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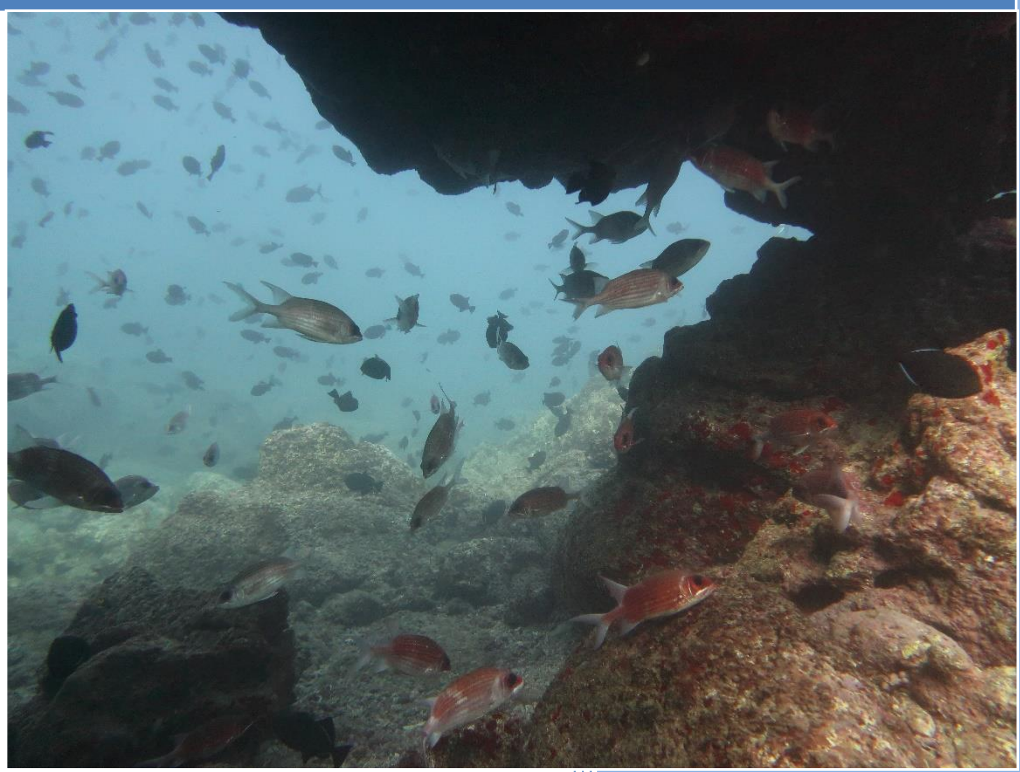
Ascension Island Natural Capital Assessment: Valuation of carbon storage, sequestration and social cost by benthos in Ascension Island's EEZ



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Review table

Name	Reviewed by	Date
Version 1	Ness Smith	02/03/19
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Version 4		

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Valuation of carbon storage, sequestration and social cost by benthos in Ascension Island's EEZ

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Non-technical summary

As it grows and reproduces life on seabeds (benthos) accumulates carbon and is a major source of carbon storage, termed 'blue carbon'. Through long-term aging, burial and ultimately conversion to rock, benthos removes carbon from cycling (between air and water), referred to as sequestration. We used seabed mapping, seabed camera imagery and collections of seabed life to estimate how much carbon is being stored by benthos in water shallower than 1000 m deep in Ascension Island's Exclusive Economic Zone. This essentially comprises of coastal waters around Ascension Island and three seamounts (Harris-Stewart, Grattan and Un-named). Society benefits from this carbon storage and sequestration by biodiverse benthos, due to its mitigation value buffering climate change. Overall we estimate that from 0-1000 m depth there is at least 43,000 tonnes of blue carbon, on Ascension Island EEZ's seabed, mainly in the form of cold coral reefs. Two thirds of that occurs around the main island of Ascension, but it is very unevenly distributed on the seabed The vast majority of Ascension's EEZ seabed is deeper than 1000 m and probably also contains considerable blue carbon stocks, but these were not considered in this report. Ascension EEZ's biodiversity and blue carbon ecosystem services strongly reflect its isolated and geologically young nature. Seabed roughness (e.g. rocky outcrops) seems most important for the development of blue carbon hotspots. Warming, plastics and localized pollution pose threats to near surface coral dominated benthos. About 21% of this total blue carbon is considered to be sequestered (removed from the carbon cycle for 100+ years) = 9,060 tonnes Carbon. At the 2019 Shadow Price of Carbon the proportion of CO_2 considered sequestered is US$ equivalent to £29 and £59. As 9,060 t C is equivalent to 33,250 t CO_2, the 2019 lower value of this blue carbon sequestered is 33,250 x 29 = £964,300 and the upper value is £1,961,800. With time, this increases with rising value of carbon but also annual increment of carbon deposition, to £2,130,000 and £4,330,000 by 2030 (lower and upper values respectively).

Accompanying documents

Accompanying this report are Appendices 1 and 2 and a separate excel spreadsheet of work on SUCS images showing carbon estimate data as well as calculations underpinning the report.

Introduction

This study was conducted by the British Antarctic Survey and its findings contribute evidence to a programme of natural capital assessments (NCA) being implemented by the UK Joint Nature Conservation Committee (JNCC) and conducted by the South Atlantic Environmental Research Institute (SAERI) in the UK South Atlantic Overseas Territories. Funded by the Foreign and Commonwealth Office (FCO) managed Conflict, Stability and Security Fund (CSSF), the work sits under its Environmental Resilience programme which includes objectives to integrate natural capital considerations into economic and social development planning.

Two consultation workshops were held on Ascension Island in February 2017 and June 2018, which resulted in the identification of priority areas for further study. In June, with an upcoming decision on a potential Blue Belt MPA designation, the marine environment was a high priority. Further research identified an assessment of benthic blue carbon values within Ascension Island's EEZ as a useful study. Particular thanks go to

Background

This project investigates and evaluates carbon storage and sequestration ecosystem services of benthic organisms in the mid-Atlantic. This carbon stored in marine animal tissues and skeletons is generally termed 'blue carbon'. More specifically the current project evaluates so-called Natural capital in the benthic habitats of Ascension Island's EEZ (Figure 1); around the coastal shelf of Ascension Island and three of its associated seamounts (Harris-Stewart, Grattan and Un-named). Of these the largest single area is the shelf around Ascension Island (Appendix 1). The ultimate goal is to evaluate the societal benefits of biodiversity and our stewardship of such, for example through Marine Protected Areas. The project uses previously peer-reviewed methodology [1,2] to estimate the amount of blue carbon stored in ecosystems using three sources of evidence, both collected on the 2015 and 2017 scientific voyages of the RRS James Clark Ross. The first part of this evidence comprises a series of highly accurate images of the seabed to identify animals (to functional groups) and their density. The second part comprises the specimens collected (using an Agassiz trawl) and their measured carbon content, as well as previous regional specimens and the literature base. The third part of evidence is the physical and oceanographic data collected using CTD and multibeam swath (of the seabed). These information streams are combined into spreadsheets showing biological constituents of each photographed area of the seabed, with their estimated carbon storage, with corresponding environmental information.

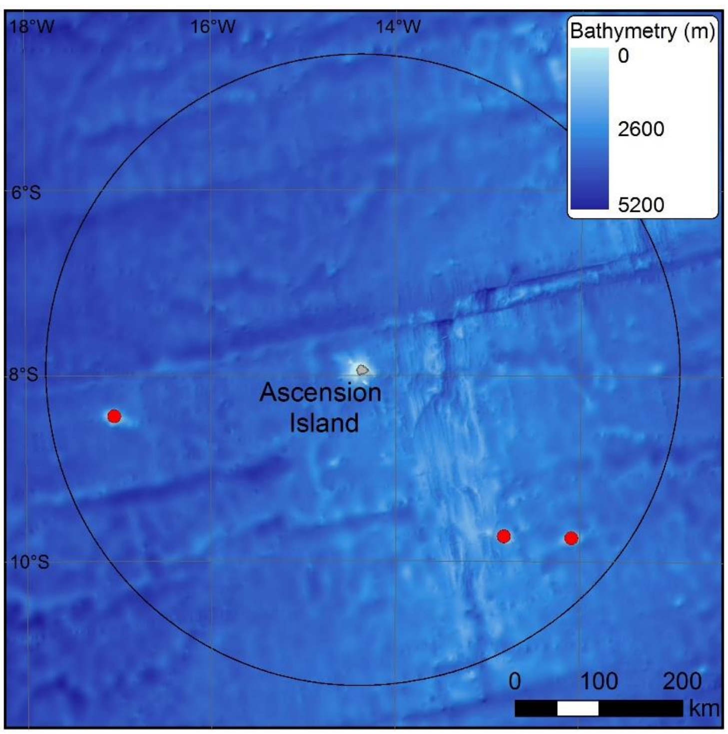

Figure 1 *Locations within Ascension Islands EEZ with seabed <1000 m deep (seamounts shown as red dots). Bathymetric data is GEBCO held by the Polar Data Centre.*

The key to the resolution and accuracy of this work is twofold. Firstly it is about matching four sampling techniques (multibeam swath, near-seabed water column oceanography, physical specimen collection), and imagery using the Shelf Underwater Camera System (SUCS). Secondly, our bespoke SUCS imaging has the advantage over nearly all other systems of being (tested to be) mm accurate over its entire field of view. This is because the camera is a) always perpendicular to the seabed, whatever the orientation of the seabed, b) has a neutral focal length (ie not wide or telephoto) thus allowing a flat (rather than dome) port to minimise distortion and c) the powerful, live controlled dual angle lighting system enables setting a middle aperture diameter (F stop), minimising lens distortion. These features enable accurate measurement in any plane and accurate density determinations.

Sample detail

The following results are drawn from 421 SUCS images around Ascension Island and 271 SUCS images at three nearby seamounts. Biological support for this was provided by 7 Agassiz tows around Ascension Island and 6 around the seamounts. Biological specimens were identified and recorded to at least Phylum and Class and preserved in 96% ethanol for further detailed identification later. The physical and oceanographic context of this was supported by multibeam swath of most seabed shallower than 1000 m depth at each location and 5 CTD casts around Ascension and 3 at the seamounts. Once calibrated, information (e.g. sea temperature, salinity, oxygen and chlorophyll content) from the nearest (geographic and bathymetric) CTD casts were matched to each SUCS image. Thus an XLS spreadsheet of image, environmental characteristics and identifiable biological composition was constructed. From this the following tasks were performed;

1) Benthic functional groups of Ascension Island's EEZ

Thirteen functional groups (Appendix 2) of benthic organisms were identified in the images recorded by the SUCS. The overall frequencies that each functional group were observed at are shown below in Table 1. The raw presence numbers (of Table 1) for each functional group were then standardized (corrected for the total n of benthos sample numbers) into proportion of all benthic fauna (shown in Table 2) by each of the four sites. However more useful still is standardizing to density.

site	SP	SC	SS	DC	DV	DS	GC	PS	PC	PM	PL	PA	**FS**
Asc	361	167	61	2	3	9	109	172	899	3	85	130	1325
StH	105	46	4	-	-	2	8	18	5	-	-	31	20
Gra	162	37	-	3	-	4	19	263	216	5	32	89	306
UNa	300	510	-	1	-	2	54	33	2	-	13	60	16

Table 1. *The functional groups are; suspension feeder pioneers (SP), climax suspension feeders (SC), sedentary suspension feeders (SS), deposit feeding crawlers (DC), deposit feeding vermiform (DV), deposit feeding, shelled burrowers (DS), calcareous grazers (GC), scavenger/predator, sessile soft bodied (PS), scavenger/predator, sessile calcareous (PC), scavenger/predator, mobile soft bodied (PM), scavenger/predator, mobile calcareous (PL), scavenger/predator, arthropod (PA), and flexible strategy (FS). The sites are Ascension (Asc) and seamounts; Stewart-Harris (StH), Grattan (Gra) and Un-named (UNa).*

site	SP	SC	SS	DC	DV	DS	GC	PS	PC	PM	PL	PA	**FS**
Asc	0.11	0.05	0.02	-	-	-	0.03	0.05	**0.27**	-	0.03	0.04	**0.40**
StH	**0.48**	**0.21**	0.02	-	-	0.01	0.04	0.08	0.02	-	-	0.14	0.09
Gra	0.14	0.03	-	-	-	-	0.02	**0.23**	0.19	-	0.03	0.08	**0.27**
UNa	**0.56**	0.10	-	-	-	-	0.10	0.06	-	-	0.02	0.11	0.03

Table 2. *Proportions of benthic fauna sampled at each site represented by differing functional groups. All abbreviations are as for Table 1.*

The proportion data (Table 2) shows that the flexible feeding strategy (Ophiuroidea - brittlestars) dominated numbers of benthic organisms around Ascension Island and Grattan seamount. Sessile scavenger/predators such as corals were also very abundant at Ascension and Grattan seamount. In contrast sessile suspension feeders (ascidians, bryozoans, brachiopods, some polychaete worms and sponges) were the most numerous benthos at Stewart-Harris and Un-named seamounts.

2) Densities of benthic functional groups of Ascension Island's EEZ

The proportional abundance data was converted to density (per meter square) in Table 3. This necessarily shows the same dominance pattern as in Table 2 but scaled such that they can be compared in time, or with elsewhere, or crucially for this work - for carbon calculations. By density, biodiversity seems to be organised by two broad patterns; Brittlestar (FS) and coral (PC) dominated at Ascension and Grattan seamount, compared to a more mixed suspension feeder assemblage at the other two seamounts investigated.

Assemblage structure was explored visually using non-metric Multidimensional Scaling (nMDS) in R. The 2 dimensional plots were a reasonable representations of multidimensional structure for each of habitats, sites and substratum rugosity (Figure 2a-c), but a high number of (SUCS) images with no or few faunal components forces the clustering to the centre of each plot. Observed structure was mainly in Ascension Island's highly rugose rocky environments.

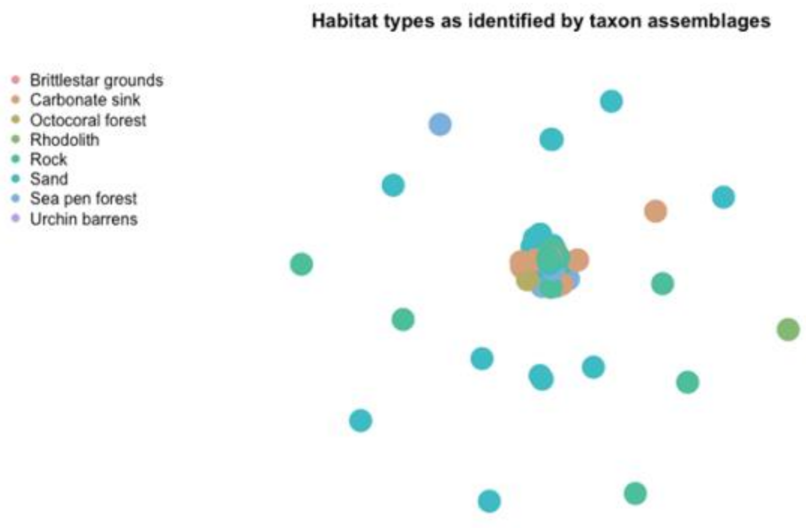

Figure 2a

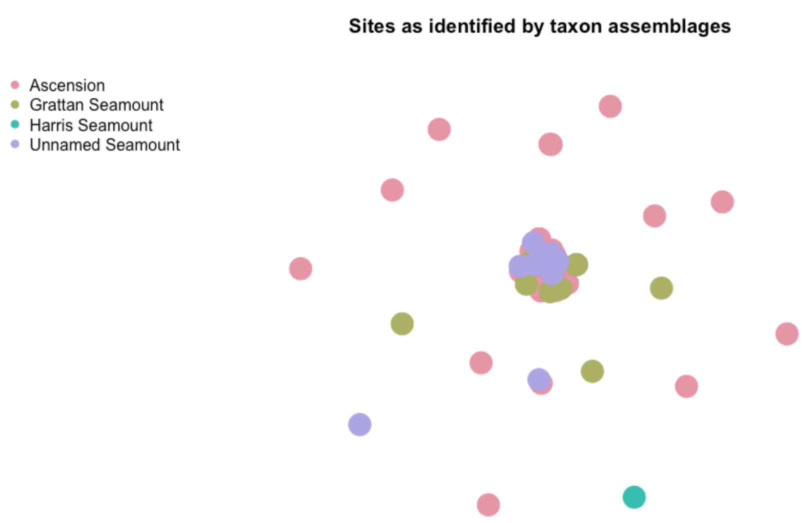

Figure 2b

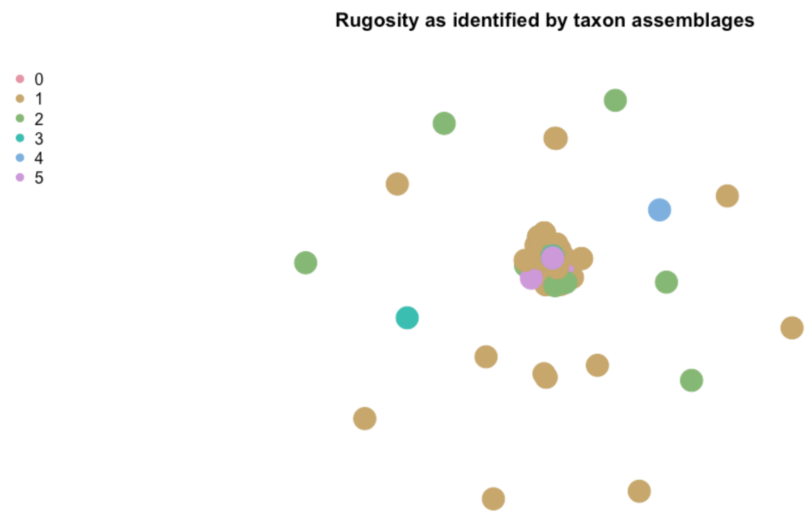

Figure 2c

site	SP	SC	SS	DC	DV	DS	GC	PS	PC	PM	PL	PA	**FS**
Asc	6.21	2.87	1.05	-	0.03	0.05	1.88	2.96	15.5	-	1.46	2.24	22.81
StH	18.1	7.94	0.69	-	-	0.35	1.38	3.11	0.86	-	-	5.35	3.45
Gra	8.15	1.86	-	0.15	-	0.2	0.96	19.9	10.87	0.25	1.61	4.48	15.4
UNa	25.6	4.35	-	0.09	-	0.17	4.6	2.81	0.17	-	1.11	5.12	1.36

Table 3. *Densities of benthic fauna (numbers of individuals per square meter) sampled at each site represented by differing functional groups. All abbreviations are as for Table 1.*

Rather than by island/seamount, this density data can be reshown by habitat or other key factors such as seabed rugosity (roughness or level of 3D structuring). There were eight recognizable habitats including fish nursery, octocoral (sea whip), sea pen forest, brittlestar grounds, sand barrens and three more carbon-important types of rhodolith rubble (coralline algae), sea urchin (echinoid) clusters and hard corals. However, whilst it is clear that these are very likely to have differing carbon storage and sequestration values we could only identify and discriminate between these habitats using SUCS imagery. SUCS imagery is not available for most of Ascension's EEZ, nor could it practically ever be as there is only one such system that has been developed to date, the study area is remote requiring considerable vessel repositioning costs, and even if funded, substantial time is required to obtain the minimum number of images for meaningful analyses (in this case, two entire research expeditions to target four sites). Thus we prioritised analysis of factors which could be determined more rapidly, easily, widely and by non-specialists. Seabed rugosity is such a factor as it can be determined from multibeam swath from virtually any vessel. SUCS images can gain further detail on rugosity and so we scored each of the 692 photographs on a rugosity scale of <1mm, 1-10mm, 11-20mm, 21-30mm, 31-40mm and 41+mm seabed roughness.

3) Estimate the proportion of seabed at each location by relevant factor in Ascension Island's EEZ

BAS Mapping and Geographic Information Centre determined the area of seabed from coast to 1000 m depth at each of the four sites surveyed (Fig. 1). These are shown in column 2 of table 4, together with a total area of the four surveyed sites. The total area of 'shelf' and seamount (defined as shallower than 1000 m) was calculated for the whole of Ascension Island's EEZ, using publicly available bathymetry information (held by the Polar Data Centre).

		Estimated substratum rugosity in mm					
Site	Area	*0-1*	*1-10*	*11-20*	*21-30*	*31-40*	*41+*
Ascension	328.5	2.3	187.4	70.6	34.9	25.0	8.3
Surveyed Seamounts	265.8	20.6	122.6	65.7	30.4	10.8	15.7
Unsurveyed seamount	16.4	1.3	7.5	4.1	1.9	0.7	1.0
EEZ Total (<1000 m)	**610.7**	**24.2**	**317.5**	**140.4**	**67.2**	**36.5**	**25.0**

Table 4 *Areas <1000 m deep around Ascension by each rugosity level. Only 16.4 km2 of a total of 610.7 km2 was unsurveyed by the research cruises JR864 and JR16-NG.*

The proportion and area of each rugosity type was determined for each surveyed site (columns 3-8 of table 4). The mean values across the three surveyed seamounts were then scaled up to the total area of all seamount area and added to the values from around Ascension Island to give estimated EEZ total. The total area under consideration for this report is 610.7 km^2.

4) a] Stored zoobenthic carbon

The estimated mean zoobenthic carbon stored by each functional group (by image) across each of the four study regions is shown in Table 5. Thus the most important functional groups were sessile calcareous predators (corals) at Ascension and Grattan seamount and sessile suspension feeders at Stewart-Harris and Un-named seamounts.

site	SP	SC	SS	DC	DV	DS	GC	PS	PC	PM	PL	PA	**FS**
Asc	0.88	0.56	0.16	-	0.01	0.07	0.76	0.49	**4.88**	0.01	0.88	0.27	**1.69**
StH	**2.73**	0.99	0.1	-	-	0.09	0.55	0.48	0.26	-	-	0.68	0.01
Gra	0.97	0.29	-	0.02	-	0.05	0.41	1.21	**4.25**	0.08	0.74	0.59	0.18
UNa	**3.73**	0.8	-	0.01	-	0.08	**2.01**	0.65	0.06	-	0.77	0.5	0.01

Table 5. *Estimates of carbon held by live zoobenthos, in grams per SUCS image. The functional groups are; suspension feeder pioneers (SP), climax suspension feeders (SC), sedentary suspension feeders (SS), deposit feeding crawlers (DC), deposit feeding vermiform (DV), deposit*

feeding burrowers (DS), calcareous grazers (GC), scavenger/predator, sessile soft bodied (PS), scavenger/predator, sessile calcareous (PC), scavenger/predator, mobile soft bodied (PM), scavenger/predator, mobile calcareous (PL), scavenger/predator, arthropod (PA), and flexible strategy (FS). The sites are Ascension (Asc) and seamounts; Stewart-Harris (StH), Grattan (Gra) and Un-named (UNa).

These total for each region as 5.9-10.7g per SUCS area of living fauna (Ascension Island highest) and a further 0.6-7.8g per SUCS area in dead calcareous skeletal remains (again Ascension Island highest). This was area-corrected into g per m^2 (thus tonnes per km^2) for comparability (Table 6).

site	SP	SC	SS	DC	DV	DS	GC	PS	PC	PM	PL	PA	**FS**
Asc	6.18	3.94	1.12	0.03	0.05	0.49	5.3	3.46	**34.2**	0.06	6.14	1.9	11.8
StH	**19.1**	6.9	0.73	0	0	0.62	3.83	3.35	1.8	0	0	4.79	0
Gra	6.82	2.05	0	0.14	0	0.36	2.9	8.5	**29.8**	0.58	5.18	4.12	1.28
UNa	**26.1**	5.61	0	0.08	0	0.54	**14.1**	4.56	0.39	0	5.39	3.52	0

Table 6. *Estimates of carbon held by live zoobenthos, in grams per m^2 by functional groups. All abbreviations are as for Table 1.*

These total for each region as 41.1-74.6g per m^2 of living fauna (Ascension Island highest) and a further 4-55g per m^2 in dead calcareous skeletal remains (again Ascension Island highest).

4) b] Zoobenthic carbon storage and sequestration by critical factor

There were very high levels of variability of zoobenthic carbon storage, within and between study sites, ranging from >1.2kg m^2 to none per image detectable by imaging. Rugosity, location (Ascension and the three seamounts) and substratum type (measured as hard, soft or mixed) were all significant terms but most variability was explained by rugosity[1] (Table 7).

Source	DF	Adj SS	Adj MS	F	P
Rugosity	5	857037	171407	**12.3**	0.001
Location	3	251100	83700	6	0.001
Substratum	2	155591	77796	5.6	0.004
Error	695	9721061	13987		
Total	705	11473501			

Table 7 ANOVA of zoobenthic carbon storage across Ascension shelf waters.

[1] *Rugosity. The difference in richness and biomass between two images, one of flat sand, the second the same with a small rock protruding from the sand by 20mm is considerable due to the number and types of organisms that are able to attach and colonise the rock, often different to those whose habitat is sand. Similarly, the increase in surface area from a flat rock habitat to a more ridged rock provides more and different habitat again increasing richness and biomass. To take this into account "Rugosity" was devised as a factor where the maximum height of the substrate relative to the "flat" was determined by measuring shadow fall. Five categories were defined based on height variation from category 1 (0-1 mm) to category 5 (41+ mm). Categories 2-4 are 10 mm slots between.*

Of location, Ascension Island, had more stored carbon than the seamounts and of substrata, hard surfaces had more stored carbon, principally in the form of *Lophelia* coral outcrops. Overall estimates of benthic carbon increased with seabed rugosity, but there was considerable variation at each rugosity level, at both Ascension and the nearby seamounts (Fig. 3). Mean values of benthic carbon by rugosity level at least showed a more linear increase.

Estimating sequestration is difficult, especially so from imagery, so error could be considerable. Our estimates were driven by chance of burial, so any evidence of this or just nearby sediment was taken into account, as of course was how much of each benthic item was skeleton and what form this takes (e.g. hard coral polyps are more likely to fossilize than sea cucumbers). At Ascension we estimate that ~27% of stored zoobenthic carbon can be considered sequestered locked up for 100+ years.

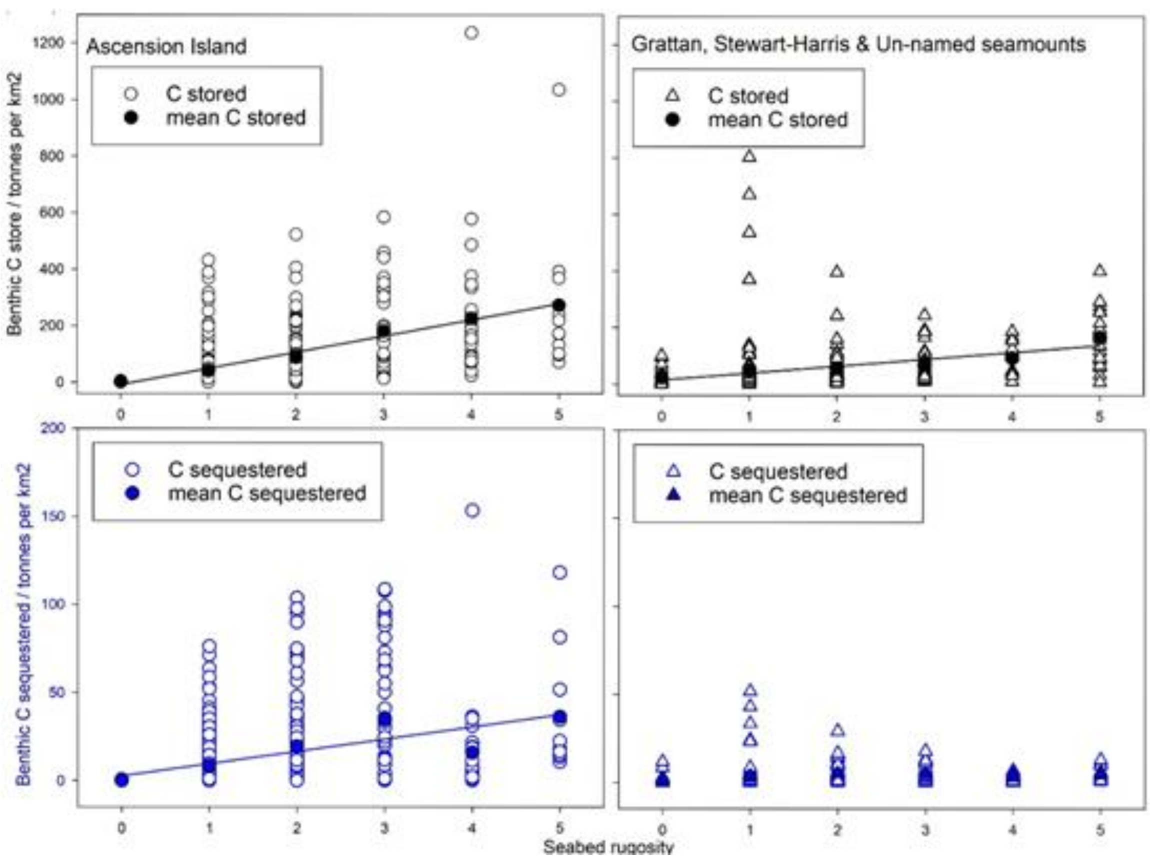

Figure 3 Zoobenthic carbon storage and sequestration with rugosity levels in Ascension shelf waters.

Although relationships are apparent between rugosity and carbon storage (and at Ascension specifically, sequestration) at the sample level (Fig. 3), no relationships were apparent at site level (Fig. 4). This is likely to make remote assessments of carbon storage and sequestration potential (e.g. from seabed multibeam characteristics) challenging. Mean values of blue carbon storage estimates per km^2 are shown in Table 8 by rugosity level and location.

	Substratum rugosity in mm

site	Mean	0-1	1-10	11-20	21-30	31-40	41+
Ascension	**83**	2	41	87	**181**	**225**	**272**
Stewart-H	**45**	ND	35	50	47	ND	ND
Grattan	**63**	24	65	49	52	67	**154**
Un-named	**61**	ND	25	71	**111**	**132**	**199**

Table 8. *Zoobenthic carbon storage by rugosity and area, in tonnes per km². At some locations we found no seabed with certain rugosity levels, which we indicate as No Data (ND). Mean values across all rugosities are shown left (low in value because high rugosity levels were rare).*

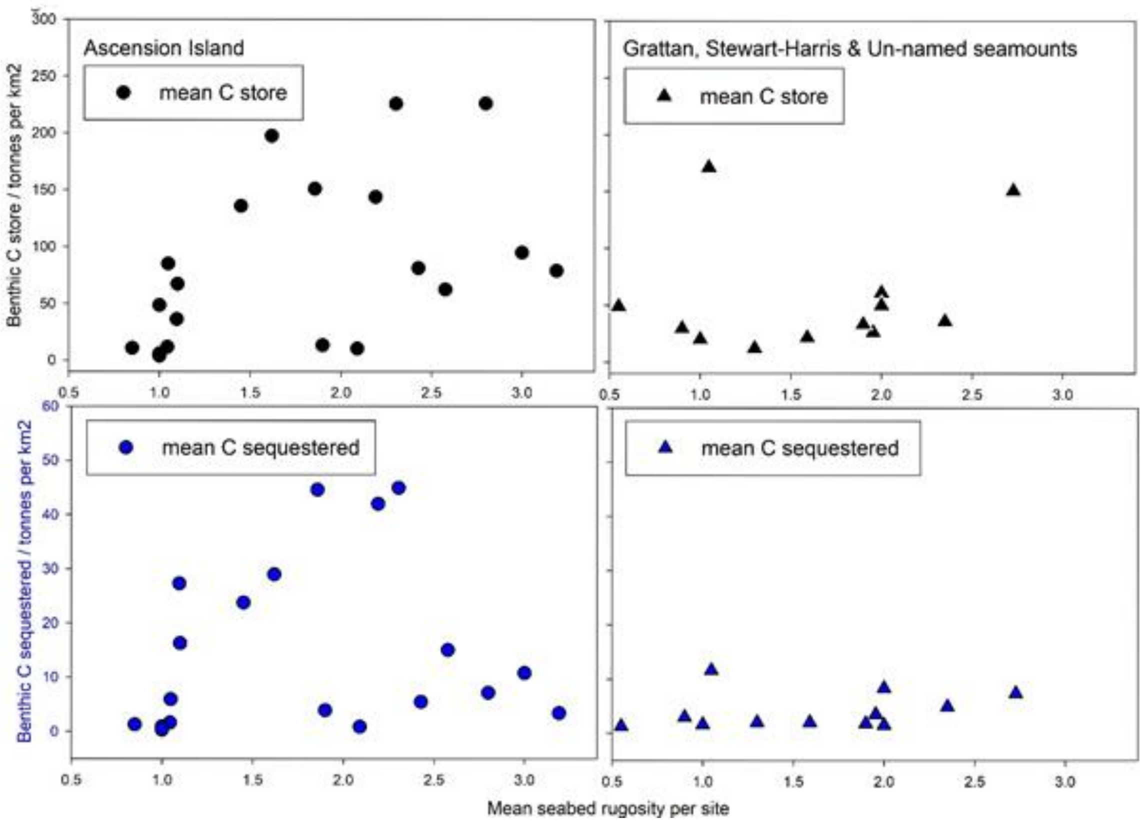

Figure 4. Zoobenthic carbon storage and sequestration with mean rugosity level across sites in Ascension shelf waters.

5) Scaling up Carbon storage to shelf areas of Ascension Island's EEZ

The calculation to scale up our zoobenthic blue carbon estimates required several components. The first was to multiply up the proportion of surveyed seabed each rugosity level for each location. So for example 57.5% of Ascension Island's surveyed seabed <1000 m depth had a rugosity level of 1-10 mm. Assuming the proportion of these rugosity levels are representative of unsurveyed areas <1000 m depth, we multiplied the total area of Ascension Island's shelf (328.5 km²) x 0.575 = 188.8 km² of shelf with this level of rugosity. This was multiplied by mean carbon storage for each rugosity level at each location (Table 8), so for Ascension island's 1-10mm rugosity area, this was 188.8 x 40.7 (g m² or t km²) = 7,687 t km². This was repeated for all rugosity levels at all <1000 m depth locations (Table 9).

		Substratum rugosity in mm					
site	Total	*0-1*	*1-10*	*11-20*	*21-30*	*31-40*	*41+*
Ascension	**27890**	4	7687	6177	6141	5617	2263
Stewart-H	**3917**	0	796	2313	788	20	0
Grattan	**5445**	299	2741	648	441	203	1114
Un-named	**5559**	0	1163	1750	1076	712	857
Unsurveyed	**233**	1	131	73.4	18	2	8
EEZ Total (<1000 m)	**43045**	304	12519	10963	8464	6554	4242

Table 9. *Zoobenthic carbon storage by rugosity and area, in tonnes. The last row shows totals by rugosity level and overall (left-most).*

One rugosity level and one location dominate the study area. Much (52%) of the <1000 m depth seabed we imaged in Ascension Island's EEZ was low in rugosity (1-10mm). On average we estimate that this supports ~41 t C km^2 (see Table 4) comprising just 29% of total zoobenthic carbon (12,519 t see Table 9). Similarly, seabed shallower than 1000 m around Ascension Island, occupies more than half the total EEZ area <1000 m depth (53.7%). It supports disproportionally high blue carbon stocks. Nearly two thirds (65% [27890/43045 see Table 9]) of Ascension's EEZ estimated benthic blue carbon occurs around the main island. In terms of natural capital and ecosystem services it is clear that areas of seabed a) around Ascension Island and b) of higher rugosity (31+mm) are most important. The latter especially considering the small (10%) area they occupy. Overall we estimate that Ascension Island's <1000 m area supports ~43,000 tonnes of blue carbon, mainly as *Lophelia pertusa* (cold coral) reefs as well as abundant echinoids such as the cidaroid *Cidaris cidaris*.

Blue carbon standing stock is patchy and sequestration possibilities similarly so, and likely to vary considerably with depth, proximity and nature of soft substrata, and proximity and nature of blue carbon sources. Our mean estimate of sequestered carbon was ~21% of living standing stock. This equates to ~9,060 t C for area <1000 m depth. This does not imply that conversion rate of carbon storage to carbon sequestration is 21%. Conversion rate is likely to be much lower (possibly by an order of magnitude). Much of the carbon that we consider sequestered could have been there for hundreds or even thousands of years, so it is a cumulative build up. Much of the fast growth is by organisms less likely to sequester, either because they are in high energy habitats of the shallows or because they mainly comprise soft tissues which are easily consumed on death by other macrobes or broken down in the microbial loop (and thus the carbon is recycled rather than sequestered). However, our 9,060 t C total value of sequestered carbon is likely to be a considerable underestimate, because it does not take into account sequestration of primary production or secondary production into >1000 m depths. There is some evidence that this could be considerable, but unquantified around seamounts [3].

6 & 7) Use published literature of growth rates of relevant taxa to estimate the temporal increase of blue carbon storage

Growth rates of calcifying benthos such as corals vary considerably even within species between locations, depths and water masses [4-7]. We used a conservative estimate of 0.1g.m^{-2}.day^{-1} across benthic taxa, which in line with cold coral literature is slow compared to global mean reef production 2.5–7.4 g.m^{-2}.day^{-1} [7] or 2.2 g.m^{-2}.day^{-1} of the nearest Caribbean reefs [8]. The value of 0.1g C $m^{-2}.day^{-1}$ was only applied to seabed areas which had at least 10g C living zoobenthic estimated standing stock. However, using this as a whole environment carbon accumulation rate has several problems, all of which are underestimates. This value does not include near surface primary production standing stock or sequestration export nor does it include the nearshore faunal standing stock or export, which we estimate to be in the region of ~18 g C m^2 (see accompanying Excel worksheet) and is likely to grow very much quicker [7,8]. Thus our production estimation is very conservative.

We estimated that 506 of the 695 SUCS images contained less than 10 g C m^2 of live fauna. Thus we considered that only 695 – 506 = 189 of the 695 were significant generators of blue carbon. We thus applied our growth rate ($0.1g.m^{-2}.day^{-1}$) to 189/695 = 27.2% of Ascension Island's <1000 m depth area (610.7 km^2); 0.272 x 610.5 = 166 km^2. The calculation we used was thus 0.1 t C km^2 x 166 km^2 x 365 (days) = blue carbon stock generation = ~6060 $t.yr^{-1}$ in the <1000 m area of the Ascension Island EEZ. This is equivalent to ~14% of our blue carbon standing stock estimate.

8) Geographic variability in blue carbon, drivers influencing this and key threats faced.

Geographic variability in blue carbon

Blue carbon occurring within the top 1000 m of seabed in the Ascension Island EEZ is extremely unevenly distributed, across multiple spatial scales. Within our Ascension EEZ data, the highest levels of variability occurred on the cm to m scale (associated with rugosity). Other important spatial scales were larger 10s m (associated with different substratum types and 10-100 km (associated with seamount/island identity). However above the spatial scale of Ascension EEZ, that of 1000s km (associated with different archipelagos and continents) there can be even higher levels of blue carbon variability. This scale is associated with different continents, oceans and major climatic regimes (Table 10). Overall Ascension Island EEZ (<1000 m) is estimated to support 70 t carbon km^2, an order of magnitude more than the South Orkney Islands (8 t c km^2) which are considered as a polar blue carbon hotspot [3]. There are few continental shelves where accurate estimates have been produced, but standing stock around South Georgia is probably half that of the South Orkney islands and the South Sandwich Islands may be as little as 1% of Ascension EEZ per unit area.

Spatial scale	driver	variability in blue carbon	other considerations
1000s km	history, energy, area, isolation	100x	governance, protection, climate
100s km	Habitats, area	2-5x	
10s km	Currents, habitats	2-5x	
0.1-1Km	Depth	2-5x	

10s m	Substratum	2-10x
M	Rugosity	10x

Table 10. Level and factors of spatial variability in seabed blue carbon magnitude.

This report only investigated blue carbon above 1000 m depth, however assuming that the abyssal seabed around Ascension is typical, it is likely to be very low in biomass and blue carbon per unit area. Thus the Ascension EEZ well illustrates the extremes of geographic variability in blue carbon distribution. As much as 99% of Ascension EEZ could be within the <1% of the seabed shallower than 1000 m. Even within that, most blue carbon seems to be around Ascension Island's coast and, even within that, most is associated with the 10% of the seabed which is rough and complex. We found areas where there was 3 orders of magnitude variability in estimated blue carbon standing stock within tens of meters apart.

Drivers influencing spatial variability in blue carbon

The extreme variability over multiple spatial scales makes isolating which factors are causal of variation extremely challenging. However the location and nature of most of the dead calcareous skeletal remains (mainly around Ascension Island), suggests that there has not been considerable temporal variation. Likewise the growth rate estimates suggests slow growth and build-up of the cold coral reefs around Ascension. We think that the prevailing reasons for such sparse and patchy blue carbon are 1) isolation from nearest larval supply and 2) recruitment conditions for young. Isolation is important because Ascension and its associated seamounts are far apart, and all very far apart from other nearest adult concentrations for larval supply. This is exacerbated by them being small in area and relatively young. Thus local retention of larvae is probably very important to development of biomass and thereby blue carbon, but during the process of SUCS image capture we observed considerable water movement across all depths and locations. In addition to high water movement, imaging using SUCS showed some sand at every site and location. Thus recruitment conditions involve unstable soft sediments and 'sand blasted' hard surfaces, which may be partly why rugosity emerged as such a strong factor. Roughness slows water down (allowing larvae to settle) and provides protection from particles being driven against surfaces by current. We think most areas of blue carbon importance establish and develop close to adult supply sources (i.e. downstream of previous or current biomass) where the seabed is rough to maximise recruitment success.

Neither temperature nor a proxy of primary production (phytoplankton) emerged as explanatory factors and thus were not mentioned in previous reports. There is good reason to suspect that both of these are important drivers but complicated and confounded in various ways. Most biomass is associated with coral reefs, which in Ascension EEZ are in shallow warm waters but also deep cold waters, but only where there is enough hard surface to establish and even then only (perhaps by chance) in some of those areas. Where shelf seabeds are in contact with phytoplankton blooms, such as round Ascension Island's coast they can be very important for suspension feeders and their predators (but not so much for many other carbon rich benthos). However the depth of blooms vary between locations and strongly with time. Our two surveys were both far too brief to establish durations, depths and nature of these blooms.

Threats to blue carbon

We think there are three main considerations to threats to Ascension Island EEZ's biodiversity and blue carbon ecosystem services, what they are likely to be, how to monitor for these and how to mitigate any that prove to be demonstrably impacting. It was not apparent from our 2015 and 2017 surveys that there were immediate strong impacts. However given the remote nature of most of the seabed we surveyed, most of the threats are likely to be quite diverse and global in nature. Most threat from local sources is likely to be to blue carbon around the main island of Ascension's coast.

Pollution: Plastic pollution was evident on the sea surface and seabed [9] - we even saw plastic entangled in coral, but this was only apparent in 0.5% of samples. Plastic can mechanically damage biota, increase disease susceptibility and decrease efficiency and slow growth through being ingested. Whilst this appears to be an increasing issue in Ascension waters, most has no local source nor obvious solution (although nearby landfill sites could be made more secure to wind blowing material into the nearby ocean). Refuelling and human coastal use also provide some threats to pollution, mainly to shallow coral communities in bays.

Climate Change: As with many remote locations much of the threat is climate change related in the form of pH decrease (acidification), temperature stress and other physio-chemical ocean change. Whilst thermal tolerance issues are probably most severe for shallow biota, acidification is probably the most serious issue for most blue carbon storing biodiversity, because of reduced sequestration potential. Even if organisms whilst alive can buffer decreased pH, the chances of burial are reduced because of increased dissolution and the large build-ups of ancient calcareous reef remains will be increasingly dissolved.

Harvesting (overfishing): Across oceans drastic reduction of populations through fishing, and bycatch from bottom fishing or birds near the surface is a major and rising problem. However, around Ascension it is unlikely that regional fishing provides much threat since it is small scale and pelagic, apart from gear loss (plastic pollution). Although gear loss (ghost fishing) has been found around other Atlantic islands and seamounts we did not encounter any on our 2015 and 2017 surveys.

Suggestions for monitoring blue carbon (high carbon storing biodiversity) health and performance are through regular surveys, by SCUBA in shallows and research ship in deeper waters. These are expensive financially, in time and expertise, and deeper work would require multibeam, deep cameras and limited targeted physical collections (to monitor temporal growth effects) but there are few such vessels and science teams passing Ascension Island. However we could not find multibeam (SWATH) signatures for centres of blue carbon interest and the resolution of such systems at that depth make them unlikely to provide rapid 'remote' monitoring solution. Unless it is in response to a particular event (e.g. oil spill) we would suggest resurvey each 5-10 years in the manner of our 2015 and 2017 surveys, but the cost of these could be minimised by mainly focussing on the most productive areas (high rugosity seabeds around main Ascension Island). In the shallows it is likely that coralline algae (such as rhodoliths) is one of the most important contributor to blue carbon and this is probably quite robust to impacts. However we would recommend repeat surveys (using SCUBA photography and sampling) each 5-10 years.

9) Estimates of shadow carbon cost of sequestration by Ascension Island's marine life

There is a very wide range of estimates for Social Cost of Carbon (SCC) and shadow price of carbon (SPC) between nations, years, discount rate and even models. Here we report using 2019 values in £ GBP Sterling, based on the High level commission on Carbon prices (https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59244eed17bffc0ac256cf16/1495551740633/CarbonPricing_Final_May29.pdf). This places a value of approximately US $ 39-78 per tonne CO_2 in 2019. In UK these translate to GBP £29-59 per tonne CO_2 (2019). It is important to note that this value increases considerably with time so that any value presented in this report needs to be rescaled for any year it is read other than 2019.

We estimate that blue carbon storage by marine biodiversity in less than 1000 m depth in Ascension Island's EEZ approximately totals at 43,000 tonnes. This is split between ~28,000 tonnes around Ascension Island and 15,000 tonnes around three offshore seamounts. This 43,000 tonnes of blue carbon in benthic biodiversity there is estimated to capture an additional 6,000 tonnes per year (but will also have losses in respiration and microbial breakdown). We estimate that ~21% of that stored zoobenthic carbon can be considered sequestered (9,060 tonnes). 43,000 t C is equivalent of 158,000 t CO_2 and the fully sequestered 9,060 t C is equivalent to 33,250 t CO_2. Thus the 2019 lower value of this blue carbon sequestered is 33,250 x 29 = £964,300 and the upper value is £1,961,800. Each year this value increases with both increased value of carbon but also annual increment of carbon deposition, such that 2030 lower and upper values of sequestered blue carbon are estimated to be £2,130,000 and £4,330,000.

This valuation does not take into account if there is any underlying trend in the change of rates of sequestration (e.g. increase or decrease in blue carbon capture, storage and sequestration is response to physical changes in the environment). Monitoring using data here as baseline should be able to address this potential source of error. Total valuation did not include the surrounding deep seabed production and sequestration, yet that is by far most of Ascension Island's EEZ. Deep water blue carbon storage is little known anywhere in the world and unmeasured around Ascension but even if it is only 5% of that above 1000 m, it would double the total value of the EEZ standing stock.

10) Conclusions

The current series of reports have been a first attempt at estimating the blue carbon standing stock, growth and value in Ascension Island's EEZ shallower than 1000 m. Unsurprisingly most (65% [27,890/43,045 tonnes]) of this is found around the main island, which is the largest single area across these depths. Higher rugosity (31+mm) seabed was also disproportionally rich in blue carbon, mainly in the form of cold coral reefs dominated by *Lophelia pertusa*. Other biota were important as well, such as the cidaroid *Cidaris cidaris*, and because of likely faster growth rates (than cold coral) they will be even more important to short and medium term growth of blue carbon stocks. It was apparent from SUCS images that soft and hard substrata are intermixed at multiple scales, suggesting that there could be high rates of burial of blue carbon leading to proportionally high sequestration levels. Collection of deep water sediment cores could confirm this.

Our estimated value of Ascension Island's EEZ (<1000 m) is moderate at £1-2 million at 2019 shadow Price of Carbon. However that this natural capital rises to a projected £2-4 million by 2030 and £6-12 million by 2050 makes this a key future value, especially considering that it is for a small island with little population. This includes no value for abyssal depth seabed which makes up 99% of Ascension Island's EEZ. Thus it is highly likely that the total blue carbon sequestered is more than double the 9,060 t C estimated for < 1000 m depth, and thus more than double these monetary values.

The current work establishes a testable baseline not just for Ascension Island but also for future work elsewhere to compare to. To date there is almost no strictly comparable values in the literature (see 1, 2) mainly because this is an emerging area of science and difficult to measure and scale. Intuitively the standing stock of blue carbon in Ascension Island's EEZ is likely to be low on a global scale because it is young, small and isolated (all factors associated with low biodiversity) despite being tropical. However it is also relatively undisturbed (because of isolation, low human density and much biodiversity being at great depth). The immediate level of threat to benthic marine biodiversity, blue carbon storage and sequestration around Ascension would appear to be low. Nevertheless it should be considered vulnerable partly due to the vast majority of blue carbon being located in a very small part of the EEZ, partly because so much is associated with slow growing sensitive cold corals and because key stressors are global and hard to buffer (e.g. plastic pollution and climate forcing). If the shallowest 1000 m does contain most of the EEZ's blue carbon, and even more so if this is mainly around Ascension Island, this does confer advantages in ease and regularity of monitoring, simplicity of comparison and facilitates any responsive action if necessary.

Our standing stock estimate for Ascension Island's EEZ was 43,000 t c standing stock with ~9,060 t C considered sequestered. We further estimated using literature [4-6] growth rates of cold corals that this standing stock might generate a further 6,000 t yr^{-1} of which approx. 600 t may be sequestered. Our estimates have many and diverse sources of error. We did not consider deeper water, which is the vast majority of Ascension Island's EEZ, albeit likely to be low in carbon standing stock. In addition our methodology could not be applied to the shallowest depths where growth, carbon capture and storage may be greatest, but sequestration is likely to be low in such higher energy near surface environments. Within the zone we investigated only future sampling will show how representative the sampling to date has been, and only a different type of sampling will reveal how much benthos is sequestered by burial. We found some evidence that blue carbon deposition associated with seamounts, but not in the <1000 m depths could be considerable, in the form of boosted secondary pelagic production. It is therefore likely that there may be increased sequestration of primary production in the same areas – zones of influence of the three seamounts.

Following the findings based on the 2015 [10] and 2017 [11] field results and this 2019 report we would suggest resurvey (monitoring) of Ascension island's EEZ marine biodiversity natural capital each 5-10 years. Use of similar methodology to ours would have advantages in comparability but we would suggest additional sediment core collection and analysis as well as evaluation of blue standing stock and burial in water shallower than 40 m, perhaps using SCUBA techniques.

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Appendix 1

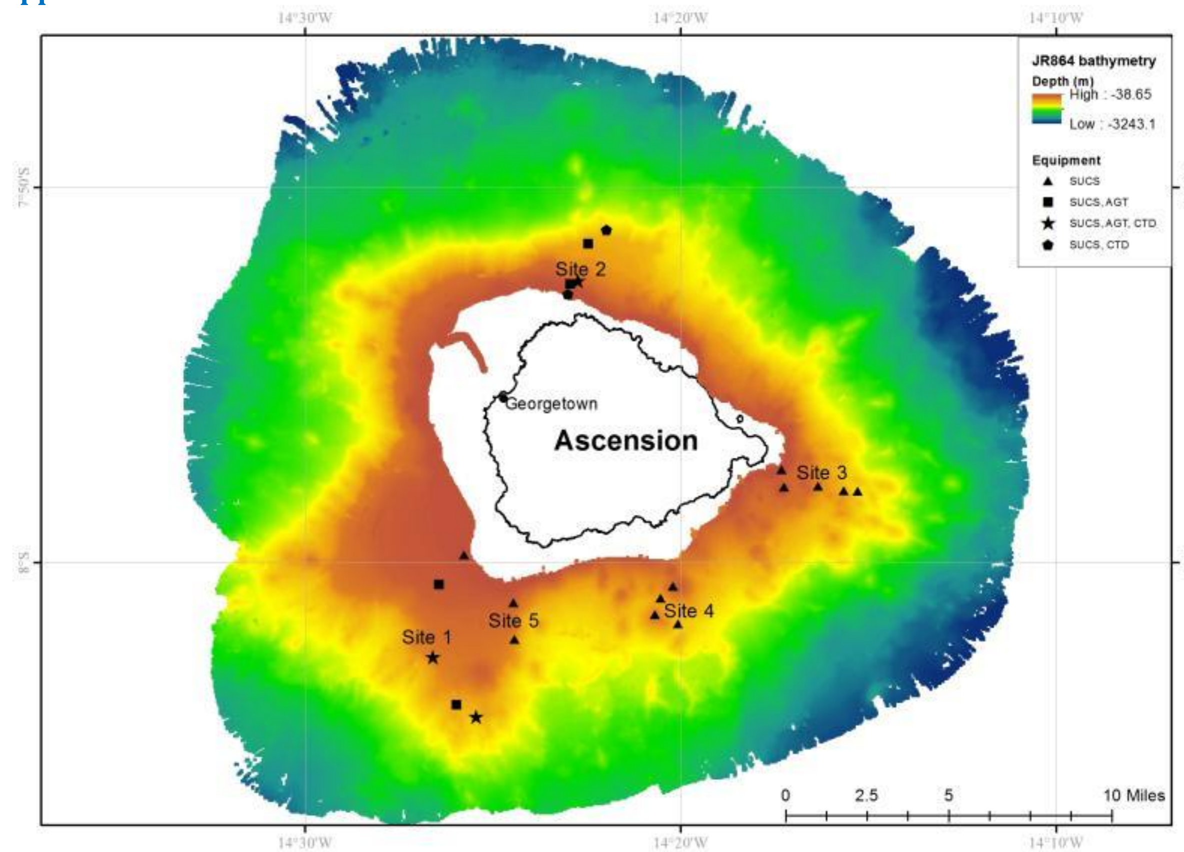

Figure A1: Bathymetry around Ascension Island determined by RRS James Clark Ross research cruise in 2015 (JR864). The sites surveyed are shown with numbers and individual deployment with black symbols.

Appendix 2

Project Background

The UK Government, through the FCO managed Conflict, Stability and Security Fund, is supporting a suite of natural capital projects across the UK's South Atlantic and Caribbean Overseas Territories. This work is designed to improve economic stability in the Territories through enhanced environmental resilience as part of a programme led by the UK's Department for Environment and Rural Affairs (Defra). The natural capital project began in September 2016 and will be completed by March 2019 with the Joint Nature Conservation Committee as the Implementing Body.

In the South Atlantic, the natural capital project work is being undertaken by the South Atlantic Environmental Research Institute (SAERI) under contract to the JNCC. One of the three UK Overseas Territories with which the project is working is Ascension Island. Ascension has no permanent resident population, however the island UKOT has key strategic importance in terms of links to St Helena UKOT, military staging post to Falkland Islands, UK Government Blue Belt Programme, fisheries and tourism. The waters around Ascension Island and associated seamounts support a wide variety of wildlife, including globally threatened species and endemics.

Context

Marine organisms act as a reserve or sink for carbon within living tissue and by facilitating burial of carbon in seabed sediments. Through this natural carbon sequestration and storage process, the deep sea removes emissions from the atmosphere; in ecosystem services terms, this delivers an indirect use value to people through natural regulating services (Figure B1).

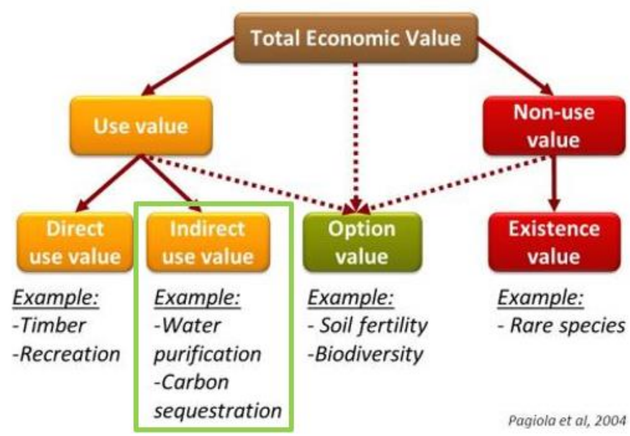

Figure B1: Total Economic Value categories including carbon sequestration as an indirect use value. Source: Shan Ma and Robert Griffin, Natural Capital Project, presentation.

The oceans are the largest natural carbon (often termed 'blue-carbon') sinks and the shallow shelf seabeds around remote islands can be very important to global carbon storage and sequestration potential (Barnes & Sands 2017). This importance may be linked to their stability, lower anthropogenic impact and high local primary production. Yet, given this, very few studies of the economic value of carbon have focused on remote regions.

A recent special volume of the Journal of Marine Biological association of the UK highlighted the richness, importance and uniqueness of Ascension Island's habitats and biota (Figure 2). In particular Nolan et al (2018) provided the first biological exploration of Ascension's deeper biota from 100-1000m depth. That work used the RRS James Clark Ross to establish imagery of its representative habitats, together with matched biological and oceanographic samples and multibeam seabed mapping physical data in 2015. Two years later this was built on by a National Geographic 'Pristine Seas' expedition using the same vessel to collect similar data, specimens and map three seamounts in Ascension's EEZ (Figure B2 and B3)

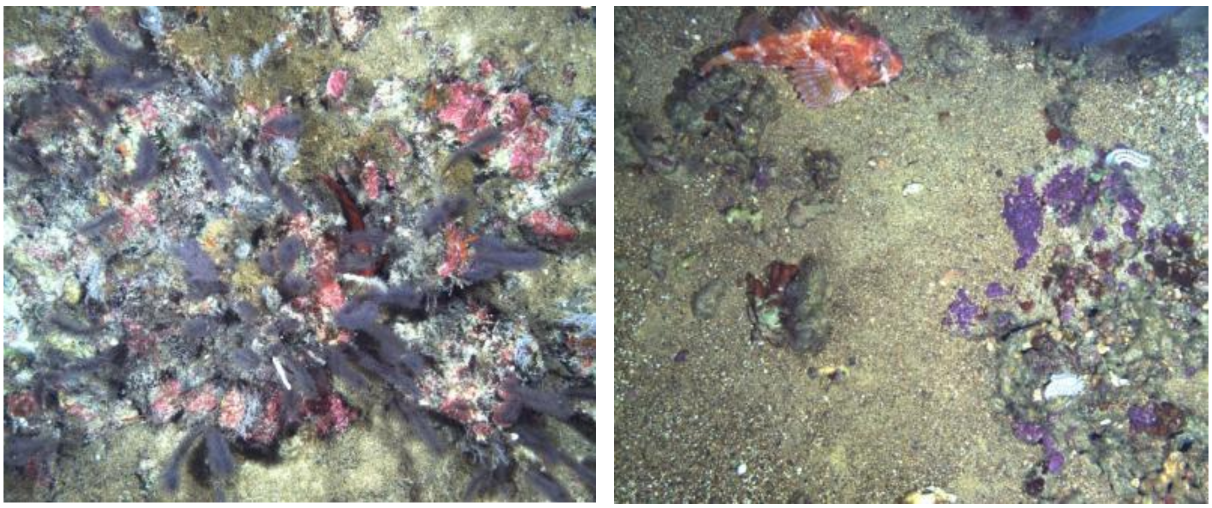

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Figure B2: Blue carbon rich benthic habitats around Ascension Island (left) and associated Grattan Seamount (right).

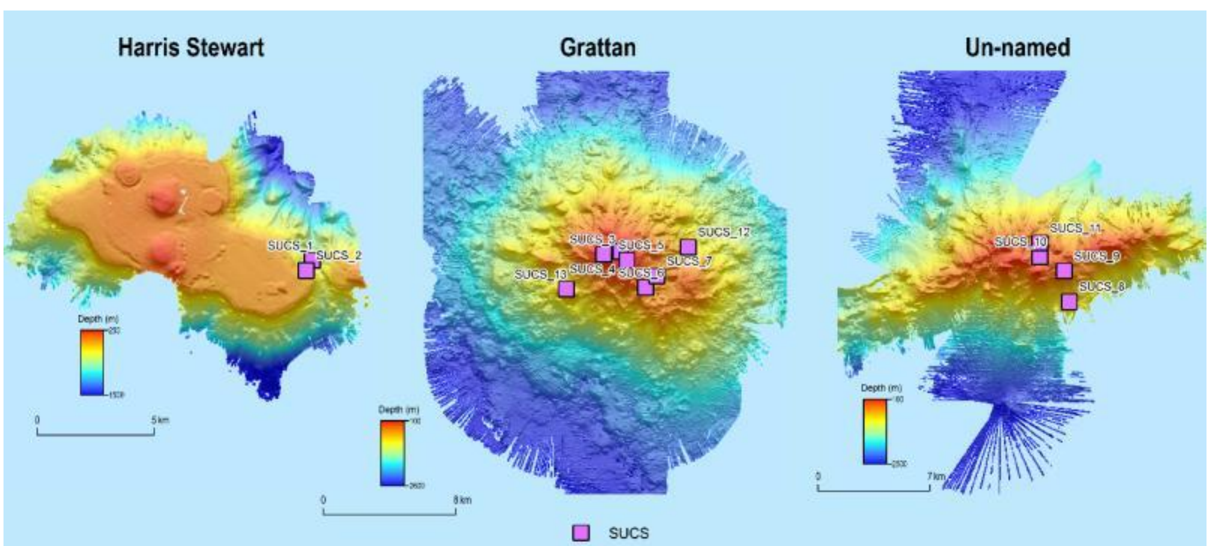

Figure B3: National Geographic's 2017 expedition was the first to map the seabed around Ascension's EEZ seamounts. The pink squares represent sites where imagery was collected using the Shelf Underwater Camera System (SUCS).

Blue carbon valuation

Carbon sequestration and storage valuations are arguably the most common and well known application of ecosystem services assessments and such values are used to inform Government policy worldwide. Valuations can, amongst other methods, be made using the market price of carbon, which reflects the value of traded carbon emissions (for example, through the EU Emissions Trading System, EU ETS) and the 'Social Cost of Carbon' (SCC) principle, where a value is placed on a theoretical economic cost for every metric tonne of CO_2 equivalent emitted to the atmosphere. The social cost of carbon is usually estimated as the net present value of climate change impacts over the next 100years (or longer) of one additional tonne of carbon emitted to the atmosphere today. It is the marginal global damage costs of carbon emissions (Mangi et al, 2011).

The proposed project uses a tried, tested and peer-reviewed methodology (Barnes 2015, Barnes & Sands 2017) to estimate the blue carbon ecosystem services of benthic habitats of Ascension Islands EEZ; around Ascension Island its associated seamounts of Harris-Stewart, Grattan and Un-named (near Grattan).

Methodology
Steps 1) to 3) detailed in Report I (December 2018)
Steps 4) to 7) shown in current Report II (February 2019)
Steps 8) to 9) due in final Report III (March 2019)

Table 1. Functional group categorization of benthos on South Georgia's shelf.

Functional group	Example taxa
Pioneer sessile suspension feeders	Encrusting bryozoans, ascidians, some polychaetes
Climax sessile suspension feeders	Demosponges, glass sponges, brachiopods
Sedentary suspension feeders	Basket stars, valviferan isopods, some polychaetes
Mobile suspension feeders	Some brittle stars, crinoids, krill
Epifaunal deposit feeders	Sea cucumbers, some polychaetes
Infaunal soft bodied deposit feeders	Some polychaetes, echiurans, sipunculans
Infaunal shelled deposit feeders	Bivalves, irregular sea urchins
Grazers	Regular sea urchins, limpets
Soft bodied, sessile scavenger/predators	Sea pens, soft corals, anemones, hydroids
Hard bodied, sessile scavenger/predators	Cup corals, whip corals, hydrocorals
Soft bodied, mobile scavenger/predators	Some polychaetes, nemerteans, octopus
Hard bodied, mobile scavenger/predators	Sea stars, fish, gastropods, some brittlestars
Jointed legged, mobile scavenger/predators	Sea spiders, shrimps, amphipods

The methodology above has successfully been used around the South Georgia archipelago to evaluate blue carbon pathways from capture to storage, to immobilization (within skeletonized fauna) to ultimate burial and sequestration (Barnes 2015, Barnes & Sands 2017). Carbon is usually considered sequestered when it cannot return to the atmosphere for more than 100 years (Robinson et al, 2014, Barange et al, 2017). At SG carbon storage was not linked to any specific functional group but accumulation and immobilization increased with the number of functional groups present and when hard substrata were present. Carbon burial rate increased with the presence of mixed (hard and soft substrata) and functional groups were also found to be important. The 2015 and 2017 benthic surveys of 100-1000m around Ascension's EEZ suggested that similar habitats and benthic functional groups populated the deep, cold waters around ascension (Nolan et al 2017). Preliminary examination of benthic images of what little area has been surveyed to date, suggests that

Ascension's EEZ could be very rich per unit area in blue carbon natural capital and ecosystem services (Figure B4).

Figure B4: Blue carbon in deep water around Ascension island. Even in spaces where there is little macroscopic fauna there is strong evidence of considerable blue carbon ecosystem services (left) as the seabed is carpeted with carbon-rich skeletons of corals, bryozoans, sponges, echinoderms and other benthos, which accumulates into thick sequestered layers. Cold coral (such as Lophelia) ecosystems densely cover hard substrata in parts of Ascension's EEZ.

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