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The discovery of deep-water seagrass meadows in a pristine Indian Ocean wilderness revealed by tracking green turtles

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ABSTRACT

Our understanding of global seagrass ecosystems comes largely from regions characterized by human impacts with limited data from habitats defined as notionally pristine. Seagrass assessments also largely focus on shallow-water coastal habitats with comparatively few studies on offshore deep-water seagrasses. We satellite tracked green turtles (*Chelonia mydas*), which are known to forage on seagrasses, to a remote, pristine deep-water environment in the Western Indian Ocean, the Great Chagos Bank, which lies in the heart of one of the world's largest marine protected areas (MPAs). Subsequently we used in-situ SCUBA and baited video surveys to survey the day-time sites occupied by turtles and discovered extensive monospecific seagrass meadows of *Thalassodendron ciliatum*. At three sites that extended over 128 km, mean seagrass cover was 74% (mean range 67–88% across the 3 sites at depths to 29 m. The mean species richness of fish in seagrass meadows was 11 species per site (mean range 8–14 across the 3 sites). High fish abundance (e.g. *Siganus sutor:* mean MaxN.site^{-1} = 38.0, SD = 53.7, n = 5) and large predatory shark (*Carcharhinus amblyrhynchos*) (mean MaxN.site^{-1} = 1.5, SD = 0.4, n = 5) were recorded at all sites. Such observations of seagrass meadows with large top predators, are limited in the literature. Given that the Great Chagos Bank extends over approximately 12,500 km^2 and many other large deep submerged banks exist across the world's oceans, our results suggest that deep-water seagrass may be far more abundant than previously suspected.

1. Introduction

The importance of seagrasses as structural components of ecosystems is well recognized. Seagrasses are one of the most productive ecosystems on earth (Duarte and Chiscano, 1999). Seagrass/algae beds have been rated the third most valuable ecosystem globally for ecosystem services, after estuaries and swamps/flood plains (Costanza et al., 1997). In the tropical Indo-Pacific, seagrass meadows are key components of marine habitats providing critical and highly valued ecosystem services (Coles et al., 2011; Costanza et al., 2014). The tropical Indo-Pacific bioregion has the highest seagrass diversity in the world with as many as 14 species growing on reef flats as well as in very deep waters (Short et al., 2007). Seagrass ecosystems also play a critical role in trophodynamics, habitat provision, substrate stability and biogeochemical cycling (Green and Short, 2003).

Global seagrass assessments largely focus on shallow-water coastal habitats and comparatively few studies have focused on offshore deep-water seagrasses (Fonseca et al., 2008). Thus the majority of what we know about seagrass ecology comes from studies on inter-tidal or coastal seagrass ecosystems. Unsurprisingly, due to logistical and technological challenges, comparatively few studies have focused on deep-water seagrasses, for example, *Zostera marina* meadows in the Mediterranean (Pergent-Martini et al., 2005), *Halophila decipiens* meadows in the Caribbean (Josselyn et al., 1986; Hammerstrom et al., 2006) and *H. decipiens* and *H. spinulosa* in the Great Barrier Reef (York et al., 2015). Recent evidence suggests that deep-water seagrass meadows are extensive and productive (Rasheed et al., 2008; Coles et al., 2009) and worthy of more extensive research efforts.

Deep-water seagrasses (> 15 m depth) have depth ranges most likely to be controlled by the availability of light for photosynthesis. Seagrass habitats in clear tropical waters can occur to depths of 61 m (Coles et al., 2009) and theoretically it is possible that seagrass can extend to a depth of 90 m (Duarte, 1991), supported by reports of 70 m seagrass from Sudan's transparent Red Sea waters (Jones et al., 1987). Although scarce below 50 m depth, *Halophila stipulacea* was collected from 145 m by dredging activities off Cyprus (Lipkin et al., 2003) and is the deepest seagrass reported worldwide (Short et al., 2007). Deep-water tropical seagrass habitats are often extensive, monospecific

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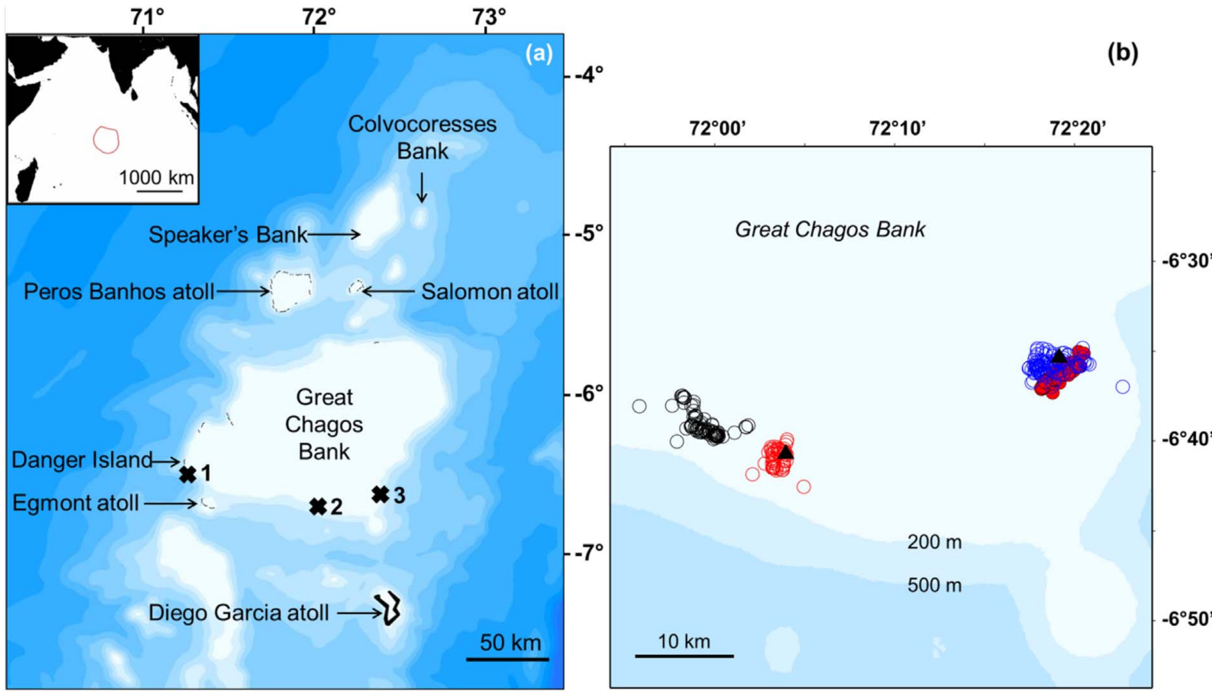

Fig. 1. (a) The seagrass study sites in the Chagos Archipelago in the Western Indian Ocean with the boundary of the British Indian Ocean Territory and Chagos marine protected area shown in red (inset). Bathymetry of the Chagos Archipelago is shown in 500 m contours (source: GEBCO) to highlight atoll locations. Seagrass surveys were carried out at three sites (distance of 128 km between sites 1 and 3) on the Great Chagos Bank (indicated by black crosses). (b) Daytime Fastloc GPS locations obtained from 4 green turtles satellite tracked from their nesting beaches on Diego Garcia to foraging grounds on the Great Chagos Bank. These turtle location data were used to select sites 2 and 3 for seagrass surveys. For clarity, different coloured circles (open red, solid red, open black, open blue) show a random sample of 100 Fastloc-GPS locations for each turtle. Open blue circles overlay many of the solid red circles indicating these two turtles used broadly the same foraging area. Black triangles show sites 2 and 3.

meadows dominated by *Halophila* species (Lee Long et al., 1993). Deep (to 70 m) coastal tropical Indo-Pacific seagrasses are also dominated by the *Halophila* species, particularly *H. stipulacea*, *H. decipiens* and *H. spinulosa* (Short et al., 2007). In East Africa, eastern Indonesia and the Torres Straits sub-tidal meadows dominated by *Thalassodendron ciliatum* are common from 0 to 15 m (Short et al., 2010). *T. ciliatum* is adapted to live in coarser substrates and is often the dominant species on these substrates in deeper waters, forming extensive mono-specific meadows (Den Hartog, 1970).

In attempting to understand the complex ecological interactions present within seagrass meadows globally, effort is largely focused around systems where stressors are present or where management actions have taken place to reverse degradation or loss (Waycott et al., 2009; Short et al., 2011), so that our understanding of seagrass ecosystems comes largely from regions of the world characterized by human impacts (Grech et al., 2012). Unfortunately, limited data exist from habitats defined as notionally pristine and, when examining the status of seagrass ecosystems, it is difficult to present them relative to a suitable baseline. This creates a scenario in which seagrass scientists as well as conservation managers and the general public are subject to the process of a shifting baseline. Data and case studies are required from locations that can be defined as pristine, particularly with respect to associated fauna.

The Chagos Archipelago that forms the British Indian Ocean Territory (BIOT) in the Western Indian Ocean is a potential example of a pristine seagrass ecosystem, lying at the heart of one of the world's largest marine protected areas (MPAs). The remoteness of the Chagos Archipelago, combined with very low levels of anthropogenic disturbance (the only inhabited island since 1970 is Diego Garcia) has resulted in some of the cleanest seas and healthiest reef systems in the world (Everaarts et al., 1999; Sheppard et al., 2012), and is of considerable importance to global biodiversity (Procter and Fleming, 1999).

Open water transparency in the Chagos Archipelago is close to maximum theoretical levels reflecting the nutrient-poor state of the central Indian Ocean. The sublittoral photic zone of the archipelago is as much as 60,000 km^2 (Dumbraveanu and Sheppard, 1999) and it is likely that large areas of this are suitable habitat for seagrass to exploit. As over 95% of the Chagos Archipelago remains unstudied, there remain opportunities to discover extensive new marine habitats (Sheppard et al., 2012). Existing knowledge of seagrass in Chagos is spatially and temporally restricted and associated data is limited (Willis and Gardiner, 1931; Drew, 1980; Sheppard, 1980; Spalding, 2005; JNCC, 2008).

The present study examines the seagrass status and abundance and diversity of associated fish assemblages on the Great Chagos Bank. This seagrass was first reported to exist anecdotally during a 2010 SCUBA based expedition (Sheppard et al., 2012). Subsequently we started to track green turtles (*Chelonia mydas*), known foragers on seagrass, from their nesting beaches on Diego Garcia to foraging sites on the Great Chagos Bank (Hays et al., 2014; Christiansen et al., 2017) which suggests seagrass may exist at multiple sites in the area. Here we report the first in-situ surveys of subtidal seagrass on the Great Chagos Bank and provide information on the importance of seagrass habitats to fish communities in the Chagos Archipelago.

2. Methods

2.1. Selecting sites for in situ seagrass surveys

In October 2012 and July 2015 we equipped 18 nesting green turtles on Diego Garcia (7.428°S, 72.458°E) with Fastloc-GPS Argos tags (SPLASH10-BF, Wildlife Computers, Seattle, Washington (n = 14) and model F4G 291A, Sirtrack, Havelock North, New Zealand (n = 4)). Turtles were located while they were nesting ashore at night and when returning to the sea they were restrained in a large open topped and bottomless wooden box and tags attached with quick setting epoxy (Pure-2 K, Powers Fastening Innovations and Pure 150-PRO, DeWalt)