoned nets (52% of deaths) or vessel strikes (20% of deaths; EAD 2016c).


Edwin Grandcourt


Dr. Salim Javed


Dr. Salim Javed

Applying the 75:25 ratio of green:hawksbill turtles used during aerial surveys of foraging turtles (H. Das, pers. comm., 28 May 2019), the amount of biomass carbon storage potential lost from 2000 to 2015 likely due to anthropogenic activities is estimated to total approximately 8.6 tonnes.

Seabirds

The current estimated standing stock of seabird biomass carbon is 32.6 tonnes, which is the smallest store of marine vertebrate biomass carbon in Abu Dhabi emirate (Fig. 10). Eight species with the longest time series were considered in the assessment of seabird biomass carbon storage potential (Table 6). Data for the three species with the highest abundance and largest biomass carbon storage potential are presented below. Data for all species is presented in Table 6 and Fig. 14.

The Socotra cormorant is currently estimated to be the largest store of seabird biomass carbon (28,583 kg; Fig. 13) and the most abundant seabird species (Table 6). The population increase of Socotra cormorants from 1995 to 2019 has resulted in an estimated net increase of 18,048 kg of carbon storage (Fig. 14a).

Lesser-crested terns are currently estimated to be the second largest store of seabird biomass carbon (2501 kg; Fig. 13) and the second most abundant species (Table 6). The population increase of lesser-crested terns from 1994 to 2018 has resulted in an estimated net increase of 632 kg of carbon storage (Fig. 14b).

Bridled terns are currently estimated to be the third largest store of seabird biomass carbon (864 kg; Fig. 13) and the third most abundant species (Table 6). The population decrease of bridled terns from 2008 to 2018 has resulted in an estimated net loss of 624 kg of carbon storage (Fig. 14c).


Dr. Himansu Das

DISCUSSION

This exploratory study represents a preliminary test case of marine vertebrate biomass carbon stores in the UAE with a focus on Abu Dhabi emirate. It is important to note that while the present study analyzed marine vertebrates at the species or family level, these data should not be interpreted in isolation. A comparison of the biomass carbon values presented in this study with results from other biomass carbon and oceanic blue carbon studies is presented in Table 7.

Abu Dhabi was the focus of this exploratory study due to lack of available data from other emirates that met selection criteria for inclusion in the analysis.

Thus, results should not be generalized to other emirates or the entire UAE. This study also highlights data gaps and identifies potential areas for future research throughout the UAE.

Fisheries

The overall decline in fisheries catch from 2001 to 2018 may be attributed to increased fisheries pressure over the past 30 years which has reduced stock size. A nearly six-fold increase in the number of fishing vessels in Abu Dhabi from 1976 to 2015 has resulted in an estimated 90% decline in abundance of demersal species (Blooshi et al. 2017). The three key UAE demersal species - orange-spotted groupers, painted sweetlips, and spangled emperors – are considered severely over-exploited (Blooshi et al. 2017). Furthermore, the conservation status of orange-spotted groupers and painted sweetlips is of concern globally.

While fisheries catch of most families is declining or steady, catch of barracuda and mackerel is on the rise. The three-fold increase in narrow-barred Spanish mackerel fisheries catch from 2001 to 2018 is of particular concern given their vulnerable conservation status (Buchanan et al. 2019).

From an oceanic blue carbon perspective, increased fisheries catch leads to further losses in biomass carbon storage potential. However, the loss of critical habitat necessary for the life cycle or foraging needs of fishes also warrants concern. For example, coral reefs in the southern Arabian Gulf have experienced dramatic loss and degradation over the past two decades. As a result of an extreme bleaching event, 73% of live coral was lost from all reefs in Abu Dhabi emirate in 2017. Fisheries health can also be negatively impacted from dredging and coastal development which degrade marine habitats (e.g., seagrass beds) important to fishes (Burt 2014, Burt et al. 2019).

Marine Mammals

In Abu Dhabi emirate, dugongs were found to be the most abundant marine mammal, despite their globally vulnerable and decreasing conservation status (Marsh and Sobtzick 2015). Their stable population and large size (Table 1) make them an important contributor to biomass carbon storage. Further, with the longest known lifespan of any marine mammal assessed in this study, they have the potential to store carbon for >70 years. Continued efforts to protect this species will have positive effects for overall biomass carbon storage and ecosystem health in the UAE. In particular, strategies to reduce mortality due to anthropogenic activities (e.g., fisheries, vessel strikes) will be particularly valuable. Given that a sustainable level of human-inflicted mortality is typically a few percent of the female population per year, and the reproductive interval is 3-7 years (Marsh 2018), any loss of life is detrimental to the biomass carbon storage ability and health of this population as a whole.

As for all cetaceans in the UAE, study of dolphins in Abu Dhabi emirate is in its infancy. While Preen (2004) revealed a statistical decline in dolphin populations, it is currently unknown if populations of Indian Ocean humpback and Indo-Pacific bottlenose dolphins are increasing, decreasing, or stable.

There is a critical need to increase understanding of Indian Ocean humpback dolphins as, according to one recent study (Díaz López et al. 2016), Abu Dhabi emirate is thought to hold the world's largest known population of this globally endangered and decreasing species. To date, all other known humpback dolphin populations contain <500 individuals (Braulik et al. 2017).

Large whales known to occur in UAE waters, such as Bryde's whales (*Balaenoptera brydei*), Arabian Sea humpback whales (*Megaptera novaeangliae*), blue whales (*B. musculus*), and sperm whales (*Physeter macrocephalus*) (Baldwin et al. 1999), in addition to whale sharks (*Rhincodon typus;* Robinson et al. 2016), were not assessed in this preliminary study. These species have potential to contribute towards biomass carbon storage in the UAE given their relatively large body sizes and long lifespans. Efforts to enhance understanding of cetacean and whale shark populations in the UAE will increase knowledge and accuracy of biomass carbon stores in addition to advancing conservation strategies. As umbrella (Araujo et al. 2016) and keystone (Zacharias and Roff 2001) species, conservation of cetaceans and whale sharks is likely to have positive effects on carbon storage in addition to overall marine biodiversity and ecosystem health in the UAE.

Sea Turtles

Despite being more abundant than marine mammals, sea turtles comprise less of the estimated biomass carbon standing stock than marine mammals due to their smaller body size (Table 1). However, the long lifespan of sea turtles indicates they can be important carbon stores.

EAD

While populations of green and hawksbill turtles in Abu Dhabi emirate are thought to be either increasing or stable, they are still threatened by human-inflicted mortality. Over a 15-year period, the amount of lost biomass carbon storage potential that was likely attributable to fisheries or vessel interactions (8.6 tonnes) is nearly equal to the current hawksbill turtle biomass carbon storage potential (10 tonnes). Reducing sea turtle mortality could be important in maintaining and increasing Abu Dhabi's biomass carbon stores in addition to protecting the other important ecological functions of sea turtles such as maintaining biodiversity and providing ecosystem services important to creating and maintaining healthy ecosystems (Bouchard and Bjorndal 2000).

For this initial, preliminary assessment, nesting hawksbill turtles were not considered as the available datasets did not meet inclusion criteria. However, nesting turtle data should be considered in future work.

Seabirds

While seabirds were the most abundant non-fish marine vertebrate group assessed and have the highest total body carbon content (18.4%; Horn and del la Vega 2016) of any species group assessed, due to their small body size they collectively made the smallest contribution towards the overall standing stock of biomass carbon. Further, it is likely that their shorter lifespans lead to carbon storage over shorter durations (<20 years) as compared to marine mammals and sea turtles (Table 1). However, this does not mean these taxa should be neglected. Rather, efforts should focus on maintaining and rebuilding these populations to further enhance biomass carbon stocks, maintain or increase biodiversity, preserve vital ecosystem services provided by seabirds such as nutrient cycling, and enhance overall ecosystem health (Graham et al. 2018).

Further, of all non-fish taxa considered in this study, the level of data resolution for seabirds was the most comprehensive. This provides an in-depth understanding of biomass carbon dynamics that can facilitate conservation action.

The Socotra cormorant population exhibited a net gain of 18 tonnes of carbon over the past two decades, the largest gain of any seabird species. This is due to their 271% increase in population from 1995 to 2019 in addition to their large body size which is twice as large as the next largest seabird assessed (Table 1). Conservation efforts for this globally threatened (Vulnerable) species should be continued due to their contribution towards seabird biomass carbon stores in addition to their role in ecosystem functioning (summarized in Muzaffar et al. 2015) that may include nutrient cycling (Khan et al. 2009c).

The red-billed tropicbird showed the most severe population decline of any seabird species assessed, plummeting from 1000 individuals in 1972 to two individuals in 2016. While this may be partially attributed to lack of access to some other potential breeding islands (EAD 2016b), this finding is concerning. Due to their relatively large body size (Table 1), conservation efforts to rebuild the red-billed tropicbird population in the UAE will yield biomass carbon and other ecological benefits.

LIMITATIONS OF THE STUDY

As a result, few datasets met inclusion criteria for analysis in this study, the geographic scope was primarily limited to Abu Dhabi emirate, and the species breadth was relatively narrow.

As a result, few datasets met inclusion criteria for analysis in this study, the geographic scope was primarily limited to Abu Dhabi emirate, and the species breadth was relatively narrow.

Second, while it was beyond the scope of this initial study to incorporate residency and migratory patterns into the analysis, this should be considered in future studies. For example, a weighting factor could be used to account for differences in biomass carbon stored in species present in the UAE year-round (e.g., dugongs) vs. species present for only a portion of the year (e.g., green turtles).

Third, it should be recognized that carbon trapped in the bodies of marine animals constitutes carbon storage on the order of decades and not carbon sequestration on the order of hundreds of years or more. Therefore, biomass carbon should not be viewed as a stand-alone option for climate change mitigation.

Finally, the estimated biomass carbon values provided should be considered as first-order approximations at best. While marine vertebrates can store carbon in their bodies, they can also release carbon back to the atmosphere via respiration or carcass decomposition on shore. Consideration of respiration, terrestrial decomposition, and other potential carbon pathways were beyond the scope of this preliminary study and thus the biomass carbon values presented represent gross carbon stores only. Future studies should consider additional carbon pathways related to biomass carbon to fully assess the potential net biomass carbon potential of marine vertebrates. Future studies should also consider assessing the other eight oceanic blue carbon mechanisms (Fig. 1) to determine how they may be able to collectively feed into climate change mitigation and adaptation strategies and advance knowledge of oceanic blue carbon in the region.

RECOMMENDATIONS FOR FUTURE RESEARCH

This exploratory test case revealed several important recommendations and avenues for future research that should be recognized and addressed if understanding of biomass carbon in the UAE is to be advanced. First, marine vertebrate population abundance data are needed from all emirates. Out of necessity, this study focused on marine vertebrates in Abu Dhabi emirate. However, to truly understand the potential value of biomass carbon in the UAE, comparable data from all emirates are needed.

Second, increased detail in reporting fisheries catch at the emirate and national level is needed. Currently, data sufficient for analysis of long-term trends is only available for Abu Dhabi Emirate. Increased resolution and consistency in fisheries catch reporting will facilitate comparison of biomass carbon removal between emirates and the development of sustainable fisheries practices throughout the UAE.

Third, biomass carbon storage values for fish were not available at the time of analysis. Future studies should utilize fish abundance data to estimate the biomass carbon storage potential of fishes as a counterpoint to the fisheries catch data used to estimate lost biomass carbon storage potential. The "Fish resources assessment survey of the Arabian Gulf waters of the UAE report" (Hurst and Bagley 2017) which contains fisheries biomass data (Stevens et al. 2017) based on trawl (Bagley et al. 2017) and trap (Hurst et al. 2017) surveys, is one such data source.

Fourth, the marine mammal data were limited in geographic scope and species diversity. There is a need for systematic surveys across all emirates, both in the Gulf and along the east coast where a higher biodiversity of marine mammals (including large whales) is likely to occur (R. Baldwin, pers. comm., 4 July 2019). In Abu Dhabi emirate, dugong surveys should be expanded to include areas outside of marine protected areas and dolphin surveys should occur on an annual basis to monitor population changes.

Fifth, methods to discriminate between foraging green and hawksbill turtles during aerial surveys should be investigated. Green turtles are estimated to weigh five times as much as hawksbills (Table 1) so, if possible, obtaining more accurate abundance estimates of each species will help to increase the accuracy of biomass carbon values. Photographic methods coupled with artificial intelligence techniques for automated species identification is one potential option.

Sixth, for seabird surveys, it is recognized that uneven sampling effort by colony between years is attributed due to challenges with accessing the islands (EAD 2016b). As a result, it is unknown if fluctuations in reported abundance are due to real population changes or sampling limitations. In cases when on-the-ground sampling is not possible, other methods could be investigated. Additionally, remote sensing techniques using satellite imagery are emerging whereby it may be possible to approximate colony density by examining guano reflectance on the substrate (Lynch et al. 2012, Schwaller et al. 2013, LaRue et al. 2014).

Finally, regional data are needed to increase the accuracy of marine vertebrate body mass estimates. For this preliminary study, regional data were available only for hawksbill turtle body mass. Increasing the accuracy of marine vertebrate body mass estimates will help to increase the accuracy of the estimated biomass carbon values.

CONCLUSION

Understanding of marine vertebrate biomass carbon is in its infancy. More data are needed to determine if/what application this has to conservation and climate change mitigation strategies in the UAE and elsewhere. Biomass carbon, and the other oceanic blue carbon mechanisms, should not be viewed in isolation. Rather, they should be viewed as additional avenues for pursuing marine conservation in conjunction with protection of coastal habitats and ecosystem health. Oceanic blue carbon can be one component of a suite of data used in the development of climate change mitigation strategies, sustainable fisheries, conservation policy, and marine spatial planning.

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TABLES

Table 1. Body mass, lifespan, and IUCN Red List of Threatened Species status for marine mammals, sea turtles, and seabirds assessed in this preliminary study.

Species	Mass (kg)	Lifespan (yrs)	IUCN Status
Dugong, *Dugong dugon*[1]	>570 (max.)	>73	Vulnerable, decreasing
Indian Ocean humpback dolphin, *Sousa plumbea*[2]	280 (max.)	>40	Endangered, decreasing
Indo-Pacific bottlenose dolphin, *Tursiops aduncus*[3]	230 (max.)	>50	Data deficient, unknown
Green turtle, *Chelonia mydas*[6]	148	>60	Endangered, decreasing
Hawksbill turtle, *Eretmochelys imbricata*[7]	39 (mean)	30-50	Critically endangered, decreasing
Bridled tern, *Onychoprion anaethetus*[8]	0.13	18 (max.)	Least concern, unknown
Crested tern *Thalasseus bergii*[9]	0.36	-[10]	Least concern, stable
Lesser-crested tern, *Thalasseus bengalensis*[11]	0.21	-	Least concern, stable
Red-billed tropicbird, *Phaethon aethereus*[12]	0.70	-	Least concern, decreasing
Saunders's little tern, *Sternula saundersi*[13]	0.045	-	Least concern, decreasing
Socotra cormorant, *Phalacrocorax nigrogularis*[14]	1.52	-	Vulnerable, decreasing
Sooty gull, *Larus hemprichii*[15]	0.46	-	Least concern, decreasing
White-cheeked tern, *Sterna repressa*[16]	0.1275	-	Least concern, decreasing

[1] References: Jefferson et al. 2015, Marsh and Sobtzick 2015
[2] Reference: Braulik et al. 2017, Jefferson et al. 2015
[3] Reference: Hammond et al. 2012, Jefferson et al. 2015, Wang 2018
[4] Reference: Jefferson et al. 2015, Minton et al. 2008
[5] References: Chen et al. 1997, Hsu et al. 2014, Pierce and Norman 2016
[6] Reference: NOAA Fisheries 2019, Seminoff 2004
[7] References: Pilcher 1999, USFWS 2018
[8] References: BirdLife International 2018b, Schreiber and Burger 2001
[9] References: BirdLife International 2018h, Schreiber and Burger 2001
[10] Data not available
[11] References: BirdLife International 2018g, Schreiber and Burger 2001
[12] References: BirdLife International 2018c, Schreiber and Burger 2001
[13] References: BirdLife International 2018f, Schreiber and Burger 2001
[14] References: BirdLife International 2018d, Cook et al. 2017
[15] References: BirdLife International 2018a, Schreiber and Burger 2001
[16] References: BirdLife International 2018e, Schreiber and Burger 2001

Table 2. Annual fisheries catch (in tonnes) by family in Abu Dhabi emirate.[1]

Year	Carangidae	Epinephelida[2]	Gerreidae	Haemulidae	Lethrinidae	Lutjanidae	Scombridae	Sparidae	Sphyraenidae	Total
2001	763	1233	115	586	1484	93	-[3]	-	26	5751[4]
2002	1347	2020	79	860	2043	69	-	-	34	8150
2003	1301	1600	71	719	2911	121	-	-	46	8998
2004	848	1240	145	519	1995	65	-	-	28	6609
2005	1024	970	28.7	748	1268	116	1697	131	30	6293
2006	1043	871	87	630	1307	78	1168	189	22	5652
2007	897	1265	58	720	1200	63	434	238	82	5213
2008	769	926	148	568	1084	141	303	200	70	4966
2009	1009	940	132	727	1111	275	954	162	176	5809
2010	1059	1064	161	684	947	133	1618	121	169	6479
2011	557	825	45	379	839	36	780	80	70	3834
2012	-	-	-	-	-	-	-	-	-	4399
2013	533	824	12	286	739	32	1015	65	84	3730
2014	571	799	28	261	645	40	1440	87	124	4158
2015	928	820	29	274	679	50	1806	95	193	5085
2016	774	609	16	150	284	57	1884	36	69	4100
2017	936	710	28	146	347	110	1812	57	100	4369
2018	1331	614	26	80	273	64	1941	32	138	4624
2001-18[5]	**15,690**	**17,329**	**1208**	**8337**	**19,156**	**1543**	**16,851**	**1494**	**1461**	**98,220**

[1] References: EAD 2005, 2006, 2007, 2008, 2009a, 2010, 2011, 2014a, 2016a, 2017a, 2018abc, 2019a; Grandcourt et al. 2002, 2003, 2004; Hartmann et al. 2004
[2] Formerly Serranidae
[3] Data not available
[4] Total does not equal the row total because only the top 9 families representing the highest catch are shown
[5] Totals may not equal column totals due to rounding

Table 3. Estimated biomass carbon standing stock by species or species group in Abu Dhabi emirate.

Species or Species Group	Estimated Biomass Carbon Value (tonnes)
Dugongs	262
Dolphins	99
Sea turtles	126
Seabirds	33
Total	**520**

Table 4. Recorded abundance (no. individuals) of marine mammals in Abu Dhabi emirate.

Year	Dugongs[1]	Humpback dolphins[2]	Indo-Pacific bottlenose dolphins[3]
2004	2925	-[4]	-
2008	-	-	-
2010	2846	-	-
2014	2876	-	-
2015	-	701[5]	-
2016	-	-	1834[6]

[1] Reference: EAD 2014b
[2] Reference: Díaz López et al. 2017
[3] Reference: EAD 2016d
[4] Data not available
[5] Abundance estimate represents 2014 to 2015
[6] Abundance estimate represents 2014-2016

Table 5. Recorded abundance (no. individuals) of sea turtles in Abu Dhabi emirate.[1]

Year	Green turtles	Hawksbill turtles
2004	4125	1375
2009	4830	2170
2010	3912	1304
2014	4779	1593
2015	5616	1872

[1] References: EAD 2015b, UAE Ministry of Climate Change and the Environment 2019

Table 6. Recorded abundance (no. individuals) of seabirds in Abu Dhabi emirate.[1]

Year	Bridled tern	Crested tern	Lesser-crested tern	Red-billed tropicbird	Saunders's little tern	Socotra cormorant	Sooty gull	White-cheeked tern
1972	-[2]	-	-	1000	-	-	-	-
1994	-	2360	48,369	138	240	-	470	34,649
1995	-	-	-	-	-	37,668	-	-
2002	-	-	-	-	-	40,000	-	-
2003	26,678	2752	50,246	21	233	-	690	17,137
2004	-	-	-	-	-	11,092	-	-
2005	-	-	-	94	-	2130	-	5136
2007	-	-	-	310	-	17,062	-	-
2008	61,747	506	82,634	216	810	16,000	4210	29,786
2009	60,784	1278	75,356	450	222	15,040	2332	19,936
2010	59,708	1072	81,384	700	220	16,400	1920	26,670
2011	43,320	1294	86,778	318	192	22,156	2384	10,158
2012	31,440	2570	104,982	204	96	25,392	1250	12,914
2013	33,510	-	118,212	-	-	30,008	1912	14,724
2014	33,630	2256	84,502	80	136	37,776	2354	14,594
2015	36,100	3026	116,738	14	314	65,280	2646	18,116
2016	39,060	3014	107,968	2	118	65,400	1156	10,054

2017	32,200	-	86,660	-	-	103,624	2758	8044
2018	35,840	-	64,722	-	-	110,300	2556	8458
2019	-	-	-	-	-	102,200	-	-

[1] References: EAD 2009b, 2014c, 2015a, 2016b, 2019b; Javed 2004; Javed and Khan 2004; Javed et al. 2007; Khan et al. 2009abc, 2010, 2011, 2012
[2] Data not available

Table 7. Estimated biomass carbon potential stored or lost in the UAE in comparison to estimated carbon stores via other oceanic blue carbon mechanisms (after Lutz et al. 2018).

Mechanism	Carbon source	Location	Study area size (km^2)	Estimated Population Size	Estimated C value	Reference
Biomass carbon	Marine mammal, sea turtle, and seabird standing stock	Abu Dhabi	46,000	5411 marine mammals, 7488 sea turtles, 216,910 seabirds	520 tonnes/yr stored[1]	This study
Biomass carbon	Cumulative fisheries catch, 1980-2017	UAE	58,218	N/A	369,824 tonnes biomass carbon storage potential lost	This study
Biomass carbon	Cumulative fisheries catch, 2011-2018	Abu Dhabi	46,000	N/A	11,295 tonnesbiomass carbon storage potential lost	This study
Biomass carbon	Annual tuna (*Thunnus albacares, Katsuwanus pelamis, Thunnus obesus*) fisheries catch	Eastern Tropical Pacific	21,000,000	N/A	62,506 tonnes/yr biomass carbon storage potential lost	Martin et al. 2016
Biomass carbon	Cumulative fisheries catch, 1918-2011	Eastern Tropical Pacific	21,000,000	N/A	3,252,389 tonnesbiomass carbon storage potential lost	Martin et al. 2016

Biomass carbon	Cumulative spinner (*Stenella longirostris*) and pantropical spotted (*S. attenuata*) dolphin bycatch, 1958-2006	Eastern Tropical Pacific	21,000,000	3,477,121	54,509 tonnesbiomass carbon storage potential lost	Martin et al. 2016
Biomass carbon	8 baleen whale species	Global	879,412	361,132,000	8,800,000 tonnes/yr stored	Pershing et al. 2010
Trophic cascade carbon	Sea otter (*Enhydra lutris*)-induced kelp forest growth	Coastal North Pacific	51,551	N/A	15,000,000-43,000,000 tonnes/yr stored	Wilmers et al. 2012
Trophic cascade carbon	Sea otter-induced kelp forest growth	Coastal North Pacific	51,551	N/A	130,000-23,000,000 tonnes/yr sequestered	Wilmers et al. 2012
Biomixing carbon	Sperm whale (*Physeter macrocephalus*) swimming	Hawaii	10,000	80	600 tonnes/yr stored	Lavery et al. 2012
Whale pump	Sperm whale fecal plumes	Southern Ocean	20,000,000	12,000	240,000 tonnes/yr sequestered	Lavery et al. 2010
Twilight zone	Mesopelagic fish fecal pellets	California Current and North Pacific Subtropical Gyre	3,300,000	N/A	27,700,000 tonnes/yr sequestered	Davison et al. 2013

Great whale conveyor belt	Blue whales (*Balaenoptera musculus*)	Indian Ocean	6000	4727	513 tonnes/yr sequestered	Roman et al. 2014
Deadfall carbon	Great whale carcasses	Global	361,132,000	879,412	28,862 tonnes/yr sequestered	Pershing et al. 2010

[1] Carbon storage refers to carbon removed from the atmosphere for decades while carbon sequestration refers to carbon removed from the atmosphere for hundreds of years or more.

FIGURES

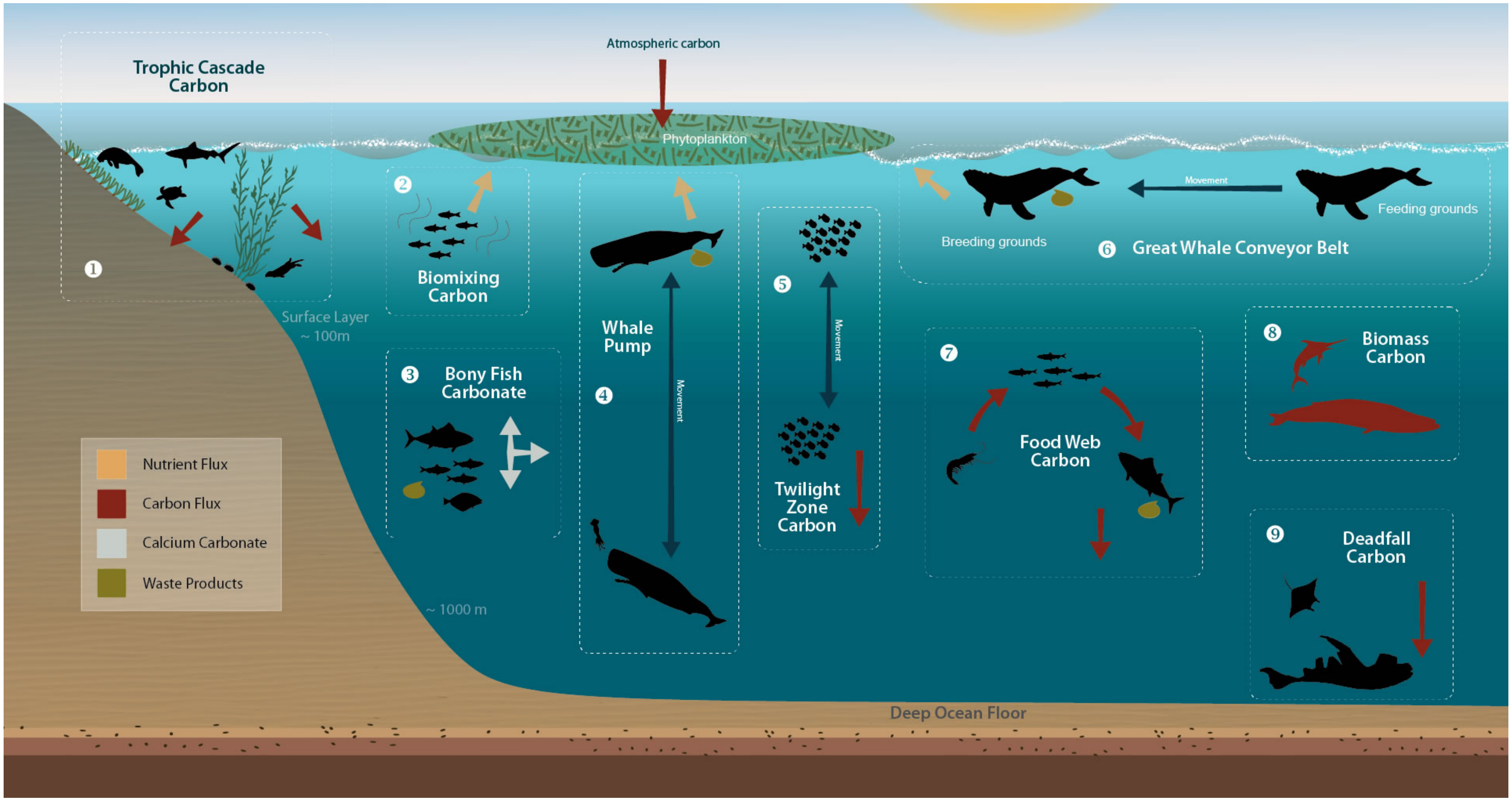


Fig. 1. Oceanic blue carbon pathways (Lutz et al. 2018). 1) Marine predators help plants to grow by keeping herbivore populations in check. This helps maintain the carbon storage function of coastal vegetation. 2) The swimming movement of marine animals can stir up nutrients towards surface waters. These nutrients can be used by phytoplankton as they grow, absorbing carbon. 3) Bony fish excrete carbon in the form of calcium carbonate. This raises the pH of seawater and potentially provides a buffer against ocean acidification, which is one effect of climate change. 4) All whales dive underwater to feed and return to the surface to breath. At the surface, they release buoyant fecal plumes that are rich in nutrients that phytoplankton need to grow. 5) Mesopelagic fish migrate towards the surface a night to feed then return to deep waters during the day. This helps transport carbon to deep waters where it cab ne released as fecal pellets. 6) Many whales migrate from nutrient-rich feeding grounds to nutrient-poor breeding grounds. On the breeding grounds, whales release nitrogen-rich urea that can stimulate phytoplankton growth. 7) Fish eat and repackage food into carbon0-rich fecal pellets that sink rapidly. Fecal material that reaches the deep sea can remain locked away for hundreds to thousands of years. 8) All living things are made of carbon and thus serve as carbon reservoirs throughout their lifespans. The larger and more long-lived the animals, the more carbon is stored. 9) When large marine vertebrates die, their carcasses sink to the seafloor. There, the carbon inside their carcasses can support deep-sea ecosystems and be incorporated into marine sediments. or

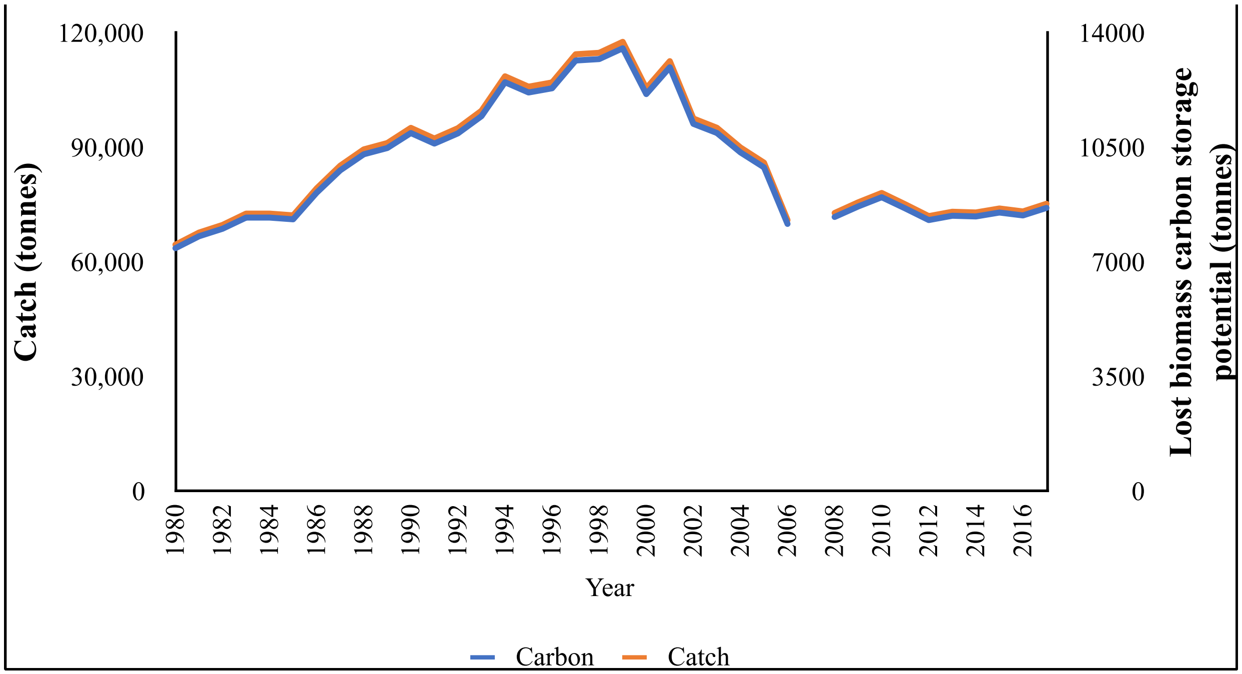


Fig. 2. Annual UAE fisheries catch and estimated lost biomass carbon storage potential, 1980-2017. Data not available for 2007. Fisheries catch source: UAE Federal Competitiveness and Statistics Authority.

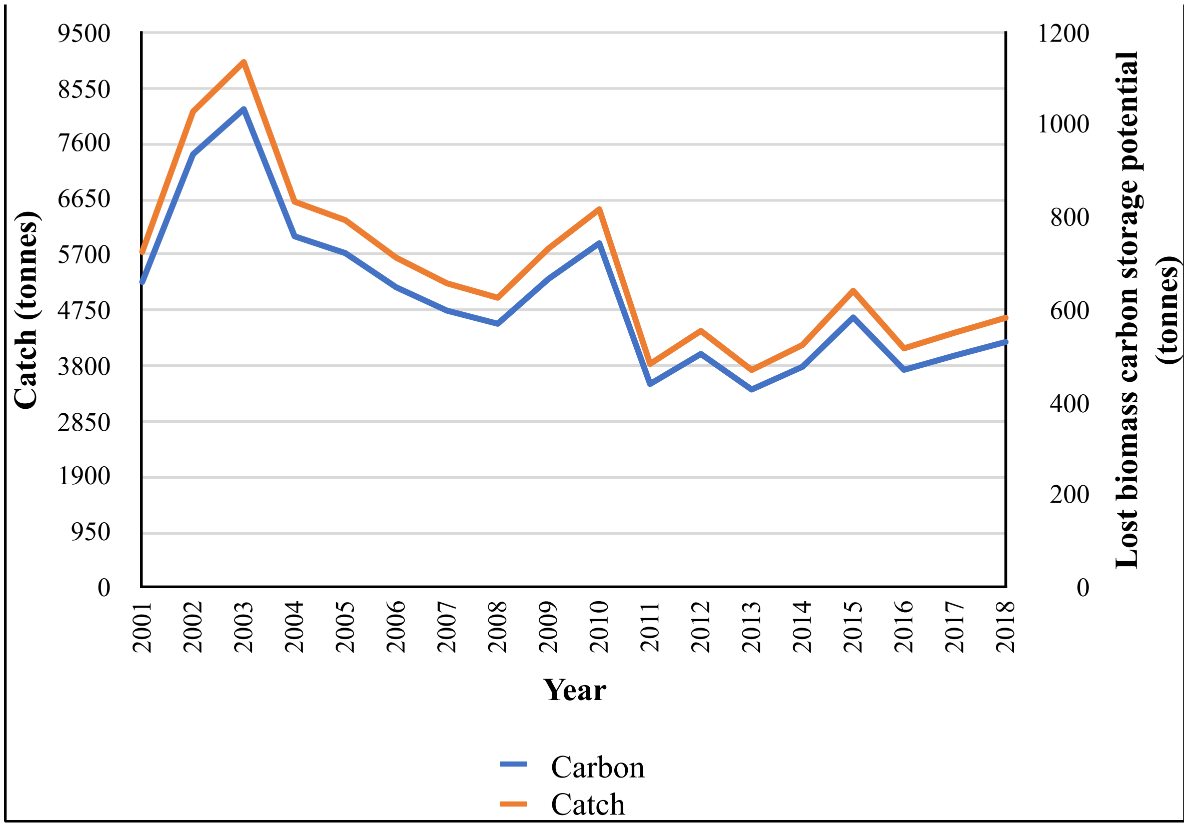


Fig. 3. Annual fisheries catch and estimated lost biomass carbon storage potential in Abu Dhabi emirate, 2001-2018.

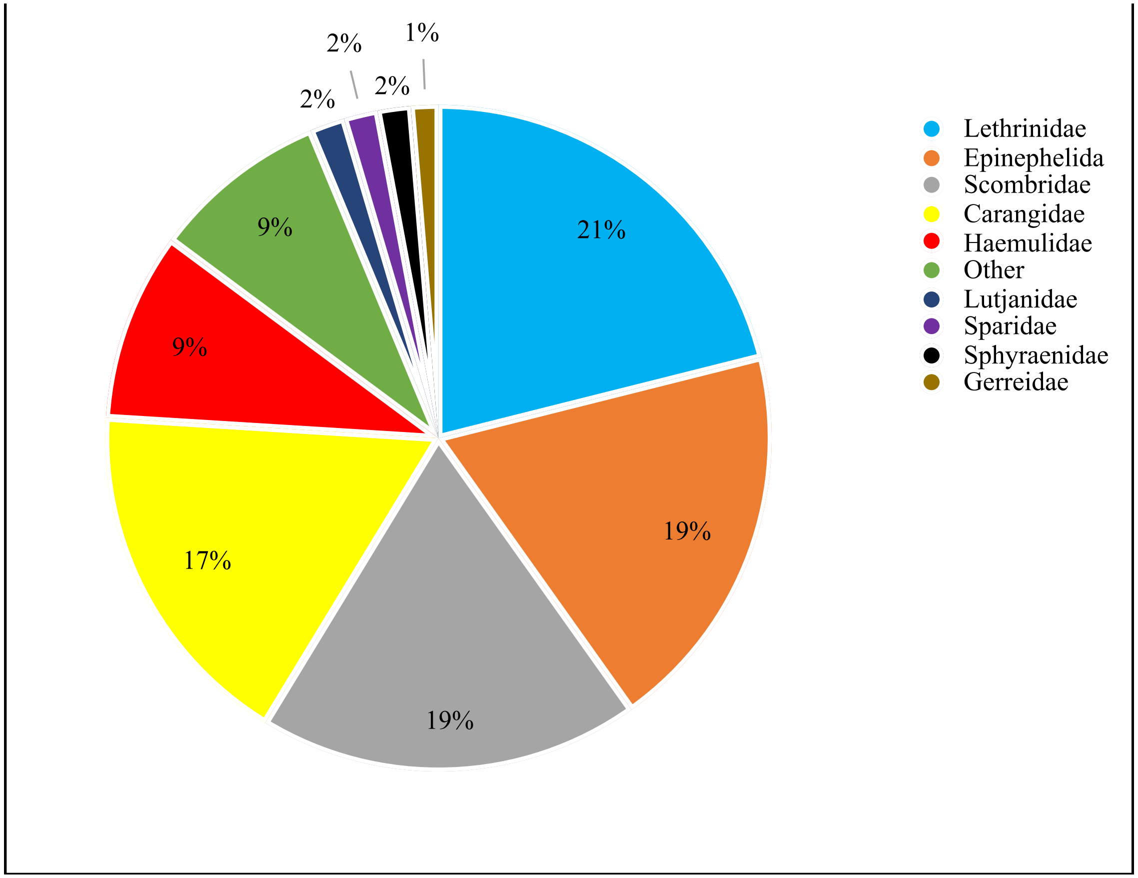


Fig. 4. Estimated lost biomass carbon storage potential by fisheries family in Abu Dhabi emirate, 2001-2018.

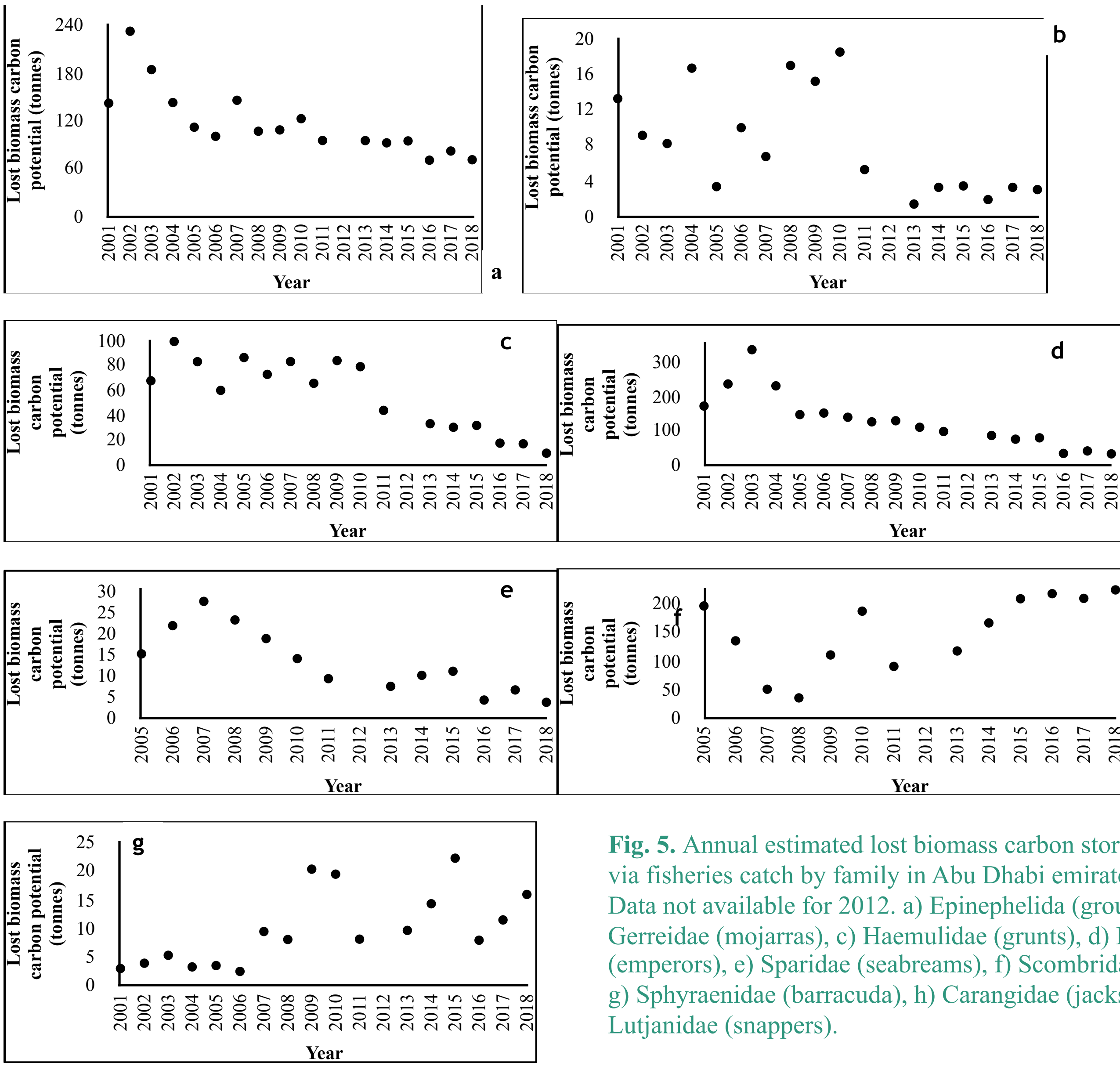
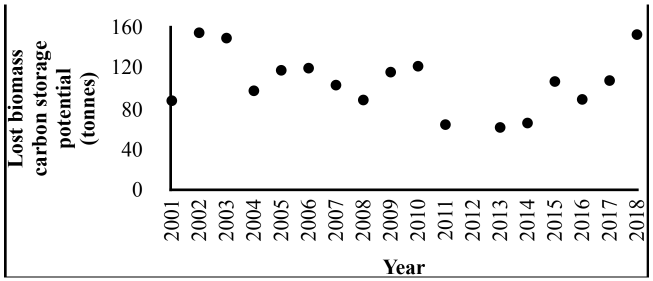
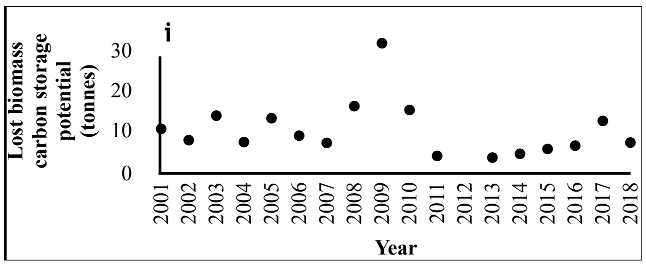


Fig. 5. Annual estimated lost biomass carbon storage potential via fisheries catch by family in Abu Dhabi emirate, 2001-2018. Data not available for 2012. a) Epinephelida (groupers), b) Gerreidae (mojarras), c) Haemulidae (grunts), d) Lethrinidae (emperors), e) Sparidae (seabreams), f) Scombridae (mackerel), g) Sphyraenidae (barracuda), h) Carangidae (jacks), i) Lutjanidae (snappers).


Lost biomass carbon storage potential (tonnes)
160
120
80
40
0
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year


i
Lost biomass carbon storage potential (tonnes)
30
20
10
0
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year

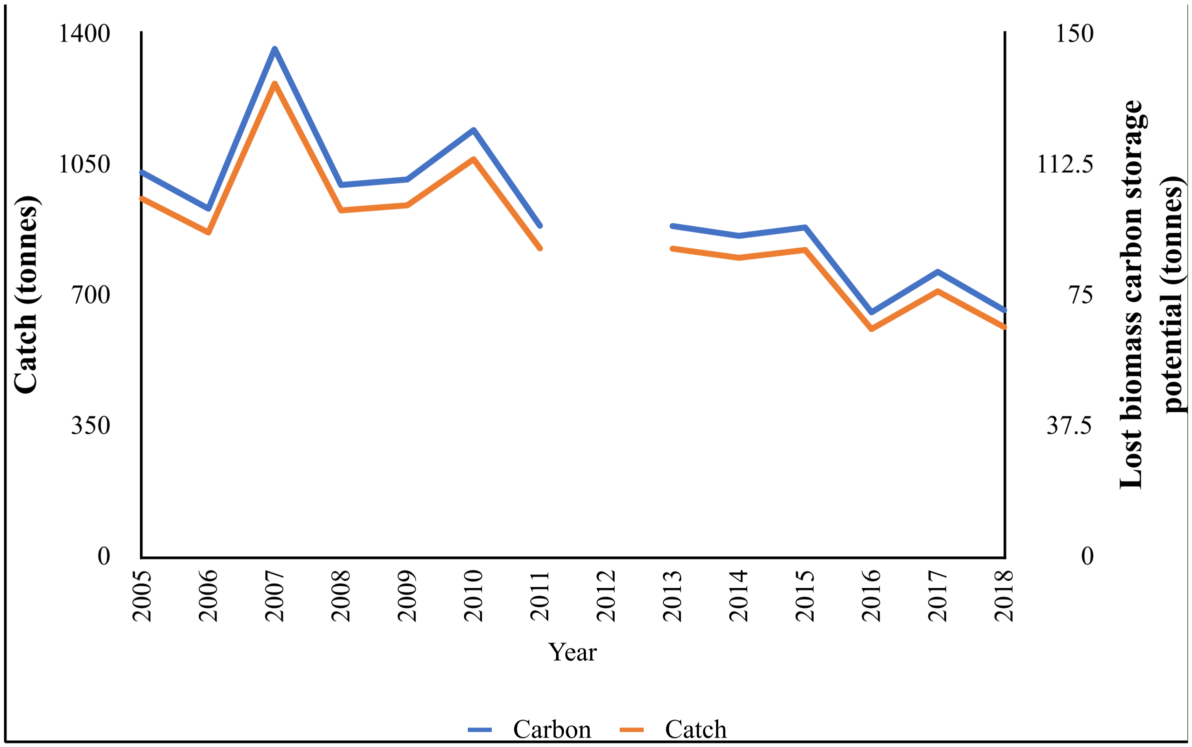


Fig. 6. Fisheries catch and estimated lost biomass carbon storage potential via *Epinephelus coioides* (Hamour, orange-spotted grouper) fisheries catch in Abu Dhabi emirate, 2001-2018, a key demersal species in the UAE. The regional conservation status of this species is vulnerable (Buchanan et al. 2019). Data not available for 2012.

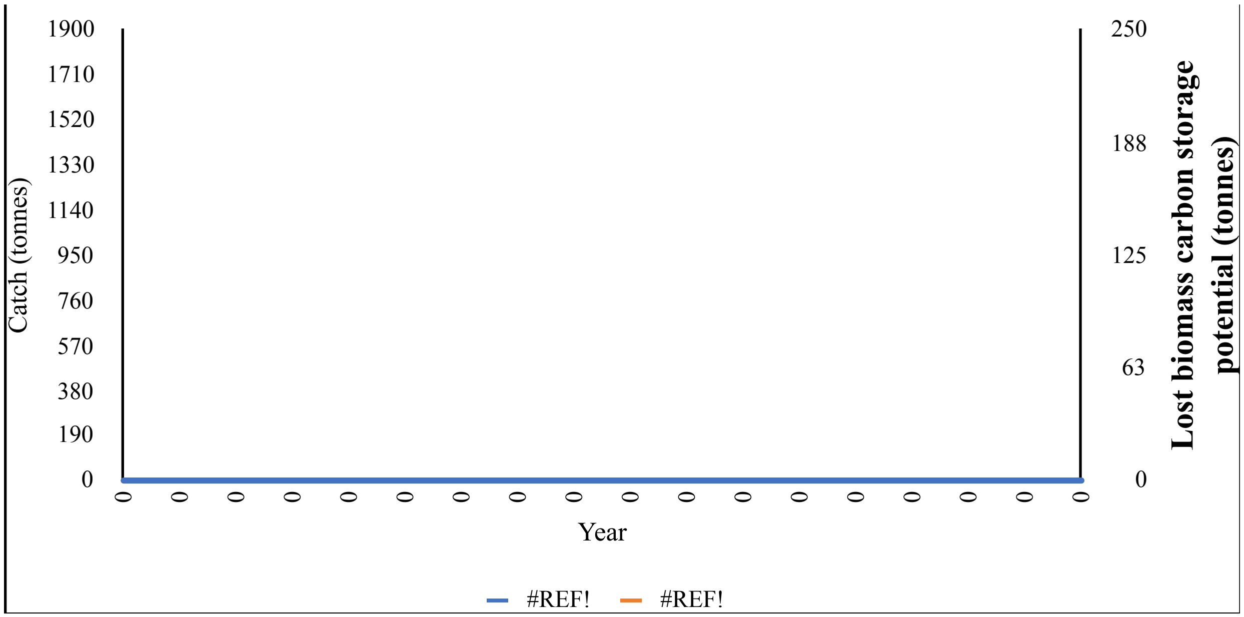


Fig. 7. Fisheries catch and estimated lost biomass carbon storage potential via *Scomberomorus commerson* (Kanaad, narrow-barred Spanish mackerel) fisheries catch in Abu Dhabi emirate, 2001-2018. The regional conservation status of this species is vulnerable (Buchanan et al. 2019). Data not available for 2012.

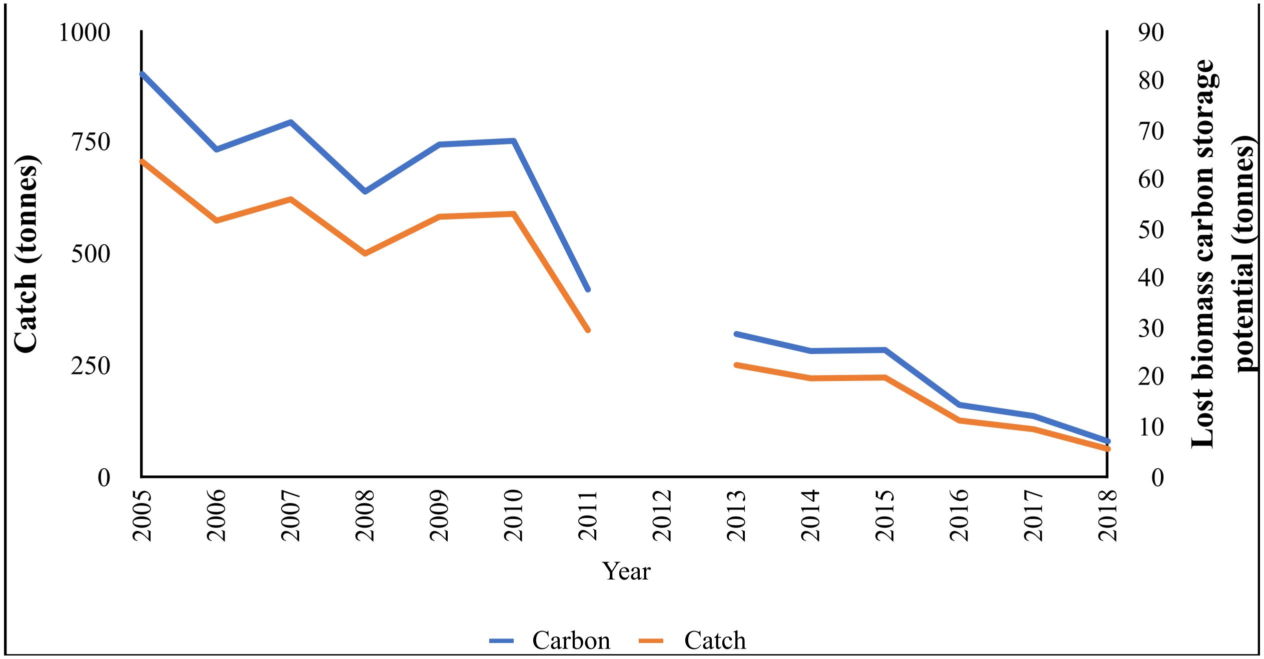


Fig. 8. Fisheries catch and estimated lost biomass carbon storage potential via *Diagramma pictum* (Farsh, painted sweetlips) fisheries catch in Abu Dhabi emirate, 2001-2018, a key demersal species in the UAE. Data not available for 2012.

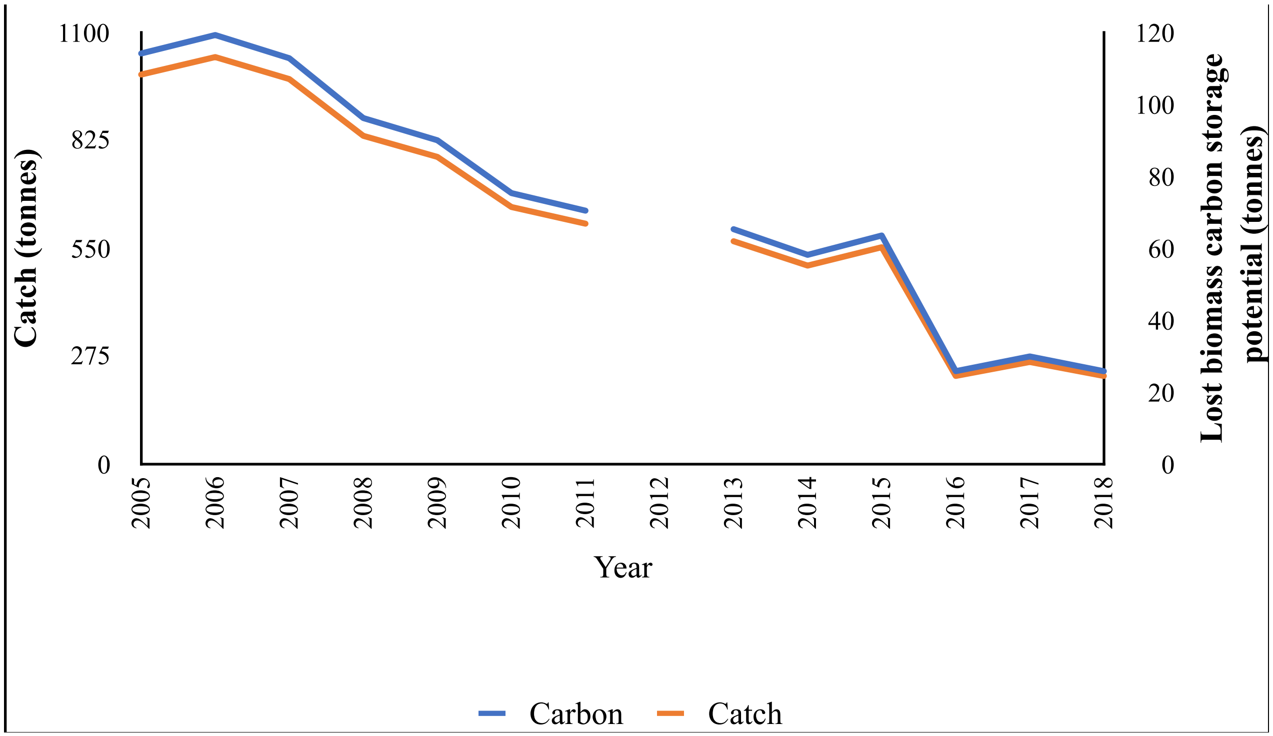


Fig. 9. Fisheries catch and estimated lost biomass carbon storage potential via *Lethrinus nebulosus* (Shaari, spangled emperor) fisheries catch in Abu Dhabi emirate, 2001-2018, a key demersal species in the UAE. Data not available for 2012.

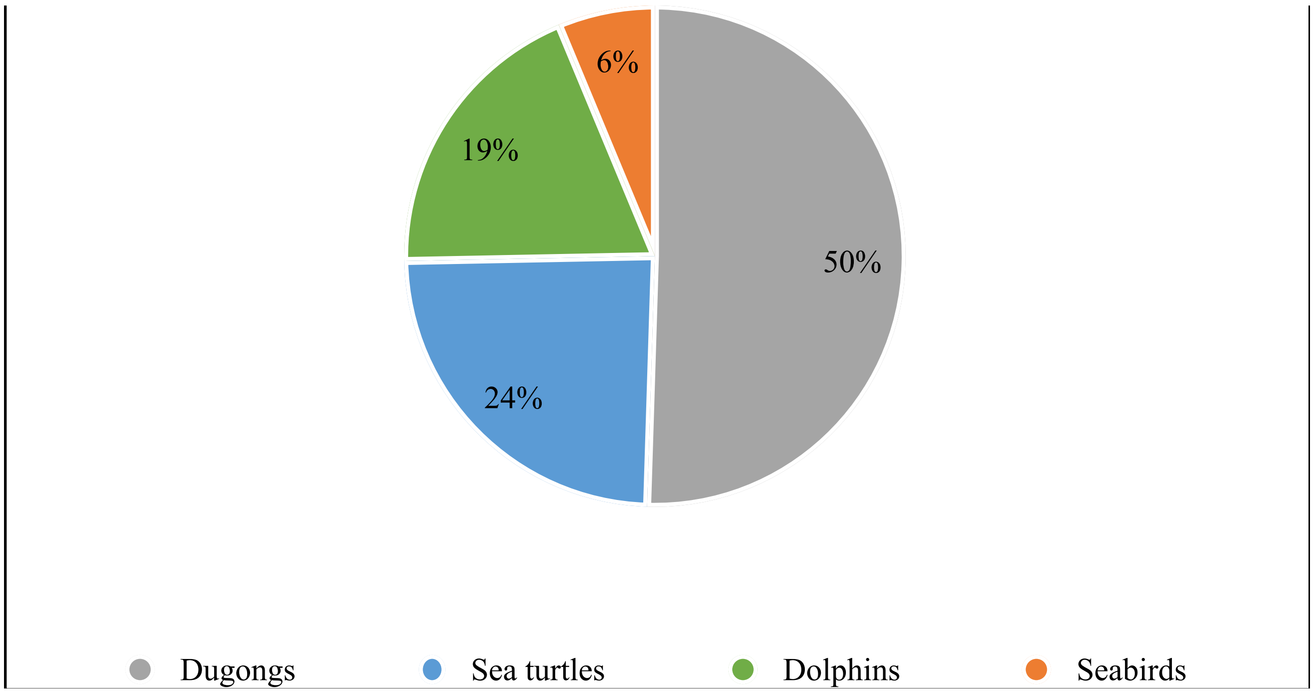


Fig. 10. Estimated contribution of each species or species group to the biomass carbon standing stock of marine mammals, sea turtles, and sea turtles in Abu Dhabi emirate.

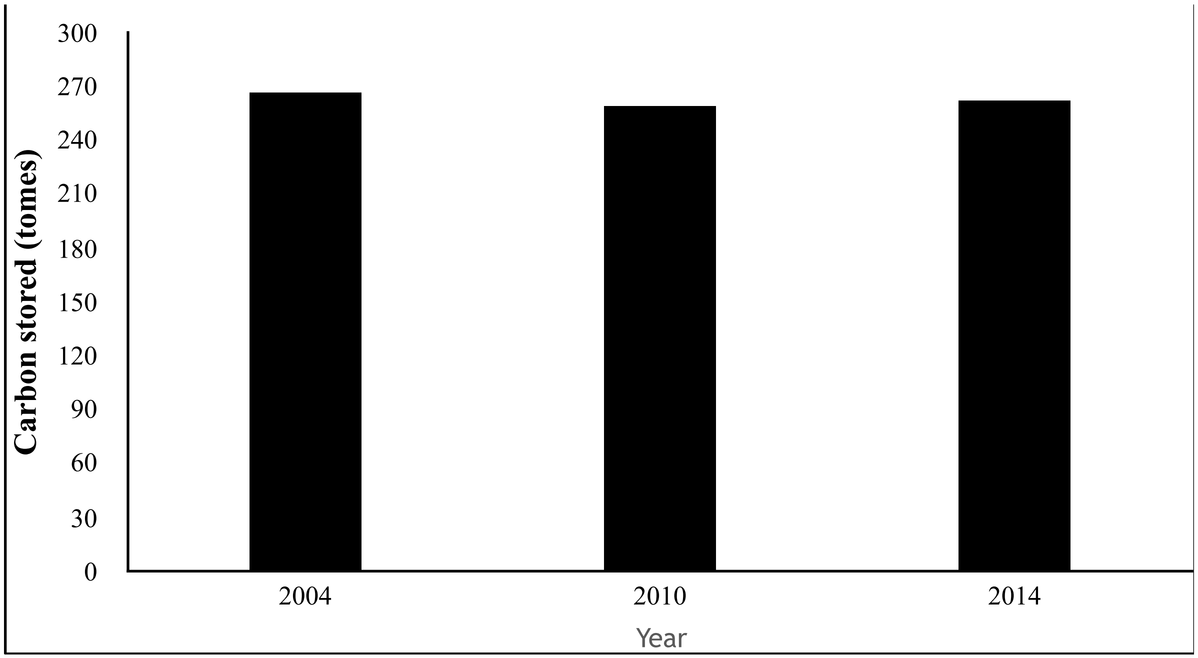


Fig. 11. Estimated dugong biomass carbon stored by year in Abu Dhabi emirate.

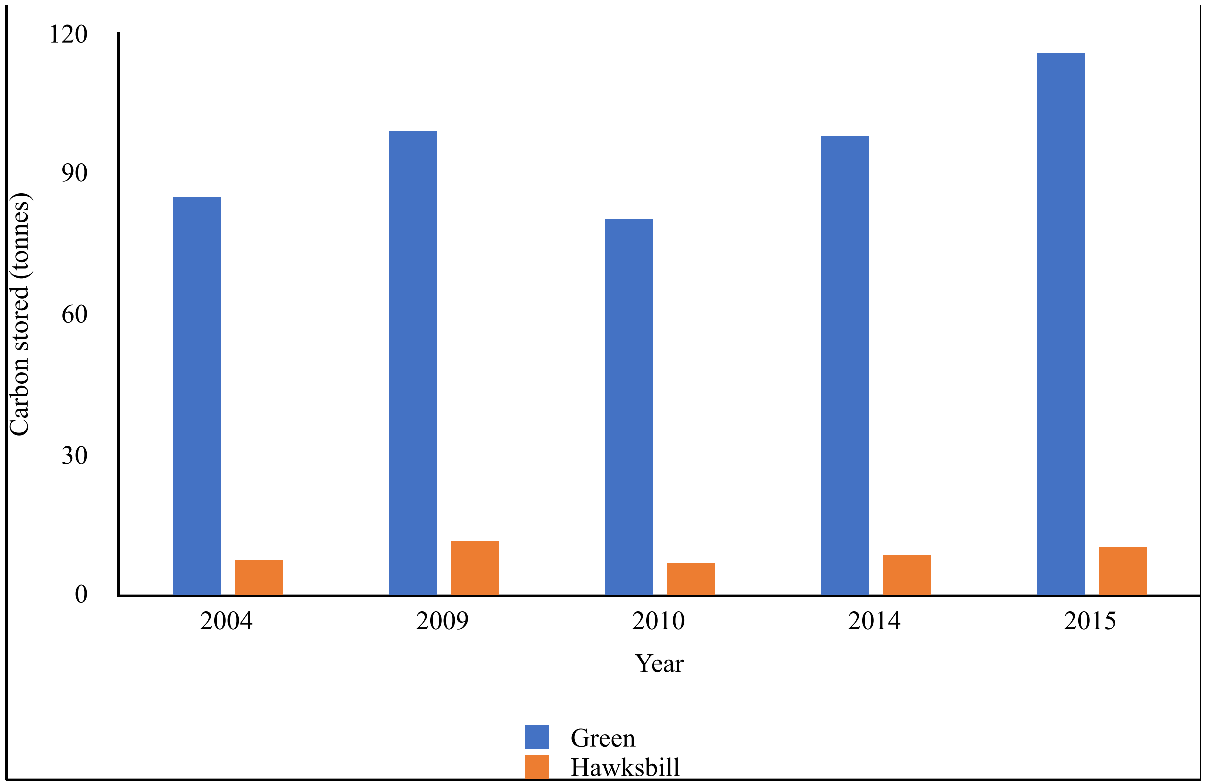
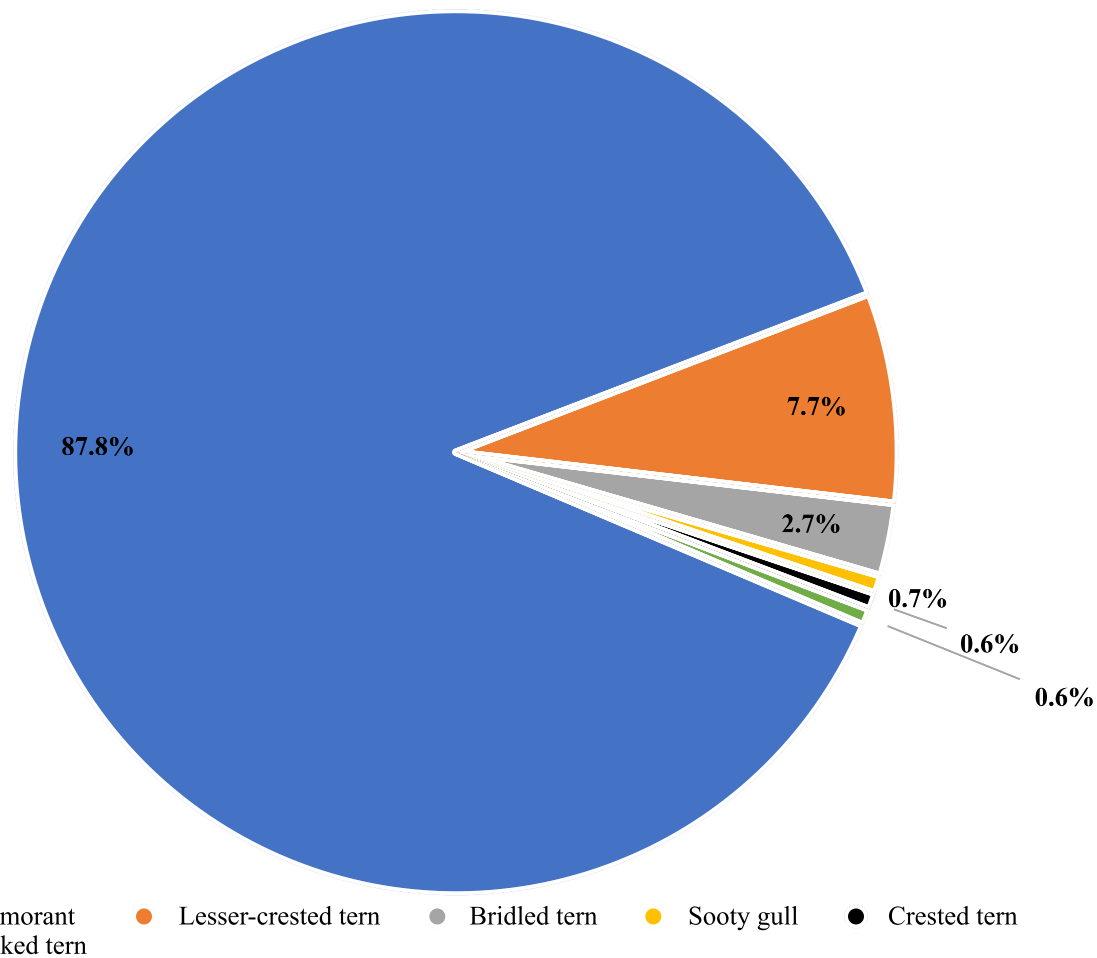
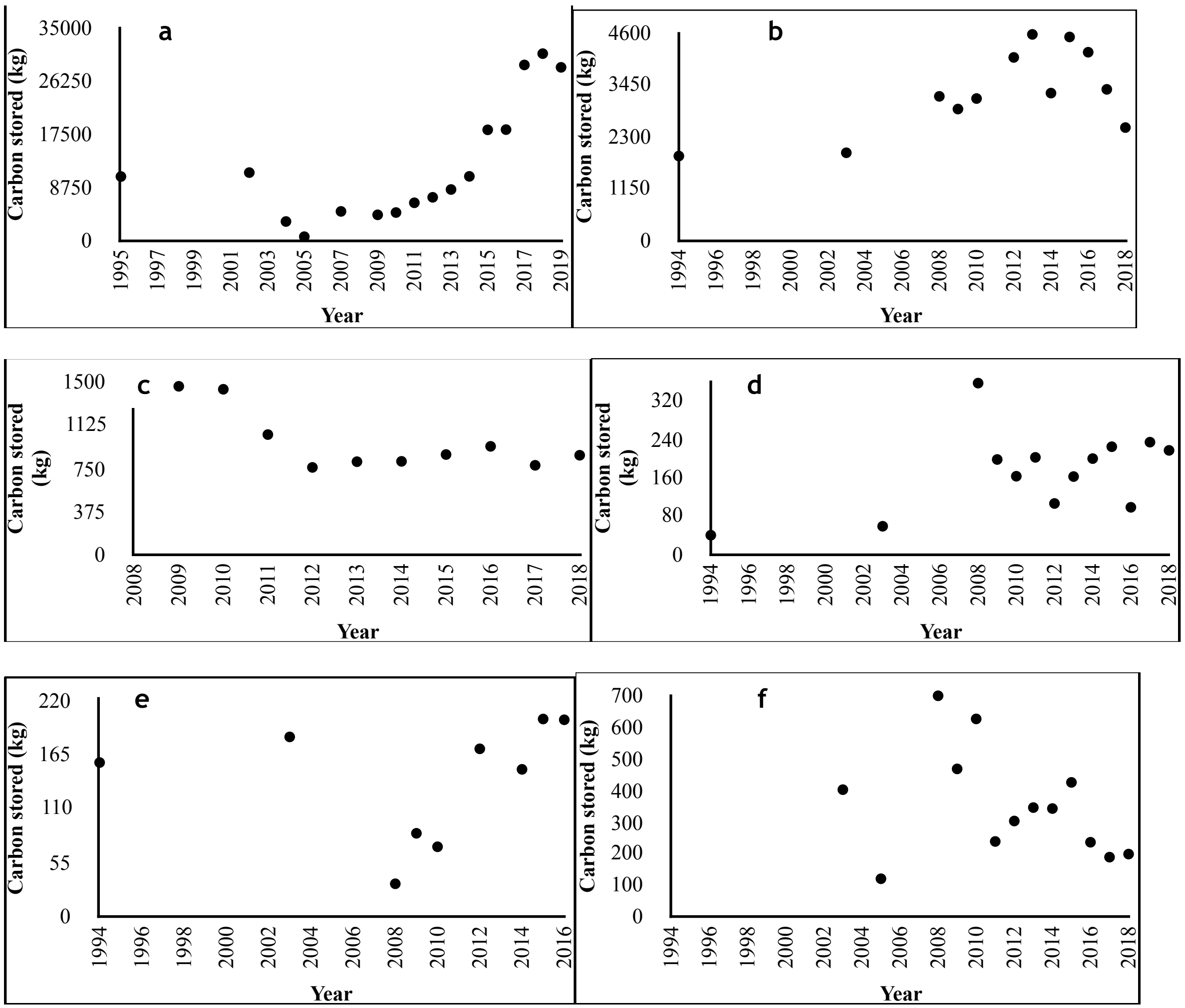


Fig. 12. Estimated sea turtle biomass carbon stored by year in Abu Dhabi emirate.

Fig. 13. Estimated seabird biomass carbon current standing stock by species in Abu Dhabi emirate. Red-billed tropicbirds and Saunders's little terns contributed <0.01% to the standing stock and are not included.




a
b
c
d
e
f
Carbon stored (kg)
Year

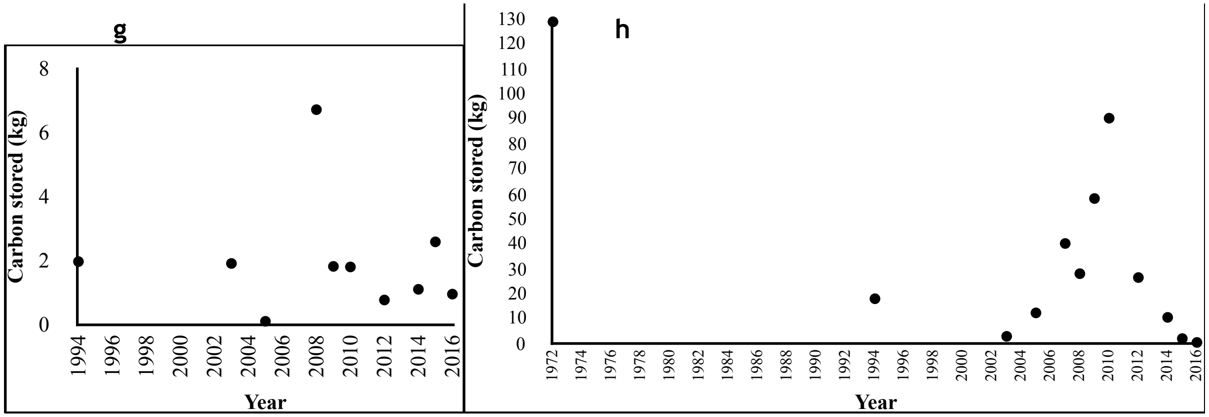
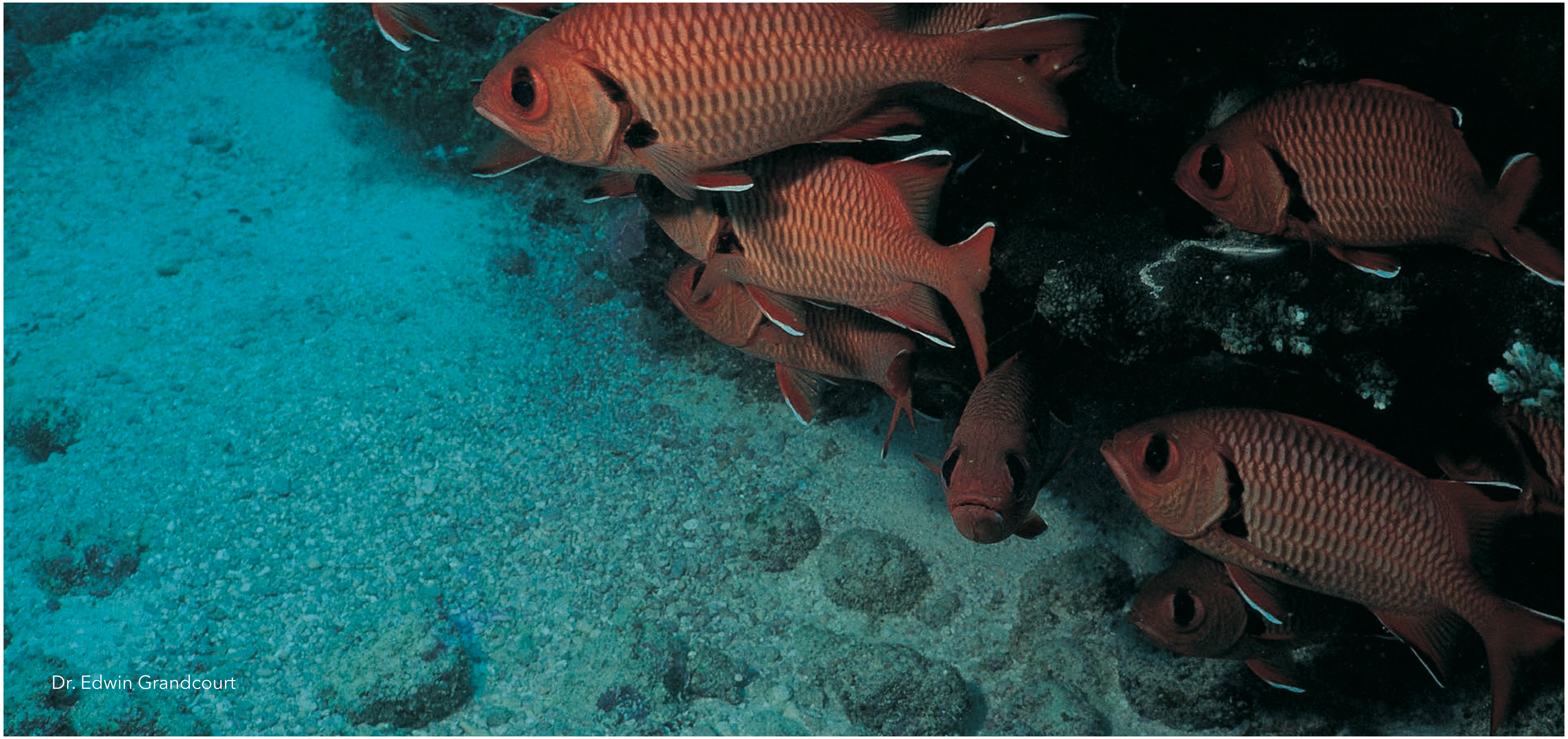


Fig 14. Estimated seabird biomass carbon stored by species by year in Abu Dhabi emirate. A) Socotra cormorant, b) lesser-crested tern, c) bridled tern, d) sooty gull, e) crested tern, f) white-cheeked tern, g) Saunders's little tern, h) red-billed tropicbird.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Abu Dhabi Global Environmental Data Initiative

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